E06226

Gaza from Samson's Mount with the Egyptian Encampment.

Patent . J.H. Le Keux

PAPERS

ON SUBJECTS CONNECTED WITH

THE DUTIES

OF THE

CORPS OF ROYAL ENGINEERS

R. E.

VOL. VI.

LONDON:
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LIST OF PLATES.

INTRODUCTION.

My absence from England upon duty for nearly four months during the Summer and Autumn of 1842, has delayed the publication of the present Volume of 'Professional Papers,' but I hope that for the future I shall be able as usual to publish a Volume at the commencement of every year.

I have to apologize for the non-performance of promises made in Volume V., by one of which I was bound to insert the conclusion of the Paper on the Island of Ascension by Captain Brandreth, which I have not been able to do, owing to his inability, from want of time, to complete the letter-press: the other promises had reference to the plans of the Line of Water Communication from Lake Erie to Montreal, and of the Iron Caisson for the Dock Entrance at Woolwich, neither of which are inserted in this Volume. The first of these, viz., the Sketch of the Line of Water Communication, must still be postponed; but the Drawings of the Iron Caisson are now in hand, and will be given in the next Volume.

I wish to call the attention of Officers to a paragraph in the Introduction to Vol. V., where it is stated that the funds arising from the Annual Subscriptions can be drawn upon to defray the expense of employing Draughtsmen to execute Drawings of those subjects which may be thought useful or interesting. I am well aware that Officers are often unable to find time to complete the Drawings necessary to illustrate and explain the letter-press of the subjects they may wish to insert in the 'Professional Papers.' I avail myself of the funds at my disposal to defray the expense of illustrating the subjects contributed by me to our Work, and by employing Draughtsmen, I am able to make the Illustrations more complete than I could possibly do were I to depend merely upon my own exertions to complete the Drawings. I am anxious that other Officers should avail themselves in the same manner of the funds at my disposal, and shall be glad to pay to their account at the Agents any sums which they may have disbursed for the purpose of completing Drawings *on a scale proper for the Work.*

It is very desirable that these Volumes should be made a depository not merely of elaborate descriptions of different Engineering Works, but also of those isolated facts, many of which are constantly occurring, and which form a valuable portion of an Officer's Note-book; and I beg to call the attention of Officers to a page or two at the end of the Volume, containing a record of a few Experiments made by me: these are printed in smaller type than the body of the Volume, and I propose to print in the same form any communication of the nature mentioned above, and to illustrate it, if necessary, with wood-cuts.

I have great pleasure in laying before my Brother Officers the following Paper, giving an account of the measure taken by several Officers of the Corps of Royal Engineers at Dublin, with the view of collecting materials for the compilation of an 'Aide-Mémoire,' a work which has long been much wanted in our service. The plan upon which it is now proposed to proceed seems well adapted to insure success, and I hope that no efforts will be spared on the part of my Brother Officers (all of whom have a direct interest in the Work) to bring it to a successful termination.

W. D.

PROPOSED

AIDE-MÉMOIRE

FOR THE USE OF THE CORPS OF ROYAL ENGINEERS.

Dublin, 23rd May, 1843.

Colonel Lewis, R.E., during forty years of constant employment in three parts of the globe, has observed the want of an Aide-Mémoire, or Memoranda of Reference, when far from practical works and practical men.

In the course of long services, the Engineer is at one time employed in the field,—in the attack and defence of places,—in the construction of works and bridges; at other times, in the colonies and remote stations; and, being perhaps the only professional person present, is called upon to furnish plans and estimates for the execution of civil and military buildings,—for canals, railroads, &c., &c., &c.

If this is the common routine of an Engineer Officer's duty, is he prepared to meet all emergencies? and can he find a library of reference in a few volumes to afford the desirable assistance to memory?

Thus far, this has not been possible. Colonel Lewis has therefore proposed to have this want supplied by the united exertions of the whole Corps of Royal Engineers, and by those of the East India Company's Service, whose duties are as varied in climate as in their nature; and he has therefore suggested the subjoined scheme to carry it into effect.

The term 'Aide-Mémoire' is selected as not involving the Editors and Contributors in the necessity of giving complete treatises, as implied by the words Encyclopædia, Dictionary, and Manual.

The Prospectus of the work will show that the whole will be gratuitous, and without profit to any one but the Publisher.

ABSTRACT OF RESOLUTIONS

MADE AT A MEETING OF THE CORPS OF ROYAL ENGINEERS.

Dublin, 11th April, 1843.

At this Meeting, held for the purpose of taking into consideration a proposition for forming an Aide-Mémoire, from Colonel Lewis, Commanding Royal Engineer in Ireland:

It was Resolved—

1. That the Officers of the Corps, generally, be requested to offer their assistance, and select such articles from an alphabetical list[1] as they may desire to contribute.
2. That Officers who have already published, have the refusal of the subjects on which they have written.
3. That the work be edited in Dublin, by a Committee of Engineer Officers.
4. That, in the event of subjects being omitted from want of contributors, the Committee be empowered to complete from the best authorities.
5. That the Aide-Mémoire form two volumes, one for the use of the Army generally, and the other as a practical work for the Corps.
6. That the Committee have no power to alter any subject offered for publication without the consent of the contributor.
7. That persons furnishing Papers, complete, for the Aide-Mémoire, have the privilege of their names or initials being placed at the termination of these articles; such treatises, however, should be in as small a space as possible,—the 'Professional Papers' of the Corps being open to disquisitions and dissertations.
8. That the proposition be submitted to the Inspector-General of Fortifications.

The Inspector-General's approval of the foregoing having been laid before a Meeting, 26th April, 1843:

Present, Major-General Sir J. F. Burgoyne, K.C.B.
Colonel Lewis, C.B., Commanding Royal Engineer.
Lieut.-Colonel H. D. Jones.
Captain Pettingal.
„ Nelson.
„ James.
Lieut. Skyring.
„ Bainbrigge.

It was Resolved—

[1] To be forthwith circulated.

1. That a Committee of Three be appointed to collect and arrange the requisite information, and to manage the necessary proceedings.
2. That the following, having given their consent, be appointed for this Acting Committee:

   Colonel Lewis,
   Lieut.-Colonel Jones, } Members.
   Captain Nelson,

   Lieut. Bainbrigge, Secretary, without vote.
3. That the Acting Committee call a General Meeting of the Officers of Royal Engineers on full pay, as a General Committee of Reference, whenever they may wish to obtain advice or support on any matter connected with the undertaking.
4. That Major-General Sir J. F. Burgoyne be President of the General Committee.
5. That any vacancy in the Acting Committee be filled up by the General Committee.
6. That the General Committee consist of not less than Seven Officers, including the Members and Secretary of the Acting Committee.

(Signed) J. F. Burgoyne,
Major-General.

These Resolutions were submitted to the Inspector-General of Fortifications, and approved.

The Committee appointed to edit the work then communicated with Mr. Weale, (Architectural Library, London,) who has, in consequence, undertaken to publish it at about 15*s*. per volume.

The Aide-Mémoire will be prepared for publication as soon as the requisite data shall have been furnished, not only by the Corps of Royal Engineers, but by those of the Hon. East India Company's Service, who are hereby, likewise, addressed and invited to join as contributors. It is hoped that these materials will be collected and ready for completion and general arrangement in about twelve months.

Of Vols. III., IV., and V. of the 'PROFESSIONAL PAPERS' some few copies still remain, and may be had at the following prices:

Vol. III.	. . .	£1 5 0
IV.	. . .	1 8 0
V.	. . .	1 16 0

PROFESSIONAL PAPERS.

I.—*Notes on the Field Equipment of the Engineer Department with the Bengal portion of the Army of the Indus. By Lieutenant* H. M. DURAND, *Bengal Engineers.*

1. THE assembly of a force destined for service in Afghanistan having been decided upon, His Excellency the commander-in-chief, Sir Henry Fane, towards the close of August, 1838, ordered Captain G. Thomson, then commanding the Bengal Sappers and Miners, to take charge, in the capacity of chief engineer to the army of the Indus, of all arrangements connected with the engineer department, and to enter forthwith upon the necessary preparations.

2. Captain Thomson was at the same time instructed that, in organizing the field equipment of his department, he was to bear in mind that no wheeled carriage would be allowed, and that the transport of all tools and stores must be effected upon camels. Moreover, that in so adapting every thing to camel carriage, the quantity of cattle called for was to be limited to the smallest number compatible with the necessity which existed of carrying all such tools and stores as, being indispensably requisite, were not likely to be elsewhere obtainable than from our own magazines.

3. These restrictions, called forth by the consideration of the nature of the countries in which the force was to operate, being of a kind which may again be imposed not only upon officers acting in the East, but also upon those liable to serve in South Africa, it is hoped that the following Notes may prove, though local in character, not devoid of interest to the engineer officers both of the Royal and of the Indian armies.

4. Under the limitations above specified, the following lists of tools and

stores were drawn out—the one to form the engineer park, the other to compose the equipment of the second and third companies of Bengal Sappers and Miners ordered to join the army in the field. Both lists are here placed in juxtaposition, for the sake of showing the total amount of tools and stores available for engineer purposes.

5. The general superintendence of the package of the sappers' tools and of the engineer park was intrusted to Lieutenant Durand, Lieutenant Brown, Adjutant of the Sappers and Miners, and to Mr. Richardson, conductor.

6. For the equipment of the sappers, it was necessary so to arrange that a detail of tools proportionate to the strength of the two companies should always accompany them on the line of march, and be at hand in case of the men having to pile their arms, ground their knapsacks, and fall to work. This object was attained by the construction of three pairs of tool racks for each company. The racks were adapted to the camel pack in common use in Hindostan: their form and the mode of loading are shown in sketch No. 1. Each rack was to carry

	lbs.
10 pickaxes	92
10 shovels	42
10 phowrahs [1]	70
2 felling axes	12
2 saws	4
Weight of one rack	28

Hence the camel load amounted, independent of the pack saddle, to 4 cwt. 48 lbs.

7. For the remainder of the sapper equipment, and for the engineer park, with the exceptions which will be noticed, a more simple and less expensive mode of packing was adopted. This consisted in an open kind of bag made of coarse hempen gunny,[2] called taut in Hindostan. When laid on the ground it was of the shape shown in sketch No. 2. The centre or main portion *a a*, on which the weight and most of the wear and tear would act, was made double. The side pieces *b b* were sewed for a short distance above their junction to the main piece *a a*, so as to form an open bag with side lappets. When the tools were laid in the bag, the lappets were crossed over, and the

[1] A tool formed like a hoe, but as large as a spade, with a straight handle as long as a spade handle.

[2] A species of coarse sacking.

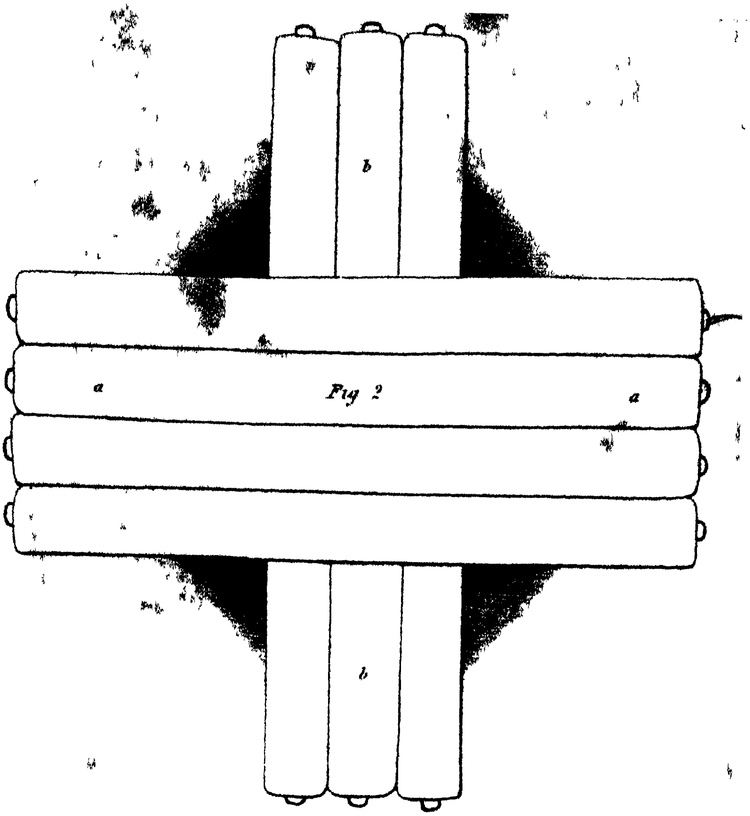


Fig 2

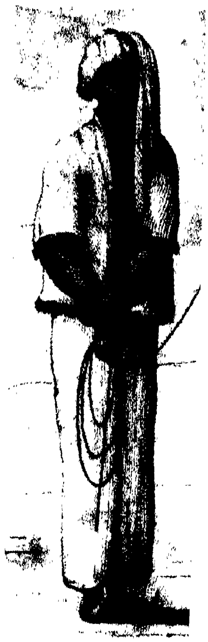


Fig. 4.

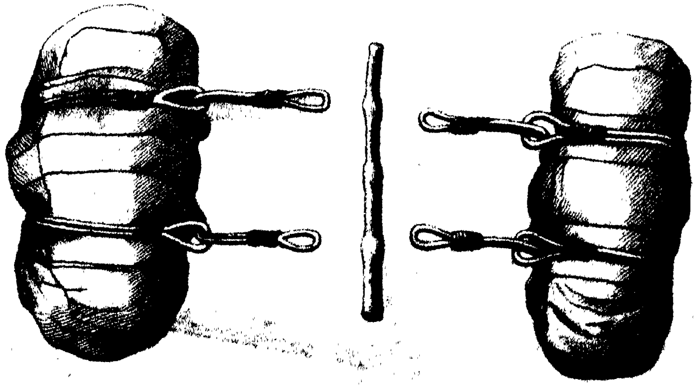
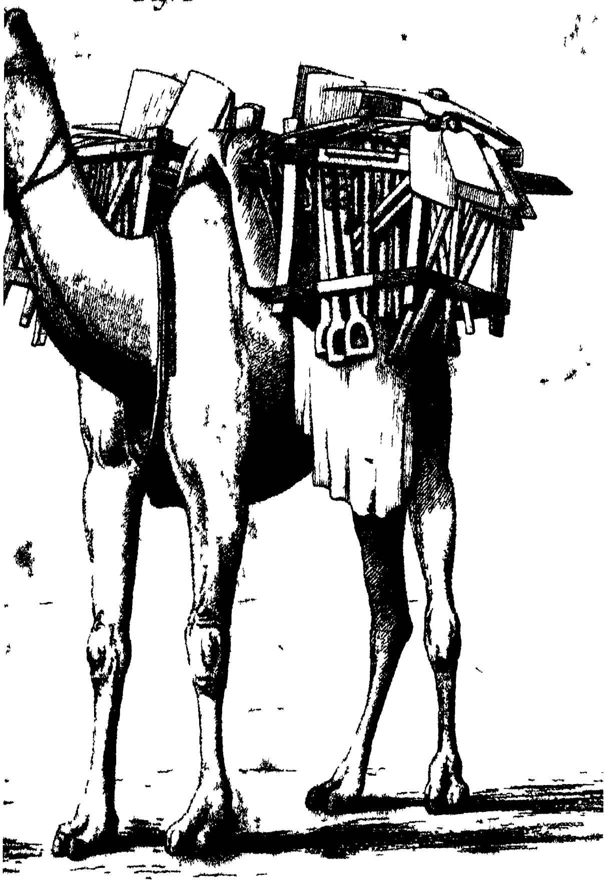


Fig. 1



of upper horizontal frame and rackwork
horizontal frame is without the rack sticks
which support the heads of the tools
nailed on both at top and bottom side
the reception of Saws

Fig 5

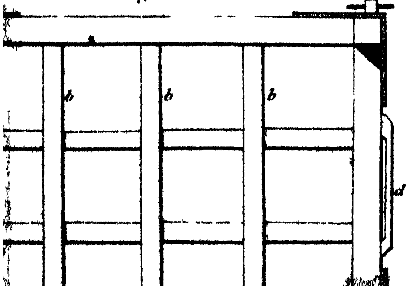
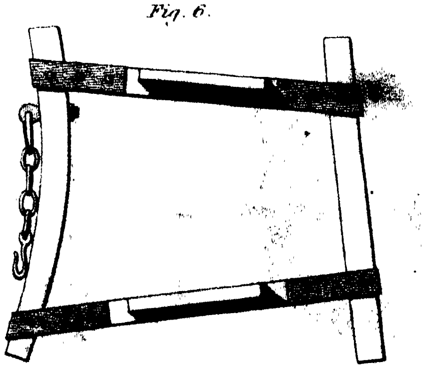


Fig. 6.



The opposite Rack is exactly similar except in having no chains to its rings e e. Scale 1 Inch to the foot.

whole made tight by folding down the main portion *a a*, and by binding the package with light rope.

8. Sketch No. 3 shows the manner in which the phowrahs were packed, by making use of the helves as a substitute for frame-work, piling the phowrahs in order upon them, and by binding the whole into one mass with moonge-string lashing passed through the helve holes of the phowrahs. The advantage of this was, that whenever the bag had to be repaired, the bundle of tools could be readily taken out and returned: thus put together, they also played less against the gunny than they would have done if packed loosely. Each package contained twenty-four phowrahs with helves complete; the camel load of forty-eight phowrahs weighed, exclusive of pack saddle, 3 cwt. 48 lbs.

9. The pickaxes being heavy, only twenty, with helves complete, went to one bag; making the camel load, of forty pickaxes, a weight of 3 cwt. 64 lbs. From their length and shape these tools proved difficult to pack tightly; in fact, this object was but partially attained, and the bags suffered from the play of the load, and from the pick points and ends working through.

10. The shovels packed well, eighty-four to the camel load, giving a weight of 4 cwt. 14 lbs.

11. Sketch No. 4 shows the manner in which the packages were united into pairs by means of a short strong piece of male bamboo run through the loops of the rope girths. When lifted and swung on the pack saddle, the weight of the packages tightened the girths, and balancing each other, the load, when the animal was in motion, was perfectly steady. Mr. Richardson, who had seen a similar method in use among the Bringarrees with their bullock loads of grain, adopted it for the park camel packages, and experience proved that it was an easy, convenient, and safe mode of lading.

12. For the smaller articles, five pairs of camel trunks were made up: these were of the usual shape.

13. However anxious to avoid the use of wheel carriage, it was evidently impossible to devise any practicable method of making camels carry the long bamboos requisite for scaling ladders: nor was it advisable to move without such a provision, for the woodless nature of the country in which the troops were destined to act was sufficiently well known; and experience proved that had it ever been requisite to make an assault by escalade, the only means available for that purpose would have been the bamboos brought from Hindostan. Excepting in the neighbourhood of Quetta and Caubul, where

young poplar sticks were to be found, no wood fit for scaling ladders occurred. Wheeled carriage was therefore for this one article indispensable, and a description of truck was ordered. But the Delhi magazine establishment was so severely taxed in order to meet the demands of the artillery branch of the force, that the Commissary of Ordnance could not undertake to put together even one truck carriage adapted to the transport of the bamboos. Recourse was therefore had to a description of carriage, obtainable from the magazine, termed a store cart with limber. On the platform of the limber the anvils were fastened, being awkward articles for camel lading. On the store cart, without any alteration to its body, the long heavy bamboos were secured by lashing them to the frame-work. The shorter bamboos were in like manner fastened upon a store cart without a limber.

14. Advantage was taken of these two carts to carry a few articles of bridge equipment, such as light grapnels, buoys, &c., which it was thought might prove useful.

15. The 10,000 lbs. of powder were carried with the artillery park, and were under the charge of the Commissary of Ordnance, by whom carriage was also provided.

Public cattle.	Camels.	Bullocks.
For the engineer park	110	8
,, sapper equipment	28	
,, ,, tents	14	
,, ,, quartermaster's stores	4	
	156	8
Spare cattle	22	
Total public cattle	178	8

List showing the Tools and Stores available for Engineer Operations.

Description of tools and stores.	Weight of each.	Park equipment.	Equipment of 2d & 3d companies S. & M.	Total.
Intrenching Tools.	lbs.			
Pickaxes, with helves . . .	10	2000	200	2200
,, spare helves . . .	2½	400	100	500
Phowrahs, with helves . . .	8	1000	200	1200
,, spare helves . . .	2¼	200	100	300
Shovels, with helves . . .	5½	1000	200	1200
,, spare helves . . .	1¾	200	100	300
Mining, &c., &c., Tools.				
Borers, of sizes	3½	10	,,	10
Crowbars	60	5	4	9
Candles, wax		lbs. 28	lbs. 50	lbs. 78
Fascine chokers	10	20	20	40
Gads, steel, of sizes . . .	2	6	,,	6
Gauges, gabion	11	2	2	4
Hammers, hand	4	5	,,	5
,, sledge . . .	14	5	4	9
Jumpers	35	10	20	30
Lanterns, dark	1	2	,,	2
,, horn	2	4	2	6
Picks, mining	7	10	10	20
Priming wires	4	2	,,	2
Scoops, mining	4	2	,,	2
Shovels, small mining . . .	5	10	,,	10
Tampers, wooden . . .	5	4	,,	4
Trucks, mining, in pieces . .	84	2	,,	2
Bellows, ventilating . . .		,,	2	2
Buckets, canvass, for mining . .		,,	8	8
Candlesticks, mining . . .		,,	12	12
Tubes, tin, ventilating . . .			ft. 200	ft. 200
Carpenters' Tools.				
Axes, felling, with helves . .	6	50	20	70
,, ,, spare helves . .	2	15	10	25
,, hand, with helves . .	1⅔	200	100	300
,, ,, spare helves . .	½	50	,,	50
Augers, carpenters' . . .	2	10	,,	10
Billhooks	2½	100	40	140
Gimlets, 10 common, 10 spike .	⅛	20	,,	20
Nails, iron, of sorts . . .		lbs. 84	lbs. 20	lbs. 104
Saws, cross-cut	14	5	2	7
,, hand	2	20	12	32
,, pit	12	2	,,	2
Compasses, box, for mining . .		1	,,	1
Reels, camp, with lines . .		2	,,	2
Smiths' Tools.				
Anvils, small	84	3	,,	3
Bellows, forge		3	2	5
Files, of sizes		20	,,	20
Vices, bench	10	2	,,	2
,, standing . . .	73	1	,,	1

List showing the Tools and Stores available for Engineer Operations.

Description of tools and stores.	Park equipment.	Equipment of 2d & 3d companies S. & M.	Total.
Hammers, forge, of sizes	6	4	10
Stores.			
Sand bags	1000	,,	1000
Bamboos for scaling ladders	30	,,	30
Borax . . . lbs.	2	,,	2
Cart, store, and limber	1	,,	1
,, without limber	1	,,	1
Chains, 100 feet	2	2	4
Dammer[3] . . . lbs.	20	,,	20
Grindstone, small	1	,,	1
Gunter's scale	2	2	4
Hides, bullock	10	,,	10
Iron, Europe, flat bar . . lbs.	112	40	152
,, ,, square . . lbs.	112	,,	112
Line, seizing, country . . lbs.	224	,,	224
Mallets, picket	20	40	60
Needles, packing	20	12	32
Paulins,[4] wax, camel	30	,,	30
,, medium size	2	,,	2
Rope, rattine . . . lbs.	112	,,	112
Saucisson, prepared . . yds.	100	,,	100
Solder, tin . . . lbs.	10	,,	10
Steel, English . . . lbs.	112	,,	112
Tape, tracing, 2-inch, 2000 yds. ,, ,, $1\frac{1}{2}$-inch, 1000 yds.	2000	1000	3000
Taut, gunny, double pieces	40	,,	40
Tent, laboratory, small	1	,,	1
Tickets, canvass, for camels	110	,,	110
Twine for sewing gunny . lbs.	28	5	33
Moonge[5] . . . cwt.	4	,,	4
Match, quick . . . lbs.	5	20	25
,, slow . . skeins	8	2	10
Knives, laboratory	,,	8	8
Scales, copper	,,	2	2
Weights, sets	,,	2	2
Scissors, laboratory	4	2	6
Tin, sheets	50	30	80
Padlocks, with keys	10	,,	10
Palms, steel	10	,,	10
Portfires	10	,,	10
Powder[6] . . . lbs.	10,000	,,	10,000

[3] A kind of pitch used to render canvass covering water-tight.

[4] A large cloth laid over the saddle of a camel before it is loaded, the ends of the cloth extending to the ground on each side: when the load is fixed, these ends are turned up to envelope it.

[5] A species of string made of cocoa-nut fibre.

[6] The 10,000 lbs. of powder were in charge of the Commissary of Ordnance.

REMARKS.

1. At the time that Captain Thomson formed the engineer park, the Bengal portion of the army of the Indus consisted of two divisions of infantry, one of cavalry, two troops of horse, and two batteries of foot artillery; making a force of about 10,000 bayonets, 3000 sabres, and 400 artillerymen.

2. Upon inquiry as to the description and quantity of ordnance which was to compose the siege equipment, it was replied that the only battering train which could be taken, and upon which the chief engineer was to calculate, would be four 18-pounders, two 8-inch mortars, and two 5½-inch ditto. The store of shot and shell which could be carried was even for this small train but a limited supply; and there appeared to be no intention of moving the Bombay battering train, also a weak one, beyond the banks of the Indus. To a representation on the smallness of the battering train, Captain Thomson was directed to be fully equipped for mining operations.

3. The fate of Herat was then uncertain, and if taken by the Persians before the British force could appear to its relief, the place, at that time represented as being an exceedingly strong one, must be recaptured.

4. Much and heavy labour was expected in surmounting the difficulties of the Bolan and other passes; and the employment of strong working parties from the line was, on such occasions, anticipated.

5. With respect to the foregoing circumstances, that is, to the strength of the force, to the limitations as to carriage, and to the nature of the operations which might be expected to be undertaken in the course of the campaign, the engineer field equipment was framed; and it is evident that with reference to these considerations a smaller equipment could not have been taken without incurring great risk that on trial the engineer department would prove inefficient.

6. On examining the list of stores, it will be at once observed that the field equipment, in consequence of the great and unnecessary weight of some of the articles, suffered under a considerable disadvantage. The pickaxes weighed on an average exactly double what they ought to have weighed, and the shovels averaged each 1 lb. heavier than was necessary. With respect to the pickaxes, their great weight was owing partly to the fact that these tools are always made too heavy, and also to the circumstance that during the practice of

the sappers and miners, stationed at Delhi for several years, batch after batch of the lighter tools had been selected, and only the rejected and heavier picks remained on hand at the time that the engineer park was formed. Had there been time, their weight might have been reduced by cutting them down, but this there was no leisure to perform. The field equipment had therefore to start, carrying exactly double the weight which was necessary for the number of pickaxes; and every engineer park taking the field will be subject, more or less, to this inconvenience, until attention is paid to having every article likely to be required in engineer operations made to a particular pattern and of a certain weight. It may be easily imagined that an implement twice as heavy as that which should be put into the hands of a British soldier is not well adapted to the Sepoy of the line, who, though in general of greater stature, has not the physical strength of the European soldier.

7. The packages required frequent examination; for the taut being of small breadth, the requisite width of bag was obtained by sewing several pieces together: their stitches frequently gave, and had of course to be immediately repaired, which was easily done by the park establishment. Instead of taut, strong prepared canvass would originally, if procurable, have been preferred, the taut being rapidly destroyed by wet, or even damp. Most fortunately, throughout the campaign scarcely any wet weather occurred: to this circumstance, and to the manner in which the park conductor, Mr. Richardson, performed his duty, may be attributed the very perfect order in which the packages reached Caubul. Experience proved that intrenching tools thus packed and carried formed an equipment well adapted for moving in countries where but little rain falls, where the roads are bad and difficult, and where, from the absence of forage for bullocks and horses, and the comparative abundance of a species of southernwood and camel thorn, the camel may be sustained with less difficulty than any other animal.

8. A disadvantage attendant upon pack lading is, that much time is required in loading and unloading, unless the park establishment be numerous, and that consequently more park men are requisite with a field equipment thus organized than with one in which wheeled carriage is employed. The inconvenience is, however, more than counterbalanced by the many resulting advantages, for the park establishment may be made very useful in all engineer operations.

9. The tool racks of the sappers and miners were found to answer the

purpose for which they were made, but it would in future be advisable to have them smaller, so as to carry only forty instead of sixty intrenching tools; the object being so to load the rack camels, that, however long the day's march, they should keep up with the advance, and as little time be lost as possible in waiting for the tools. Under ordinary circumstances the system pursued by Sir J. Keane was, to have the engineer department, with a detachment of infantry and a troop of cavalry, one march in advance of the force. Whenever the road required making, which was almost daily, parties of pioneers were told off to the duty. Wherever impediments of a more serious nature than ordinary occurred, a detail of sappers was set to work. A little delay in the arrival of the tools did not so much signify when the sappers were a march in advance; but when the proximity of an enemy was thought to demand a more cautious advance, and the sappers were only allowed a two or three hours' start ahead of the column, every moment was valuable, the cavalry and horse artillery being frequently upon the obstacle before the road was ready for them to pass over. On these occasions the work is very liable to interruption from the impatience of the troops.

10. The tool racks were of saul-wood, and in spite of numerous accidents and rough usage, lasted remarkably well, the chief repair being to re-drive the nails of the iron braces, the former being frequently started by the work and play of the joints. Screws and nuts would have given greater strength to the frames, but as they would have admitted of less play at the joints, fractures would probably have been more frequent; and it is doubtful therefore whether such an alteration would be an improvement.

11. The phowrah is a kind of spade, with the handle perpendicular, or nearly so, to the plane of the blade. The natives of Hindostan being accustomed to use this tool, it forms part of our siege equipments, but as an intrenching tool it is inferior to the shovel and spade. It must be added, however, that there is no part of a soldier's duty in which the regiments of native infantry are so totally ignorant as in the use of intrenching tools of any description. This would have been at first severely felt, had it not been for a body of 300 pioneers, raised by Captain Thomson, and placed under the charge of Lieutenant Broadfoot, Engineers. These men, common labourers, proved both a cheap and efficient body: they worked under the superintendence of sappers, and having no arms or accoutrements to carry, marched with their picks and phowrahs on their shoulders, and were always

ready to fall to work. They were of course disbanded as soon as the force returned to India.

12. The store cart and limber, as a substitute for a properly constructed truck, answered better than might have been expected. The great length of the bamboos, and the shortness of the body of the store cart, their support, caused them when in motion to vibrate much: this, together with the heat and dryness of the air, caused them to split so much that they had to be considerably cut down, and were also well bound with thongs of raw hide. For bamboo scaling ladders a truck carriage ought to be contrived, and form part of every engineer field equipment. Hitherto expeditions having been confined to Hindostan, the long-bodied cart of the country answered sufficiently well; but for moving over the roads of Afghanistan, and even in our own Indian provinces, a modification of the store cart would be preferable. The store cart and limber, with its long and awkward load, was useful in testing the roads made over the Bolan, Khajuk, and other passes; for where it travelled, the guns, with precaution, could not fail of being able to pass.

13. The sand bags made of taut are so heavy, that, notwithstanding they were likely to prove very useful in a country where brush-wood is scarce, only 1000 could be taken with the engineer park. It was, however, known that 5000 were in the artillery park, and consequently that, in case of need, these would be available for siege operations. Sand bags are useful in such a variety of ways, that it is worth while paying attention to the material of which they are made, with the view of rendering them much lighter and also more lasting than those of taut, upon which wet weather has an immediate effect.

14. It will be observed that hand grenades and other articles which usually form part of an engineer field equipment in India were on this occasion necessarily omitted, as the weight of some, and the shape and dimensions of others, rendered these stores ill-suited to camel carriage. Hand grenades should, however, form part of the stores of ammunition carried with every force in India or Afghanistan, and, as such, seem rather to appertain to the artillery than to the engineer park. To the former they would make no burdensome addition: about 200 wheeled carriages of different kinds, dragged by bullocks, and 450 camels laden with ammunition, crossed the Khajuk pass: an extra carriage, or three or four camel loads of hand grenades, would, considering the utility of the projectile, have been a valuable addition.

15. In conclusion, it may be added that in this not the least important

expedition undertaken by the Indian Government, inasmuch as it might have occurred that the towns of Candahar, Herat, Ghuzni, and the Bala Hissar of Caubul would have offered resistance, the engineer department started with one-sixth of the means provided for the reduction of Joudpoor in 1833. But when reference is had to the number of baggage cattle[7] which are allowed to accompany an Indian army into the field, to the liberality with which the various departments are furnished with carriage of every description, and to the general character of Eastern warfare, a series of attacks on small or large forts, it seems far from advisable that the present instance should become a precedent. On the contrary, it does not appear overrating the importance of the engineer department to state, that no division of infantry should, under ordinary circumstances, take the field without such an equipment of intrenching tools and other engineer stores as, inclusive of the usual proportion of spare cattle, would be apportioned to 110 camels. With a force of 10,000 bayonets there would then be an engineer park of 220 camels; and this, if the intrenching tools and stores were made of proper weight and pattern, would prove a very efficient equipment.

H. M. Durand,
Lieutenant, Bengal Engineers.

Delhi, April 4, 1840.

[7] The number of baggage and commissariat cattle is such, that the difference between the quantity of cattle requisite for an efficient engineer equipment and an inefficient one is an insignificant item in the amount of public cattle.

II.—*Note on the Defensive Works in Jellalabad, prepared by order of Major-General Sir Robert Sale, K.C.B.*

Jellalabad, 16th April, 1842.

On the 12th of November, the Major-General commanding having resolved to occupy Jellalabad, directed me, with a committee of officers, to examine and report on the works of the place.

The committee reported unanimously that they were then not defensible against a vigorous assault.

As will be seen by the accompanying plan, the town is an irregular quadrilateral, having half of the western side salient, and the southern side broken by a deep re-entering angle. It was surrounded on every side with gardens and houses, enclosed fields, mosques, and ruined forts, affording strong cover to an enemy; these were every where close to the walls, and in many places connected with them. Beyond these on three sides (N., E. and W.), at from 400 to 500 yards, run the ruins of the wall of the ancient city, on which the sand has accumulated so as to form a line of low heights, giving cover to the largest bodies of men. Opposite the south-west angle a range of heights, composed of bare gneiss rocks, commences at 330 yards from the works, and extends about 400 yards from N. N. E. to S. S. W.; these completely overlook the town, and, from the vicious tracing of the works, enfilade some of the longest curtains. Parallel to the north side, at 170 yards, runs a steep bank 20 feet high; it extends a considerable way to the west, and several miles to the east, affording a secure and unseen approach to any number of men; it is probably an old bank of the river. From it numerous ravines run up towards the walls, affording the enemy a covered passage into the buildings and enclosures adjoining the works.

Two very solid walls, 300 yards apart, run from the place to this bank, thus enclosing on three sides a space probably occupied originally by the Mogul emperor's palace, but found by us to contain a large mosque and numerous gardens and houses occupied by fakeers: one of the gates of the town opens into it, and it was traversed by a water-course about 10 feet wide, which entered the town by a tunnel under the rampart, large enough to admit several men abreast; a similar tunnel allowed it to pass out of the town on the eastern side.

The walls of the town extended about 2100 yards without reckoning the bastions, of which there were 33. The works were of earth and in the usual style of the country, viz., a high thin rampart, but in a state of ruin, without parapets, and without ditch, covered way, or outworks of any kind.

The bastions were full, but in some places lower than the adjoining curtains, very confined, without parapets, and sloping downwards from the gorge to the salient, so that the terreplein was completely exposed.

There were four gates and a postern, all of the usual vicious native construction, and, except that on the northern side, in a ruinous state.

To give some idea of the state of the works, I may mention that, of the committee sent to inspect them on the 13th November, not one except myself succeeded in making the circuit: large gaps cut off the communication, or insecure footing compelled the officers to descend among the adjoining enclosures, from which it was difficult to find the way, while on the south side the rampart was so imbedded in houses and surmounted by them, that its course could only be traced by laboriously threading the lanes of the native town.

On the north side the wall rose to a very great height *towards the town*, but sloped down to the exterior in a heap of ruins almost every where accessible; while at the foot were houses and gardens, so strongly occupied by the enemy, that during the night of the 13th November, our troops were unable to maintain their posts, and with the exception of the gateway, a line of 400 yards on the northern face was without a man on the works. Had the enemy then attacked us, we must have been reduced to a street combat.

On the following morning (14th November) the Major-General ordered a sortie in force, which drove the enemy from his positions with such loss that it was some time before he ventured near enough to disturb our works, which were now as vigorously prosecuted as our scanty supply of tools and the difficulty of procuring material allowed. We had only the tools (as per margin) brought from Caubul, with the sappers, for the operations expected in the Tezeen valley, and we were without wood or iron. Wood was obtained from the ruins of the cantonment, and from houses demolished

330 pickaxes,
390 shovels,
with other tools in proportion: many tools, such as trowels, &c., have been made here.

in the town. Iron was collected in small quantities from the neighbourhood, but it was that of the country, good in quality but imperfectly smelted, and requiring about ten times as much labour and time as English iron. By the persevering labour of the troops, however, much was done, and when the enemy next attacked us, (1st December,) ramps had been made and the guns mounted on the bastions for which they were destined; the water-courses and other passages through the walls blocked up, the foot of the scarps cleared from rubbish, and parapets built in all the bastions and many of the curtains, while much of the external cover was destroyed.

On the 1st December the enemy were again routed, and the works proceeded with little or no interruption.

By the middle of January (the commencement of the rainy season) a parapet nowhere less than 6 feet high, with a banquette as wide as the nature of the rampart allowed, was completed entirely round the place. The gates were repaired and strengthened by buttresses; two of them were retrenched, and a ditch carried round the north-west angle, while some of the most dangerous ravines were laid open to our fire, and roads were opened into the low ground on the north side.

By the middle of February the ditch was carried round the place with as good a covered way as the size of the ditch and supply of earth allowed, while the mosques, forts, gardens, and cover of every description, had been destroyed for several hundred yards round the place.

At this time Mahomed Akbar Khan moved into the valley in order to attack the place; but he was unable to effect more than a distant investment: the enemy frequently occupied the rocks on the south-west, but the parapets and traverses rendered their fire harmless.

On the 19th February an earthquake, which nearly destroyed the town, threw down the greater part of our parapets, the Caubul gate with the two adjoining bastions, the north-west bastion, and a part of the new bastion which flanked it. Three other bastions also were nearly destroyed, while several large breaches were made in the curtains; one on the Peshawur side, 80 feet long, was quite practicable, the ditch being filled and the ascent easy. Thus in one moment the labours of three months were in a great measure destroyed.

No time, however, was lost: the shocks had scarcely ceased when the whole garrison was told off into working parties; and before night the breaches were scarped, the rubbish below cleared away, and the ditches before them dug out, while the great one on the Peshawur side was surmounted by a good gabion parapet.

A parapet was erected on the remains of the north-west bastion, with an embrasure allowing the guns to flank the approach of the ruined Caubul gate; the parapet of the new bastion was restored so as to give a flanking fire to the north-west bastion, while the ruined gate was rendered inaccessible by a trench in front of it, and in every bastion round the place a temporary parapet was raised.

From the following day all the troops off duty were continually at work; and such were their energy and perseverance, that by the end of the month the parapets were entirely restored, the Caubul gate again serviceable, the bastions either restored or the curtain filled in when restoration was impracticable, and every battery re-established.

The breaches have been built up, with the rampart doubled in thickness, and the whole of the gates retrenched.

It is not easy to give an adequate idea of the extent of the labour performed by the troops.

The parapets, banquettes, &c., are built of the ruins of the buildings thrown down, cemented with clay mixed with straw, and bound together, when requisite, by bond timbers: of this masonry above 104,500 cubic feet had been built before the earthquake, and since then (including new works) about 103,900 cubic feet have been erected, making in all above 208,000 cubic feet of masonry. But the material had to be procured from a distance by the laborious process of demolition, and the ruinous wall had to be scarped, cleared at the base, and prepared for the work.

The quantity of walls of forts, mosques, gardens, &c., destroyed was considerably more than double that of the walls of the place, and the excavation from the ditch exceeds 860,000 cubic feet.

In addition to this, the troops had to build barracks for themselves and guard-rooms round the works: each corps undertook its own barracks, while the construction of the guard-rooms was superintended by Captain Moorhouse, Quartermaster of Brigade, and Lieutenant and Quartermaster Sinclair,[1] of H. M.'s 13th light infantry, whose assistance on this point left me more leisure for the defensive works.

[1] To Lieutenant Sinclair also we owe the mill used by the commissariat. I only furnished materials and workmen. The credit of the whole contrivance and construction is due solely to Lieutenant Sinclair,—(Signed) G. B.

The working parties in emergencies consisted of all men off duty, often assisted by the guards when the works were near their posts.

On ordinary occasions they consisted of all the sappers and miners, about 200 men of H. M.'s 13th light infantry, 120 of the 35th N. I., a party of artillerymen of Captain Abbott's battery, all the men off duty in Captain Backhouse's mountain train, and the detachment of the 6th infantry, Shah Soojah's force, doing duty with the mountain train. Detachments also of camp followers were employed in bringing material, &c.

Nothing could exceed the cheerful energy of every officer and man in these labours.

The sappers and miners worked from daybreak to sunset (with 2½ hours for meals), and, when occasion required, at night. Their conduct was such as to leave me nothing to desire, and it has been honoured with the Major-General's recorded approbation.

Lieutenant and Adjutant Orr and Lieutenant and Quartermaster Cunningham, who acted as my assistants, rendered me the most zealous and efficient aid; and I beg most respectfully to bring their great merit to the Major-General's notice. The European non-commissioned officers also displayed a zeal and intelligence deserving to be reported to the Major-General, more especially Sergeant-major Kelly, Quartermaster-sergeant Bruen, and acting Staff-sergeant Hughes, (from Her Majesty's 13th light infantry.)

The other troops, having very severe garrison duty, laboured for a shorter period, yet seldom less than six hours a day.

It will be seen that the largest parties were furnished by H. M.'s 13th light infantry, and I know not how adequately to express my sense of the services of this admirable body of men: though having little more than every other night in bed, they laboure for months, day after day, officers and men, with a cheerfulness and energy not to be surpassed. To enumerate all whose zeal and intelligence were conspicuous would almost require me to go over the list of the officers, and to mention even many of the valuable non-commissioned officers; but I cannot deny myself the pleasure of naming those whose more extended professional education gave their aid additional value, namely, Captain Fenwick, Lieutenant Frere, and Ensign Parker. Separate portions of the works were also intrusted at various times to other officers, especially Lieutenants G. King and G. Wade, and Ensign Scott, and I had every reason to be satisfied with their execution.

The 35th N. I. were much employed in destroying the forts and other cover around the place; and it is due to Captain Seaton to mention his great activity, and the skill with which, by directing the water-courses used for irrigation on the most massive ruins, he effected a quantity of demolition, which, with our short supply of gunpowder, would have otherwise been impracticable.

With the exception of a few of the larger bastions, the whole of the batteries were prepared by the artillery themselves (both Captain Abbott's battery and Captain Backhouse's mountain train), under the superintendence of their own officers. Besides this, a party of Captain Abbott's artillerymen was always ready to assist in the works generally, and they were most ably superintended by Lieutenant Dawes, to whom I am indebted for aid as constant as it was valuable and willingly given. Captain Backhouse, with his own men and detachment of the 6th infantry, Shah Soojah's force, not only prepared the parapets and embrasures for his own guns, and repaired the damages done to them by the earthquake, but he undertook and completed several of the most useful and laborious operations executed; among others, a large and widely branching series of ravines giving cover to many hundred men, within pistol-shot of a very weak part of the works, was filled up, or entirely laid open to fire, and that with a number of men, which, without his untiring zeal and personal exertion, would have been inadequate.

The camp followers were distributed to assist the troops, and they followed the example set them, and were extremely useful.

A plan is appended, showing in some measure the way in which the space round the fort was encumbered with buildings and enclosures, and giving an outline of the place as it now stands. The sections give some idea of the profile of the works as we found and as we leave them. Plates and I'

The gates have been retrenched inwardly, because, from the fall of the ground outside and its conformation, no adequate work could have been raised without a labour we could not at the time spare, and without occupying more time than we could ever reckon on for unmolested work.

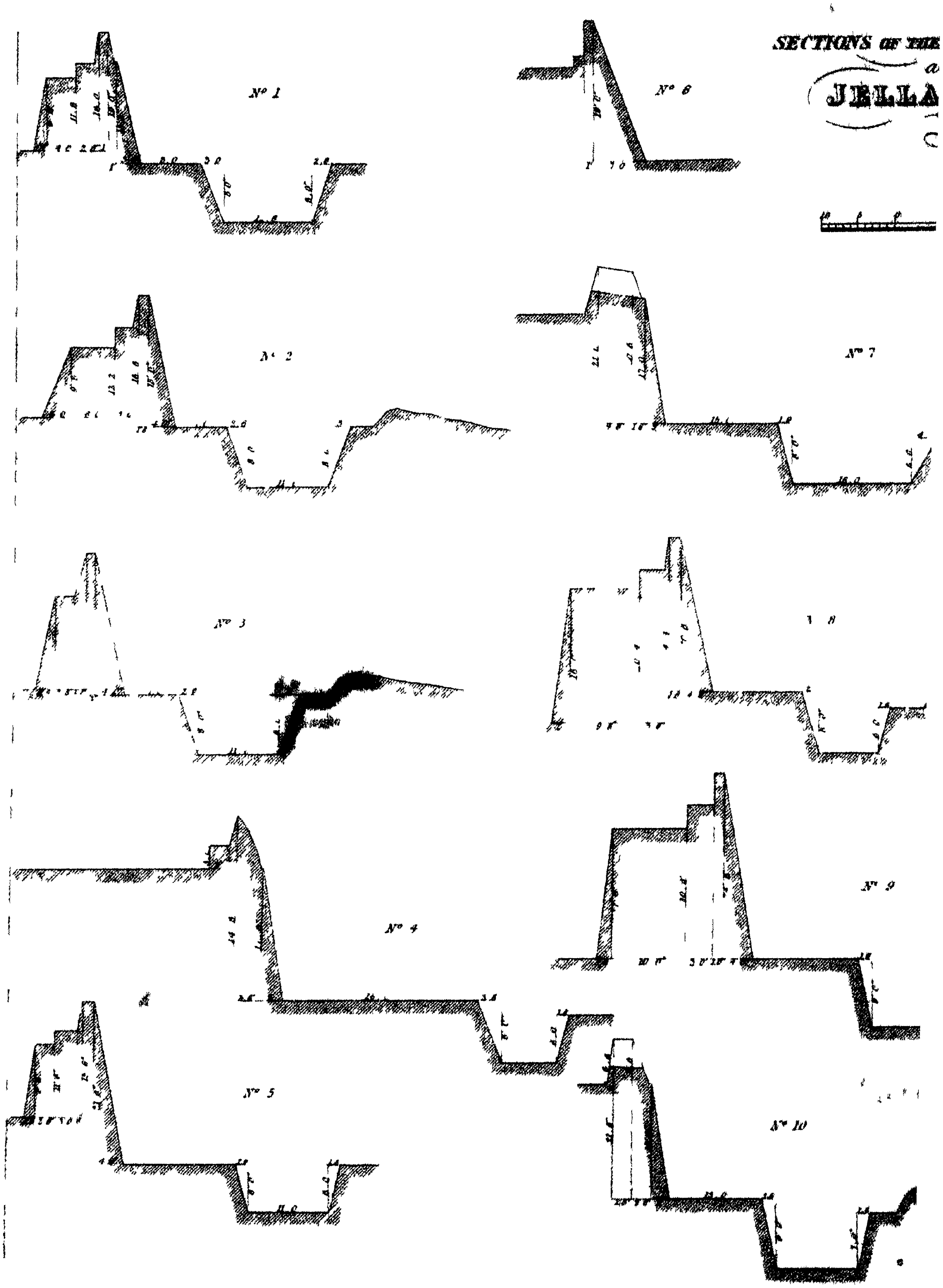
The narrowness and shallowness of the ditch are owing to our want of tools, which limited the strength of our working parties so much that any thing stronger could not have been carried round in time to accomplish our object —that of interposing an obstacle to a sudden assault and escalade on every side, while the enemy were still numerous, and elated by the Caubul disasters.

The breadth of the berm was necessary from the nature of the soil, a loose sand; and it varies as the necessity of including previous excavations, &c., obliged us to alter the tracing.

In conclusion, I have to solicit the Major-General's indulgence for this report, which has been prepared while suffering from a wound. If I have been diffuse in noticing the assistance received from the officers and troops, it must be ascribed to the admiration with which I daily, for many months, witnessed their labours, under circumstances of extraordinary discouragement, on short allowance of provisions, with heavy duties of other kinds to perform, and for a considerable time harassed by incessant conflicts with the enemy: during all this time there was not only no murmuring, but the utmost cheerfulness and zeal prevailed. It was not once necessary to resort to punishment, and I never had to make a single report other than commendatory.

(Signed) GEORGE BROADFOOT,
Captain, Garrison Engineer, Jellalabad.

To Major-General Sir R. Sale, K. C. B., &c., &c., &c.,
Commanding at Jellalabad.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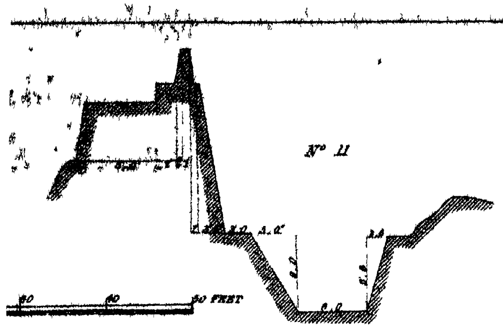
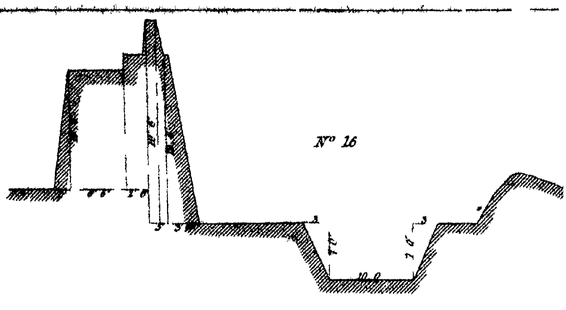
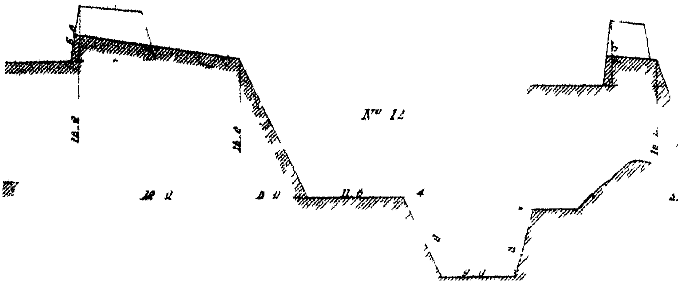
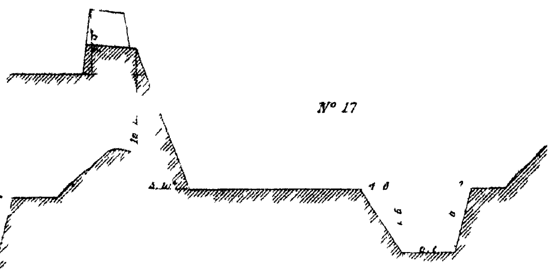
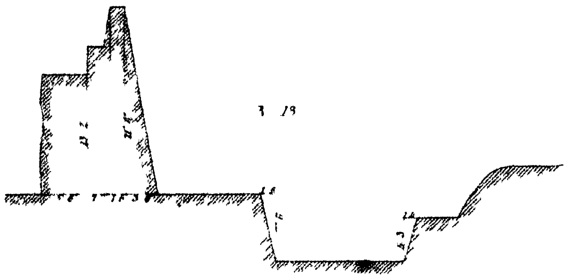
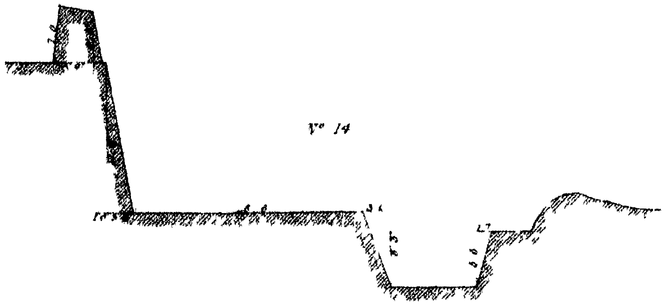


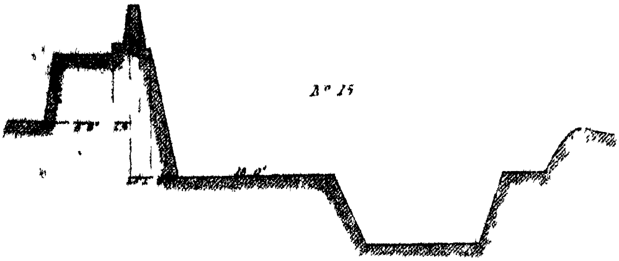






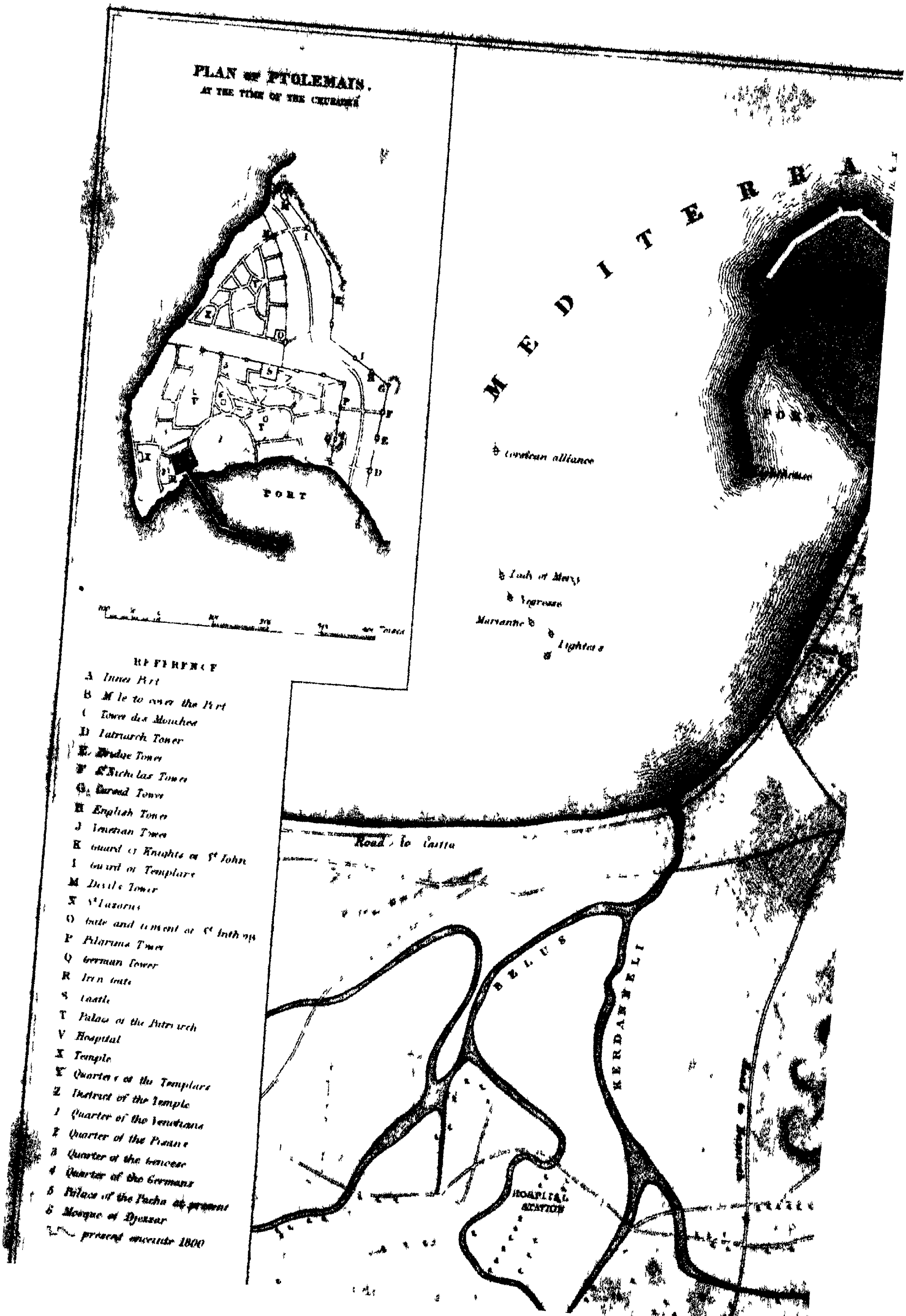






REFERENCE

1 [illegible] of Peshawur Gate
2 —— —— built up
3 —— N E Bastion
4 Bastion N E
5 Curtain left of N E Bastion
6 Salient of Work on E long Wall
7 Bastion at end of E long Wall
8 Curtain right of Watergate
9 left of D°
10 Bastion at W long Wall
11 Curtain breach at right of N W Bastion
12 Bastion N W
13 Curtain left of Cabul Gate
14 Bastion —— ——
15 Curtain near reentrant angle of Cabul Face
16 right of S W Bastion
17 Bastion S W


PLAN OF PTOLEMAIS.
PORT
REFERENCE
D Patriarch Tower
H English Tower
M Devil's Tower
N St Lazarus
P Pilgrims Tower
Q German Tower
R Iron Gate
T Palace of the Patriarch
V Hospital
X Temple
Y Quarters of the Templars
Z District of the Temple
1 Quarter of the Venetians
2 Quarter of the Pisans
3 Quarter of the Genoese
4 Quarter of the Germans
5 Palace of the Pacha at present
6 Mosque of Djezzar
present enceinte 1800
MEDITERRA
Lady of Mercy
Marianne
Road to Caiffa
BELUS
HOSPITAL STATION

III.—*Notes on Acre and some of the Coast Defences of Syria. With Plates, &c.* *By Lieut.-Col.* Alderson, *Royal Engineers.*

The fortress of St. Jean d'Acre is situated on the coast of Syria, and has long been considered as the key to Palestine.

Its original name was Accho, or Akka, and it is still so called by the Arabs. By the Greeks it is called Ptolemais, or, as at present, St. Jean d'Acre, from having been given by Richard Cœur de Leon to the Knights of St. John of Jerusalem.

The importance which has always been attached to the possession of this fortress is strikingly evinced by the numerous sieges it has sustained.

I propose in this Paper merely to notice the earlier sieges from the period of the crusades, but to enter more into the detail of the operations of the French under Buonaparte in their celebrated siege of 1799,—of that of Ibrahim Pacha in 1831-2, and of the last bombardment in 1840,—illustrating the description by such plans and sketches as my recent visit to Syria has enabled me to procure, not only of Acre itself, but also of the coast fortresses south of it, as Gaza, Jaffa, Caiffá, &c.

The Saracens held possession of Ptolemais till A.D. 1104, when it was taken by the Christians under Baldwin the First, King of Jerusalem, after a siege of twenty days.

It remained in their possession till 1187, when it was besieged by Saladin, but so well defended by the Knights Templars and Hospitallers that he was forced to raise the siege with great loss.

A few months afterwards, however, having defeated the Christians with great slaughter at the battle of Tiberias, he again advanced on Acre, which capitulated in two days.[1]

[1] The battle of Tiberias took place on the 3d July, and so fatal was it to the Christian cause in Palestine, that Saladin soon after obtained possession of all the fortresses on the coast with the exception of Tyre.

In 1189, Guy de Lusignan, King of Jerusalem, besieged the city, and although too weak at first to make much progress, and driven at times from his lines by the advance of Saladin, he persevered, and at length, by the powerful assistance of Philip of France, and Richard Cœur de Leon, and pilgrims from nearly every Christian state in Europe, the city was taken in 1191, after two years' siege.

The garrison being in want of provisions, and having extensive breaches in their walls, and finding Saladin unable with all his forces to oblige the Christians to raise the siege, capitulated. Plate V. shows the plan of Ptolemais at this period. It is described as built to the westward of an extensive plain, the Mediterranean washing its walls on two sides; and from the convenience of its port, it attracted the commerce of Europe and Asia, and even rivalled Tyre.

On the land side the defences consisted of walls well flanked by towers, the most remarkable of which was the Tour Maudite, which commanded the plain. The whole was surrounded by a deep ditch.

A mole of masonry running easterly from the south-eastern extremity of the fortress protected the port, beyond which, and on a line with the mole itself, was an enclosed work on a rock in the water, called La Tour des Mouches, which protected the entrance.

The situation of the city was unhealthy in consequence of the marshy ground in the neighbourhood, arising from the overflowing of the Belus and the stagnation of the waters which descend, during the rainy season, from the neighbouring mountains.[2]

[2] On the whole of the coast of Syria the current sets strongly from south to north, so that small rivers like the Kishon and Belus have great difficulty in keeping open their communication with the sea, in consequence of the mass of beach, consisting of sand and shells, which is forced on by the current. This constant action has contracted the mouth of these streams, and driven them by degrees farther north, so that they now run a considerable distance, nearly parallel to the beach, a short distance inland. Here they are deep, but where they cross the beach and communicate with the sea, they are always fordable, and sometimes only a few inches deep. They may be said to resemble cisterns with a waste pipe at the top to prevent their overflowing. During heavy rains, the supply being greater than the pipe can discharge, the rivers overflow their banks and form unhealthy marshes. It is very probable that a groin to the southward would keep the mouths clear of beach, and enable these marshes to become fertile plains.

At Wadi El Arisch, in which there is water only during heavy rains, there is no appearance of any outlet to the sea, the beach being many feet higher than the bed of the Wadi.

While Ptolemais, or, as it may now be called, Acre, continued in the possession of the Christians every care was taken to increase and strengthen the fortifications. A double wall was built on the land side, flanked by high loop-holed towers, with a wide and deep ditch in front, of which the King's Tower, towards the east, and that of the Templars in the centre, appear to have been the principal, whilst towards the sea the city was defended by a fortress built at the entrance to the port.[3]

Owing to these precautions, Acre remained in the possession of the Christians till 1290, when it was besieged by Sultan Khalil, and, after a siege of thirty-three days, was taken by assault, and the whole population either put to the sword or sold as slaves.

The convent of the Templars held out for three days after the rest of the town was taken, and when it was stormed only ten knights out of five hundred were found alive.

The churches and fortifications were destroyed by order of the Sultan.

From this period Acre has remained subject to the Mohammedan power, and until the middle of the last century was little better than an open village; it was then seized upon and fortified by Shiek Daher, the chief of a tribe of Bedouins, who was aware of the advantage of its position: under his superintendence it gradually rose into importance.

In 1775, Daher, who was called Prince of Acre, was assassinated, and was succeeded by Achmed El Djezzar.

Djezzar still further strengthened the fortifications of Acre, and by his defence of it in 1799, against Buonaparte, restored it in some measure to its ancient celebrity.

The details of this siege I shall now proceed to give, quoting principally from the accounts published by the French themselves.

Buonaparte having defeated the Mamelukes at the battle of the Pyramids, took possession of Cairo; one division of the routed army, under the command of Mourad Bey, took the route of Upper Egypt; the other, under Ibrahim Bey, retreated into Syria.

[3] Some idea may be formed of the reputed strength of Acre at this period, when the Sultan thought it necessary to bring 60,000 horse and 140,000 infantry to the siege.

It is also stated that there were three hundred battering rams, catapults, and covered galleries; and that the timbers of one of the machines alone were transported on one hundred waggons.—*Vide* Michaud sur les Croisades.

Buonaparte, under the pretence of punishing the Pacha of Acre, who had refused to listen to his friendly overtures, and had given assistance to Ibrahim Bey, crossed the Desert with a force consisting of near 13,000 men,[4] with a field train of twenty-seven light guns and eleven howitzers: he advanced at once on El Arisch,[5] which capitulated after a siege of three days.

[4] About 17,000 men were left in various positions in Egypt.

[5] *El Arisch in* 1841.—The fort of El Arisch is a square scarped work, each front being about 220 feet in length, with an escarp of 25 feet in height, composed of a facing of small cut stone in courses of from 6 to 8 inches, backed in with mud and sun-burnt bricks, and surmounted by a loop-holed mud parapet for infantry.

There are four small pentagonal towers at the angles, each face being about 10 feet in length, with a small embrasure in it.

There is no ditch, and the escarp is seen to its base, excepting on the north-west and part of the north-east fronts, where the village, consisting of about one hundred mud huts, lying close to the walls, conceals a small portion from the view.

The entrance is in the north-west front, the road to it being through the village; it is an arched passage about 40 feet in length, with a small divan, or reception hall, at the end; ramps to the right and left lead to the interior, where there is considerable hut accommodation for the troops, and an excellent well of water. The Governor's quarter is over the gateway.

The fort is incapable of offering a protracted resistance even to good field artillery, and owes much of its importance to its situation in the Desert. As an advanced post, near to the southern frontier of Syria, it is very useful to the Egyptians.

On any fear of invasion from the south, the rulers of Syria would do well to make a rapid march on it from Gaza, and raze it to the ground.

It is too distant from the shore to be annoyed by shipping, but batteries placed on the sand hills, which are numerous between it and the beach, might possibly receive support from them. The landing, however, is generally difficult, and often dangerous. Even in fine weather, with only a slight breeze blowing *on shore*, it would be difficult to embark or disembark troops and artillery.

The situation of El Arisch has been judiciously selected; it is at the junction of several water-courses, or streams, from mountains bordering the Desert El Tih to the south-east, and from the western side of those of Idumea, which here meet and run towards the sea, under the name of the Wadi El Arisch.

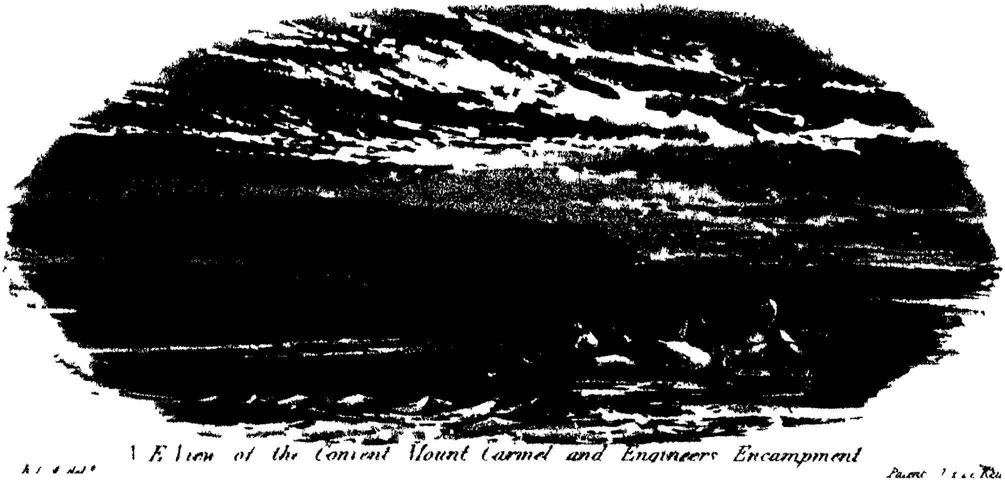
These beds are dry, excepting in the rainy season, and it is questionable if the mouth of the Wadi is ever open to the sea, excepting at some extraordinary flood, as the bank of shingles on the beach is as high at this point as elsewhere, so that from the sea there is no appearance of a river or water-course.

It is probable the water expends itself by evaporation and by sinking into the ground. Water is to be had any where in the immediate neighbourhood by sinking wells from 6 to 12 feet deep, and a few vegetables and water melons, &c., are raised by irrigation.

Close to the mouth of the Wadi, along the shore, is a large plantation of palm-trees and a large

\ W View f Tibria ad the Sea f Galilee

View f Caiffa from the Anchorage



\ E View of the Convent Mount Carmel and Engineers Encampment

A. I. A del.ᵗ Parent J. e. c. Rea

A. C. A. del.^t — P. sculp. H. Le Keux

?th We t Vie ? El Arish

R.C.A. del.t Patent _ J.H. Le Keux.

The Beach at Ascalon looking South.

London. John Weale 59, High Holborn 1848.


From the Coast
GAZA
Harrat it te fear
From El Arish
From El Arish
Special Reconnoisance of
GAZA
HARRAT IT TE FEAR

On the 21st February, the garrison, consisting of 1000 men, laid down their arms. In the fort were found 250 horses, a large supply of provisions, and two pieces of artillery. From El Arisch the French moved on Gaza,[6] which is stated to have had at that time a circular fort, forty toises in diameter, flanked by towers. Abdallah Pacha having retired, the place was given up without resistance.

Having found a supply of provisions in the magazines of Gaza, the French moved on Jaffa.[7] This place is described as being at that time surrounded by

caravansary; and it may be here remarked, that where the palm-tree grows, water is always near. The soil brought down by the streams produces a sort of mud or clay, and of this they build their huts. The stone for the facing of the fort must have been imported.

[6] *Gaza in* 1841.—Gaza is the principal town on the southern frontier of Syria, and contains, with the two villages or suburbs adjoining, about ten thousand inhabitants. Plate VI.

It is situated a short league from the coast, which is here, as at El Arisch, an open beach, and the landing difficult, excepting in very calm weather.

Gaza is the rendezvous of the Arabs of the neighbouring districts, and being the first place where an invading army from the south can receive supplies after crossing the Desert, it is of considerable importance. At present it is an open town, as it was not to the interest of Mahomet Ali to restore the castle destroyed by Buonaparte in 1799, he having no enemy to fear from the south. To the Turks, however, it is essential that it should be a fortified post, not only to protect the southern frontier of Syria from insult, but also to repress and keep in subjection its population and that of the various neighbouring tribes, who are little inclined to submit to a regular government, and are ever ready (Arab like) to give their allegiance to that power which appears to them most to be feared.

Gaza is surrounded by gardens which produce fruit in abundance, and the prickly pear hedges grow to such an immense size that troops might be bivouacked or encamped in the gardens in the plain immediately at the foot of the rising ground on which the town stands, surrounded by a natural abatis perfectly impenetrable.

The garrison of Gaza should consist principally of cavalry and field artillery, the plains in the neighbourhood being well adapted for this species of force.

[7] *Ascalon in* 1841.—As the once celebrated city of Ascalon lies on the coast between Gaza and Jaffa, a few words descriptive of its state in 1841 may not be unacceptable.

It is distant from Jaffa about nine leagues, and from Gaza three leagues, and half a league from the road between these two places at the village of Misdal.

Between this village and Ascalon, and about one mile distant from the former, is a ridge of sand hills, shutting out the city from vegetation and the habitation of man. A ruined watch tower is discernible on the top of the ridge, and points out the road to this once prosperous place.

From this tower the ruins lie before you on the sea shore, about half a mile distant.

The form of the wall surrounding the city is that of a horse-shoe, and the whole may not a wall flanked by good towers, with guns mounted on them, but without a ditch. The port and roadstead were defended by two forts, and the place was

inaptly be represented by a horse's foot with the shoe on, the heel being towards the sea. The fortifications, which consist of massive walls flanked with square towers at different distances, represent the shoe, whilst the frog of the foot is formed by a hill running from the cliff, or heel, on which are the ruins of several large buildings.

The remainder of the town lies in the sole, considerably lower than the hoof on which the fortifications stand.

The width of the heel from point to point of the shoe, as measured on the beach, is about 1250 yards, whilst the length from the heel to the toe is about half that distance.

The eastern or principal entrance to Ascalon is in the toe; here a paved road, ascending considerably, leads to two towers, now in ruins, between which apparently the gateway stood.

There are two other entrances, one to the north and the other to the south. The former is still visible, as well as the road leading to it, which is hollow and flanked by towers; that to the south is nearly buried, as well as the ruined walls on that front generally, by the drifting sand.

On both sides of the principal entrance are the remains of what appear to have been beautiful gardens; the almond, mulberry, and fig-trees were, on the 10th July, in full bearing, and their fruit delicious. They contrasted wonderfully with the view in the interior from the top of the ruined walls, by which they are protected from the sea breezes.

No language can do more justice to the scene of destruction which here presents itself than the words of the prophet upwards of two thousand years before. "For Gaza shall be forsaken, and Askelon a desolation." (*Zephaniah*, chap. ii. verse 4.) And again: "And the king shall perish from Gaza, and Askelon shall not be inhabited." (*Zechariah*, chap. ix. verse 5.) And desolate and uninhabited is this once stronghold of the Philistines, to this day. An Arab boy tending cattle grazing in the sole of the foot, and watching lest by a false step they should disappear amongst the ruins, was all that gave sign of life in the once prosperous and busy city, save a fox which was unkennelled from under the capital of a Corinthian column, and for the first time most probably broke cover to an English view halloo.

The cliff is not a solid rock, and varies from 10 to 100 feet in height; it appears to have been supported at intervals by walls whose fragments now lie on the beach.

There are no remains of the port itself, spoken of in the time of the crusaders; indeed, it is as difficult to land here as at El Arisch or Gaza.

At the south end, however, forming the line of the works produced, are rocks running out into the sea; and within the horse-shoe, near to them, on the beach, are the ruins of extensive buildings, with walls, still standing from 20 to 30 feet in height.

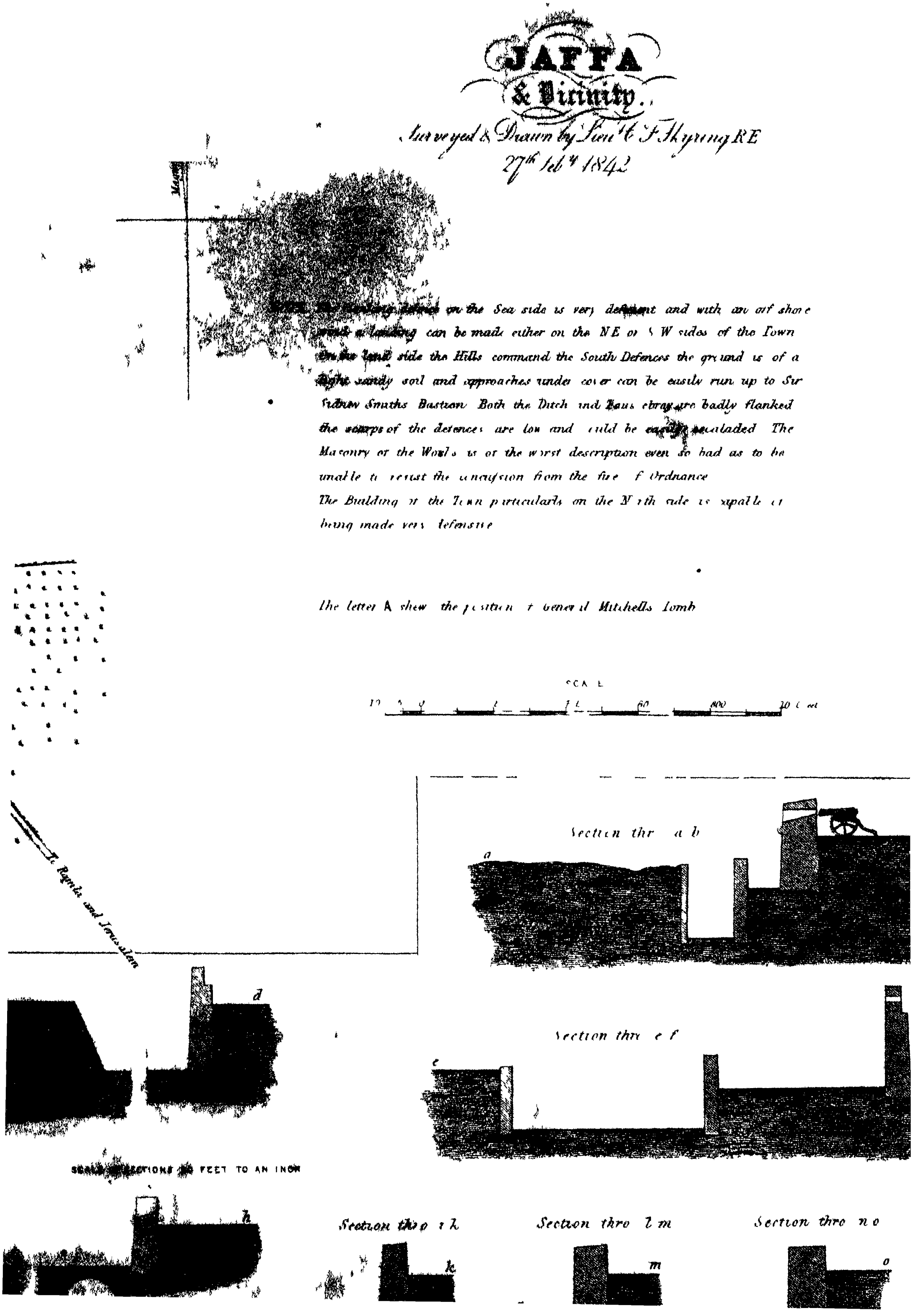
The masonry at Ascalon consists of small cut stone, seldom exceeding 6 or 8-inch courses.

Both the towers which surround the town, and these buildings on the beach, have the shafts of columns of granite and white marble, the former from 18 to 40 inches, and the latter from 8 to 12 inches in diameter, built into their walls horizontally and projecting inwardly, as if to form platforms or joists for an upper story. The pillars give an extraordinary appearance to the ruins, and belong, no doubt, to buildings of an earlier date.

The present works are probably those destroyed by Saladin towards the end of the twelfth

J. LeKeux

Anchorage for Small Vessels
Fausebray
ditch
Water Works
Burial ground


JAFFA
& Vicinity.
Surveyed & Drawn by Lieut C. F. Skyring R.E.
27th Feby 1842
on the Sea side is very and with an off shore
can be made either on the N E or S W sides of the Town
side the Hills command the South Defences the ground is of a
sandy soil and approaches under cover can be easily run up to Sir
Sidney Smiths Bastion Both the Ditch and are badly flanked
the of the defences are low and could be escaladed The
Masonry of the Works is of the worst description even so bad as to be
unable to resist the concussion from the fire of Ordnance
The Building of the Town particularly on the North side is capable of
being made very defensive
The letter A shews the position of General Mitchells Tomb
SCALE
To Ramla and Jerusalem
Section thro a b
Section thro e f
SCALE SECTIONS FEET TO AN INCH
Section thro i k
Section thro l m
Section thro n o

lere from Moun

NAWAB SALA

East View
UR

Patent... J.H. le Keux

well garrisoned.[8] After a reconnoissance on the 3d March, it was decided to attack the south-west front, the highest and strongest part of the work, and the same night the trenches were opened, and one breaching and two counter-batteries were established. A battery was also established on the north side of the work as a diversion. The 4th and 5th were employed in completing these works.

Two sorties were made by the besieged, who were repulsed with vigour, and sustained considerable loss. On the 6th at daybreak the batteries opened their fire, and at 4 P. M. the breach was reported practicable, and the assault was ordered. The tower in which the breach was made was carried, and the town entered; but the Turks continued to defend themselves gallantly from house to house and street to street; and, refusing to surrender, many were put to the sword: those taken prisoners were shot a few days afterwards in cold blood, on the plea that they had formed part of the garrison of Gaza, and had broken their parole.

The whole garrison consisted of 1200 Turkish artillery and 2500 Maugrabins

century, and which Richard I., after the capture of Acre in 1192, endeavoured to restore. He called on the crusaders to throw aside their arms and labour at their reconstruction, setting the example in his own person.

The work of restoration thus begun was but of short duration; quarrels and jealousies, but too frequent, I regret to state, amongst the crusaders, soon broke out and put a stop to these labours; and Richard soon after took his final departure from the Holy Land.

[8] *Jaffa in* 1841.—The fortified town of Jaffa is of considerable importance from its position on the coast, it being the most southern port in Syria.

It is also the sea-port of Jerusalem, from which it is only two short days' march.

Both at Jaffa and at Ramla (the ancient Arimathæa), four hours distant on the road to Jerusalem, are convents for the reception of the pilgrims who disembark at the former place.

The harbour of Jaffa, as will be seen on reference to the plan, is only adapted for vessels of small draught of water; the shelter, however, afforded by the natural breakwater by which it is formed, secures a landing at this place when it is impracticable on the open coast.

There is shelter here also for gun-boats.

The fortifications are defective in trace, but being revetted with masonry throughout, necessarily oblige an enemy to break ground before them; whilst the castle, convents, and store-houses, afford considerable accommodation for troops and stores.

The south and south-east fronts are, from the nature of the ground in their immediate neighbourhood, the most assailable, and some additional outworks appear to be very requisite.

Jaffa was evacuated by the Egyptians in 1840, after the fall of Acre.

or Arnauts; 300 Egyptians were sent home. The French lost 30 men killed and 200 wounded.

Forty pieces of artillery, forming the field train of Djezzar Pacha, sent to him by the Sultan, were found in the place, also 20 pieces, partly iron, partly brass, mounted on the walls.

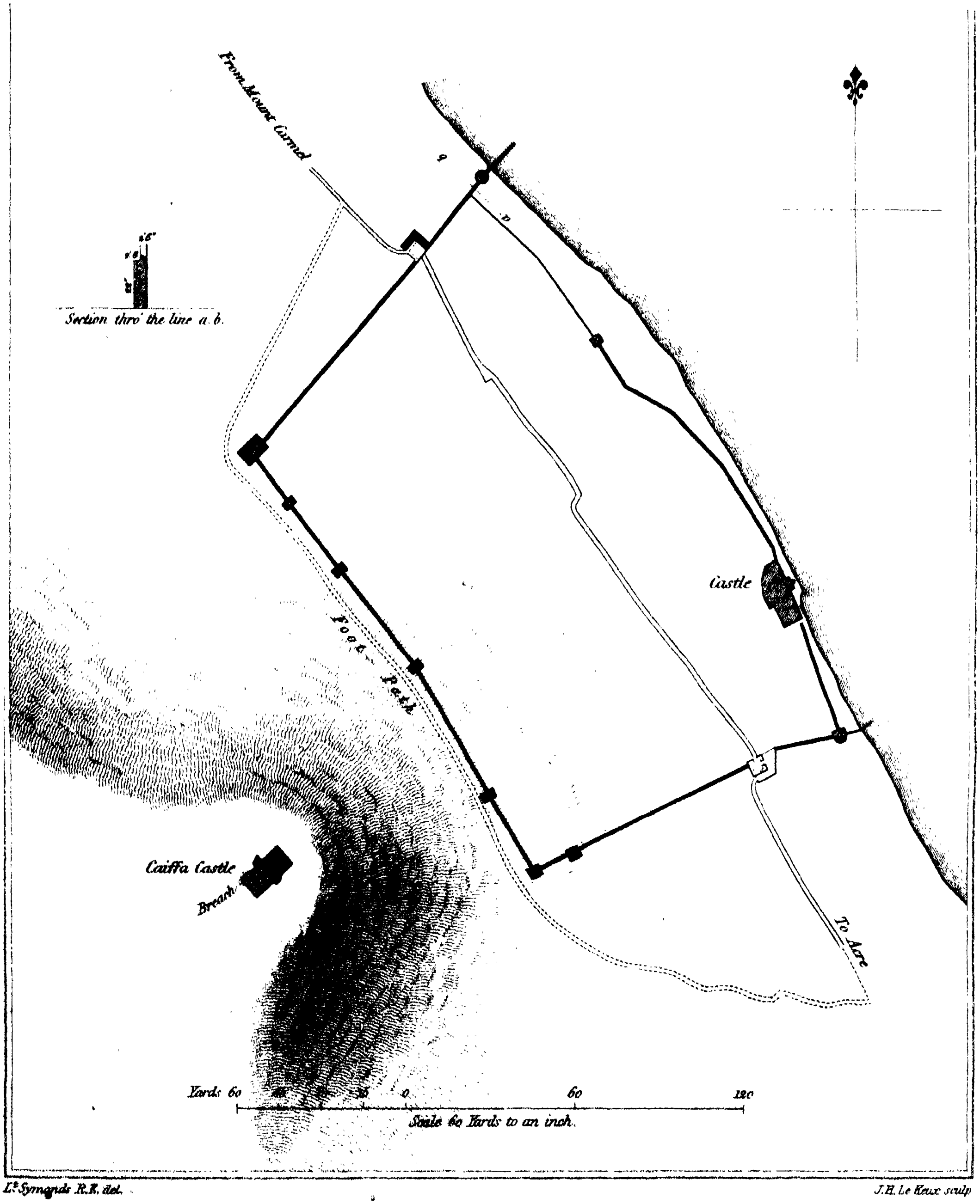
Buonaparte gave directions to have the place put into a defensible state, and established an hospital and magazine; he also formed a divan or council, consisting of the principal Turks of the place, and having determined to establish his depôt there, he made Adjutant-General Gressin governor, and sent off the account of its capture to Alexandria, with orders to Admiral Perée to sail from thence with three frigates for Jaffa: he then pursued his march upon Acre. Abdallah Pacha took up a position with 2000 cavalry on the heights of Korzoum, having on his left a body of 10,000 Turks, with the intention of checking the French by lying on their right flank, and obliging them to fight him in the mountain of Naplouse, and thus retarding, if not stopping, their advance on Acre. Lannes moved against these troops, and drove in their outposts, when he was ordered to desist from the pursuit.

On the 15th, Caiffa opened its gates to the French, though the tower commanding the town might have obliged them to have brought up their artillery to reduce it: it supplied the French with 20,000 rations of biscuit, and as many of rice.

The Turks had destroyed the wooden bridge over the Belus. General Andreossi moved up the river with a battalion, crossed it by a ford, and, taking possession of a height which commanded the place, drove back the advanced posts of the Turks, and established a communication with the troops on the left bank of the river, who quickly established a bridge; and by break of day on the 18th the French army was in position on the heights around the town.

The garrison were immediately driven in from the advanced posts, and Generals Dommartin and Caffarelli, the chiefs of artillery and engineers, made the reconnoissances of the place. The defences were found to consist of a simple wall presenting two distinct fronts, both resting on the sea: these two fronts were flanked by a large tower at the most salient point, and smaller towers were placed from distance to distance along the curtains or wall: in front of this was a dry ditch, but its dimensions could not be ascertained, neither was it known whether the counterscarp was revetted or not.

PLAN OF CAIFFA.



Lt. Symonds R.E. del.

J.H. Le Keux sculp.

The large tower appeared to be well built of good masonry, and the strongest part of the work; but being the most salient, and flanking both the land fronts, it was decided to attack it.

The trenches were opened on the 19th at a distance of about 300 yards from the place, advantage being taken of the gardens and ditches of the ancient town and of an aqueduct which crossed the glacis; and the troops were posted so as effectually to cut off all communication with the country, and to enable them to repel any sorties that might be made. The counter and breaching batteries were commenced on the same day, but the heavy artillery, which had been embarked at Alexandria, had not arrived, it having in fact been captured by Sir Sidney Smith, who had in the beginning of March been appointed to succeed Captain Troubridge, and who had under his command the *Tigre* and *Theseus*. The movements of this squadron, which co-operated so effectually with the Turks in the defence of the place, will here be narrated.

Intelligence having arrived on the 7th of the progress of the French in Syria, and of their having taken Jaffa by storm, Sir Sidney dispatched the *Theseus* to Acre with Colonel Philippeaux, a French royalist artillery officer. The *Tigre* remained in front of Alexandria, to watch the naval movements of the enemy; and some movements in the port having given intimation that an expedition was preparing, which intimation was confirmed by a merchant vessel, Sir Sidney dispatched Mr. James Boxer, midshipman of the *Tigre*, in the *Marianne* prize, with orders to examine minutely the coast to the eastward of Alexandria, and to rejoin him in the roadstead of Caiffa, in sight of and not eight miles distant from Acre, to which place he also made sail.

On the 15th March, having been rejoined by the *Marianne*, Sir Sidney, with the *Tigre* and *Theseus* in company, anchored in the Bay of Acre, and the following day he landed and paid a visit to Djezzar, and, assisted by Colonel Philippeaux, Captain Miller, and other officers, commenced putting the town, with its ruined walls, into the best possible state of defence which the time would admit of: he sent his launch with a 32-pounder mounted in it, to annoy the French on their march along the coast road, and by this means obliged them to go to the eastward of Mount Carmel, and take the Nazareth road; and as the French did not employ artillery against him, he was convinced that it was coming by sea, and accordingly kept a close watch along the coast for the purpose of intercepting it; and on the morning of the 18th a French flotilla hove in sight, consisting of one corvette and nine sailing gun-vessels. After five hours' chase, six of the latter were captured, together with one which had been taken from the British that morning. These vessels contained the battering train and siege equipage of every kind brought from Damietta, the whole of which were immediately landed, and proved of most essential service in the defence of the place. The prizes were manned and sent to co-operate with the boats in harassing the French operations on shore, and cutting off their supplies along the coast.

On the 21st an unsuccessful attempt was made to cut out four vessels which had got under the guns of Caiffa, and which were loaded with supplies for the French army.

Soon after this a violent gale obliged the *Tigre* and *Theseus* to stand off the coast till the 6th of April.

We will now return to the siege, which was prosecuted with activity. On the 25th the Turks made a sortie, which was repulsed with loss, and on the 27th the counter and breaching batteries were ready; they opened at daylight on the 28th, being armed with four 12-pounders, four 8-pounders, and 4 howitzers. About 3 P. M. the fire of the place slackened very much, and the besieged seemed to be dislodged from the tower, which was apparently very much injured.

The grenadiers offered to storm the tower, and although the artillery officers reported the breach impracticable, the troops, excited with their success at Jaffa, persisted, and the assault was ordered.

At 4 o'clock the grenadiers moved forward from the trenches, but were stopped very soon by a wide and deep ditch, with a revetted counterscarp about 15 feet high. This obstacle, however, was soon surmounted; fascines were thrown into the ditch, the ladders placed on them, and the troops, descending, moved forward to assault the damaged tower, the wall of which was found to be still standing to the height of 8 or 10 feet: the ladders were speedily planted, and the escalade commenced. At this moment, the Turks, who had at first fled, finding that the obstacles opposed to the French were greater than they had anticipated, returned to their posts, and keeping up a heavy fire upon the assailants, and throwing stones, &c., from the top of the tower upon their heads, completely succeeded in repelling the assault, and obliging the French to retreat to their trenches with some loss.

March 30.—The Turks, rendered confident by their successful resistance, made a vigorous sortie, but were repulsed with some loss. The French continued their fire upon the tower, and the miners were set to work to drive a gallery and establish a mine to blow in the counterscarp.

March 31.—The mine was completed and charged; the fire of the batteries had silenced that of the place; the tower appeared again abandoned; and although the breach did not seem much more practicable than before, yet it was determined to try a second assault, as it was considered that the alarm from the mine, and its effect in filling up the ditch, would paralyse the efforts of the defenders, and render the assault more easy.

The mine was fired in the evening, and the troops moved immediately from the trenches; the counterscarp was blown in, but the tower itself was in much the same state as at the first assault; and in consequence, after many vain attempts to escalade it, the troops were obliged to retire. Being now convinced that it was in vain to attempt to breach the tower with field artillery, and no information having been received of the arrival of the three frigates ordered to sail from Alexandria, it was decided that a gallery should be driven across the ditch and a mine established below the tower, and the miners were immediately set to work.

The Turks, in the mean time, stimulated by the success they had met with, and hoping daily to receive effective assistance from the army of the Vizier, which was now assembling behind the Jordan, made several sorties in order to hinder the progress of the works of attack, but were generally repulsed with much loss.

On the 7th, however, the *Tigre* and *Theseus* having returned to their former position, a general sortie was made in three columns: at the head of each was a party of English seamen and marines, some of whom also were employed in serving the artillery on the ramparts.

The principal object of this sortie was to destroy as much of the advanced sap as possible, and more especially to fill in and destroy the gallery leading under the tower. The noise made by the Turks in marching out rendered all attempts at surprise abortive; but notwithstanding this the French were driven from the trenches, and the Turks maintained themselves there until the English, under Majors Douglas and Oldfield, of the Royal Marines, and Lieut. Wright, R. N., of the *Tigre*, had destroyed the gallery and filled in the sap. Major Oldfield was killed, and Lieut. Wright severely wounded, and several other casualties occurred; but having succeeded in the main object, the troops were withdrawn, carrying their wounded with them.

During the time that the miners were working to re-establish the gallery and complete the chamber of the mine under the tower, Buonaparte marched with all the disposable force to assist Kleber, who had been attacked by a large force of Mamelukes and Turks, near Lake Tiberias: he found Kleber's division surrounded on the plain between the Jordan and Mount Tabor by a force of 10,000 infantry and 25,000 cavalry, but the united force of the French soon dispersed this undisciplined body with great slaughter, driving a great number into the river.

Buonaparte having thus released Kleber, left him to keep the line of the Jordan, and returned himself to prosecute the siege.

April 22.—The garrison erected a place d'arme on the beach to the south, to cover the gate by which they made their sorties.

The mine under the tower was completed, the guns opened their fire upon the breach, and the mine was sprung, but the effect of it was only to break a large mass from the foot of the escarp in the bottom of the ditch, while the tower remained standing, and the breach remained as impracticable as before: 30 men were ordered to make a lodgement to reconnoitre the breach.

The grenadiers reached the rubbish under the arch of the lower story, and there effected a lodgement; but the garrison having a communication from the gorge of the work, &c., occupying the upper story, compelled them to retire.

25th.—The batteries continued their fire on the breach; at night another attempt was made to effect a lodgement in the lower story, but the garrison, who still maintained themselves in the upper story, by showering down combustible materials obliged the French to retire.

26th.—General Caffarelli died of a wound which he had received on the 9th.

Another mine was ordered to be established under the tower. Buonaparte having received information of the arrival at Jaffa of the three frigates from Alexandria, and of their having disembarked three 24-pounders and six 18-pounders, with ammunition, ordered them to be forwarded to Acre, and sent the frigates to cruise on the coast of Tripoli, Syria, and Cyprus, to cut off the supplies sent from these places to the besieged.

The besieged established a second advanced work on the left face opposite the palace of the Pacha,[9] and constructed a battery which flanked the approach

[9] These works are described by Sir Sidney Smith as ravelins, one on each side of the enemy's nearest approach, thus bringing a heavy flanking fire on the breach: they were constructed by

to the tower and breach; they also raised cavaliers in the interior, and pushed on a counter-approach against the works of the besiegers.

The plunging fire from the towers and elevated walls gave the garrison great advantages in carrying on these works.

To silence the fire of the place, and to enable the besiegers to effect a lodgement, a greater fire was required than the means of the French would allow them to maintain, ammunition being far from plentiful in their camp; and thus the most gallant and daring attempts on their part were rendered unavailing.

On the 30th, the artillery arrived from Jaffa, and on the first of May they were placed in battery against the tower: the second mine was sprung, but the explosion took place principally in the interior, and the tower remained immoveable.

At night an attempt was made by thirty grenadiers to effect a lodgement in the tower, but the garrison, by means of the trench, or counter-approach, took the breach in reverse, and brought so heavy a fire on it that the French were obliged to retire. At the same time that this attempt was made, the garrison sallied out in force, but were repulsed with great loss.

All attempts at making a practicable breach in the tower having failed, Buonaparte at last ordered the artillery to turn their fire upon the east curtain, for the purpose of forming a breach; a sap was also to be advanced to the counterscarp, and a mine established to blow it in.

Up to the 4th, the attacks on both sides proceeded with vigour. The French, however, now began to be short of powder, and consequently to slacken their fire, which gave encouragement to the garrison, who never failed to avail themselves of the slightest advantage.

The sap on their right was pushed on with increased activity, the object of which was to cut off the besiegers' communication with the new mine.

Buonaparte ordered, at six in the evening, the companies of grenadiers to possess themselves of the outworks of the garrison: this was effected, and the defenders surprised and cut to pieces; three pieces were spiked, but the fire from the place was too well directed to let them keep possession of them long

the British marines under the directions of Colonel Philippeaux, who died on the 2nd of May, of fever brought on by exposure and fatigue: his loss is deeply deplored by Sir Sidney, who adds, however, that Colonel Douglas, of the Royal Marines, ably supplied his place as engineer, having hitherto carried on the works under his direction.

enough to effect more than partial destruction; and on the following day the garrison re-occupied them, and commenced their restoration.

The besieged also persevered in their endeavours to advance to the sap constructing to lead to the mine for the destruction of the counterscarp in front of the new breach in the curtain.

At daylight on the 6th, the besieged made a new attempt, but not being attended with complete success, they determined to break into the counterscarp themselves, as near the mine as possible.

This was perceived by the besiegers at three o'clock, and a heavy fire brought on it, but too late: an attempt was then made during the night to drive them from the lodgement, but ineffectually; they had reached the mine, destroyed the frames, and filled up the chamber.

This was fatal to the hopes of the besiegers, particularly as the mine was ready, and had been ordered to be fired the night previous. But the commanding officer of artillery had insisted on a delay of twenty-four hours, expecting an arrival of powder from Gaza.

This reduced the front of attack, and obliged the besiegers to return to the old breach in the tower, where they had encountered so many defeats, and where some of their most able and experienced officers had met their fate. The besieged took possession of all the works, except the sap which crowned the glacis of the old mine, and took the tower in reverse.

The besieged kept up so perpetual a fire as to render all courage of no avail.

On the 7th it was understood that a convoy of thirty Turkish ships, escorted by a galley and several corvettes, had left Mœris, in the Island of Rhodes, to bring the besieged provisions and a considerable reinforcement of men.

In order to anticipate the arrival of this assistance, Buonaparte ordered the attack which had taken place the night before to be renewed. Both places of arms were carried, as also the sap on the glacis and the tower of the breach, and a lodgement was formed in each of the latter.

The saps and places of arms were filled with the bodies of the defenders; numerous flags were taken and several guns spiked; but the besieged offered a very determined resistance, and kept up a heavy fire from their batteries: 18 officers and 133 men of the French were either killed or wounded in this attack.

The besieged suffered considerable loss, and their bodies served as an epaulement to the besiegers.

During the night, intelligence was received that the powder expected from Gaza would arrive next day.

The breaching battery ordered to be constructed against the tower and curtain, and consisting of the three 24-pounders just arrived, was completed, and opened its fire at daybreak.

At 3 P.M. the curtain fell, and the breach appeared practicable; Buonaparte reconnoitered it, and gave the order for the assault: General Lannes's division marched forward, having at its head the light companies and the grenadiers under Brigadier-General Rambaud; the remaining divisions were ordered to support it.

The breach was attacked and carried, and 200 men entered the town. Buonaparte had ordered the troops in the tower to attack some Turks who had formed a lodgement in the ruins of a second tower, which commanded the right of the breach, at the time the assault was given; besides which, the troops in the trenches were to have entered the exterior places of arms, so as to prevent the enemy either from coming out or from opening a reverse fire on the breach: these important orders were not executed with sufficient alacrity.

The besieged issued from the exterior places of arms, filed into the ditch from the right and left, and opened a reverse fire on the breach.

The Turks, not having been dislodged from the second tower commanding the right of the breach, opened a heavy fire, and threw combustibles on the besiegers.

The escalading party then began to waver, and ceased to file into the streets with the same impetuosity as before.

The fire kept up from the houses, from the barricades in the streets, and from the palace of Djezzar, on those who crossed the breach, and on those already in the town, caused them, for want of proper support, to make a retrograde movement. They abandoned two guns and two mortars which they had seized on the ramparts.

The whole column was in full retreat when General Lannes advanced to the front, and succeeded for the moment in rallying it.

The guides who were on foot with the reserve rushed to the breaches, and fought hand to hand with the besieged. They succeeded in ascending the breach, but their ardour was soon checked by the determined resistance by which they were met, and the first impulse no longer remained. General Lannes was dangerously wounded, and General Rambaud killed in the town.

The besieged fought so obstinately, that all the troops from the fleet, as well as the Turkish sailors, had time to be disembarked and brought to the breach to assist in its defence; and the besiegers were, after a tremendous struggle, obliged to retreat.[10]

The action had commenced at daybreak and continued until dark. A more noble defence cannot well be imagined.

The attacking party consisted of, perhaps, the first troops in the world at the time. They effected a wide and practicable breach, stormed it in force, and established themselves on its crest, and even entered the town. Notwithstanding this, they were driven back, and obliged to retrace their steps through the same breach, and acknowledge themselves beaten.

The French, after the arrival of their heavy guns, had expressed themselves confident of ultimate success: they thought that if once a practicable breach could be effected, the fall of the place would be certain. The result of this last attempt paralysed them.

Buonaparte felt that to renew the attack with the same troops was but to add another triumph to the enemy. He consequently ordered the batteries to continue their fire day and night, and sent for Kleber's division, which had earned such laurels in the battle of Mount Tabor, but had hitherto taken no part in the siege. They were a long day's march from the camp, and did not arrive until early on the morning of the 10th. Flushed with their success in the field, they expressed the greatest anxiety to be led on to the assault, determined to wipe out the disgrace of former defeats, and to show both the Turks and their English allies that further resistance was of no avail.

Buonaparte immediately reconnoitered the breach himself from the breaching battery, and being satisfied that it was practicable, ordered the brigade of General Verdier, belonging to Kleber's division, to advance to the assault.

The breach was passed without an obstacle,[11] but the besieged were found

[10] Sir Sidney states in his dispatches, that on Djezzar hearing that the English were in the breach, exposed to the heat of the fire, he quitted his palace, where, according to the Turkish custom, he was sitting to reward such as should bring him the heads of the enemy, and distributing ammunition with his own hands; that he hastened to the breach, and forcibly pulled his English friends away, declaring that if any thing happened to them all was lost.

This amicable contest, as to who should defend the breach, is described as creating an enthusiastic feeling in the Turks, which made them redouble their efforts, and gave time for reinforcements to arrive.

[11] Sir Sidney Smith states that Djezzar allowed the French to come into the town, in order

strongly posted behind entrenchments, and ready to receive them. All attempts at carrying them failed: the storming party then tried to cover themselves, and fill in the ditch of the entrenchment with the fascines they had brought with them; but so terrific and so fatal was the fire of the besieged, that they were unable to maintain themselves, and were once more forced to retire, after sustaining considerable loss. General Bon was mortally wounded.

The possession of Acre was of great importance to Buonaparte; he was unused to reverses, and, moreover, had promised Daher, the chief of the Druses, who had provisioned the army during the siege, the command of Acre, as soon as it should fall; and Daher was in the camp ready to receive his reward, and to avenge himself on Djezzar, whom he looked upon as the murderer of his father.

Buonaparte had therefore the strongest motives to urge him to carry the place. The excitement, however, under which he laboured from the repeated failures appears to have deprived him of his usual judgment; for without attempting to remove the obstacle which had caused the last assault to fail, or directing false attacks to be made to divide the attention of the garrison, he immediately ordered the remaining brigade of Kleber's division to prepare for another assault: accordingly, at 4 P. M. the head of the column is described as advancing to the foot of the breach with a firm step; then the march slackened, and soon the column came to a stand-still, under a severe reverse fire from the besieged.

The order to advance was repeated, and Buonaparte, who was near enough to see the whole, is said to have cried out with the greatest impatience, "Grenadiers, advance, or retire!" At this moment the chief of brigade of artillery, Fouler, seizing a flag, ascended the breach, crying out, "Follow me, grenadiers!" and fell at the same moment, pierced with numerous balls in his breast.[12]

The chief of the brigade, and various other officers, shared his fate. After

to close with them, according to the Turkish mode of warfare. As soon as they entered the Pacha's garden they were attacked by the Turks with sabre and dagger, which proved more than a match for the bayonet at close quarters. The breach is stated to have been wide enough for fifty men abreast.

[12] Sir Sidney Smith states that all subordination in the French army was at an end; that the French grenadiers refused to mount any more the breach or the walls over the putrid bodies of their unburied companions as well as those of their enemies.

a short struggle to overcome the same obstacles, these troops, like their predecessors, were obliged to retire, having suffered a considerable loss.

The French admit themselves that in the last two assaults they had 200 killed and 500 wounded.

From this moment there can be no doubt but that Buonaparte determined on raising the siege.

13th May.—Buonaparte now sent a flag of truce to ask for a suspension of arms to bury the dead, whose putrid bodies caused great increase to the sickness. He also proposed an exchange of prisoners. Berthier's letter to this effect was sent by a Turk who had been taken up as a spy. He states also that the governor gave no answer, but made a general sortie, which the French state was vigorously repulsed.

Sir Sidney Smith's account, however, is very different: he states that, contrary to the rules of war, whilst the garrison was deliberating on the message sent by the French, an assault was made on the place, under cover of a volley of shot and shells, in the expectation of finding the garrison unprepared, but that the assailants only contributed by their dead bodies to increase the evil complained of.

16th May.—At half-past two A. M. a sortie was made by the besieged; it was vigorously repulsed, and they suffered severely. A second sortie was made at all points at seven o'clock, with a similar result. The besieged did not penetrate into any sap; a heavy fire was opened upon them from the batteries, and they were driven into their places of arms at the point of the bayonet. They left the ground strewed with their dead. The French acknowledge to having had 20 killed and 50 wounded on this occasion. During the night the French commenced the removal of their sick and wounded, and the park of artillery.

After the advanced guard under General Junot had burnt the magazines of Tabaria, it took up its position at Safaria, to command the defiles of Obeline and of Shufammer, and cover the retreat from before Acre.

19th.—A heavier fire than usual was kept up on the town and palace of El Djezzar, and on those parts of the fortifications which had not yet been battered.

At daybreak of the 20th, the garrison made a general sortie, but were driven back. They were not, however, discouraged, but renewed it at 3 o'clock in the afternoon; the troops lately brought into the town were of the number.

They fought with greater fury than they had hitherto displayed. Their object was to destroy the batteries, and thus prevent the town being ruined.

Notwithstanding the stubbornness and the liveliness of their attacks, they were every where repulsed, and obliged to retire with great loss. They got possession of the sap which crowned the glacis in front of the breached tower, but the commandant of the trenches attacked them with two companies of grenadiers, drove them out of the sap, and pursued them as far as the exterior place of arms, killing all who did not take refuge there.

The field artillery was placed in battery in lieu of the heavy ordnance, which had been just sent away.[13]

An aqueduct which brought the water to the town from a distance of several leagues was destroyed by mines and by sap.

The magazines and fields of grain round Acre were reduced to cinders. All that was useless was thrown into the sea; and on the 20th May, at 9 o'clock in the evening, the general retreat was sounded, and the siege was raised, after sixty days of open trenches.

A few remarks upon the conduct of this siege will not be misplaced here.

The first error which was committed arose in all probability from that contempt of the enemy which their defence of Jaffa and El Arisch, together with their general conduct in Egypt, had inspired.

The French were thus led to attack the place without waiting for their heavy artillery, and to select the tower so often mentioned, which—although the most salient point, less under the fire of the other parts of the works, and decidedly the proper point of attack, had the besiegers been properly provided with siege material,—was, it was generally admitted, very strongly built, and likely to offer a greater resistance to their field artillery than any other portion of the enceinte.

The second error was in persevering in the attack on the tower, after being convinced of the inefficiency of the field artillery to form a practicable breach; and in not attempting, whilst the gallery for the mine was in progress, to turn the defences of the tower by opening a breach in the curtain to the right or left of it.

When, later in the siege, and after the arrival of some heavy guns, a

[13] Twenty-three of these guns fell into the hands of Sir Sidney Smith, the French having burnt their carriages.

breach in the curtain of the east front *was* made, and which a very few hours' firing accomplished, and the assault had failed from the heavy fire brought upon the breach, no steps appear to have been taken to keep that fire down, or to open a fresh breach in the north front, or opposite side of the tower, by which the force of the defenders would have been divided and their fire less concentrated.

In making these observations, and thus criticising the operations of the French, it is but justice to remark, that whilst the form and situation of the fortress of Acre render it peculiarly open to enfilade from the sea, they are at the same time very favourable to naval co-operation, in the event of an attack from the *land;* and that in the present instance the Turks possessed that co-operation in a most efficient form, whilst the French were unprovided with heavy and long-ranging guns to oblige the ships to keep at a respectable distance; and that this may in all probability have been the strongest reason for their limiting their operations to the confined space they did, as any attempt to extend their attack to the west or south brought them within more effective range of the British ships, which were so placed as to sweep the glacis of the north and east fronts.

Nor must we forget that we are speaking after the event, and without a perfect knowledge of the reasons and motives which induced them to act as they did, and which appeared to the French at the time sufficiently powerful to justify them.

It is, however, certain that they failed; and it is by no means certain that any other plan of attack would, with their means, have led to better results.

The defence of Acre will remain a brilliant instance of what may be done, even by undisciplined troops, when actuated by feelings either patriotic or fanatical, and posted behind walls or houses where individual courage may find opportunities of displaying itself, without being brought too directly in collision with discipline.

After the retreat of the French from Syria, the fortifications of Acre were repaired and very much increased by Djezzar and his successor Abdallah; and in 1831, the two land fronts, in addition to the wall with towers and a ditch which formed their only protection in 1799, had a second or outer line of ramparts with a deep ditch in front. Of these two fronts, that which faces the east was flanked by three bastions, and that which faces the north

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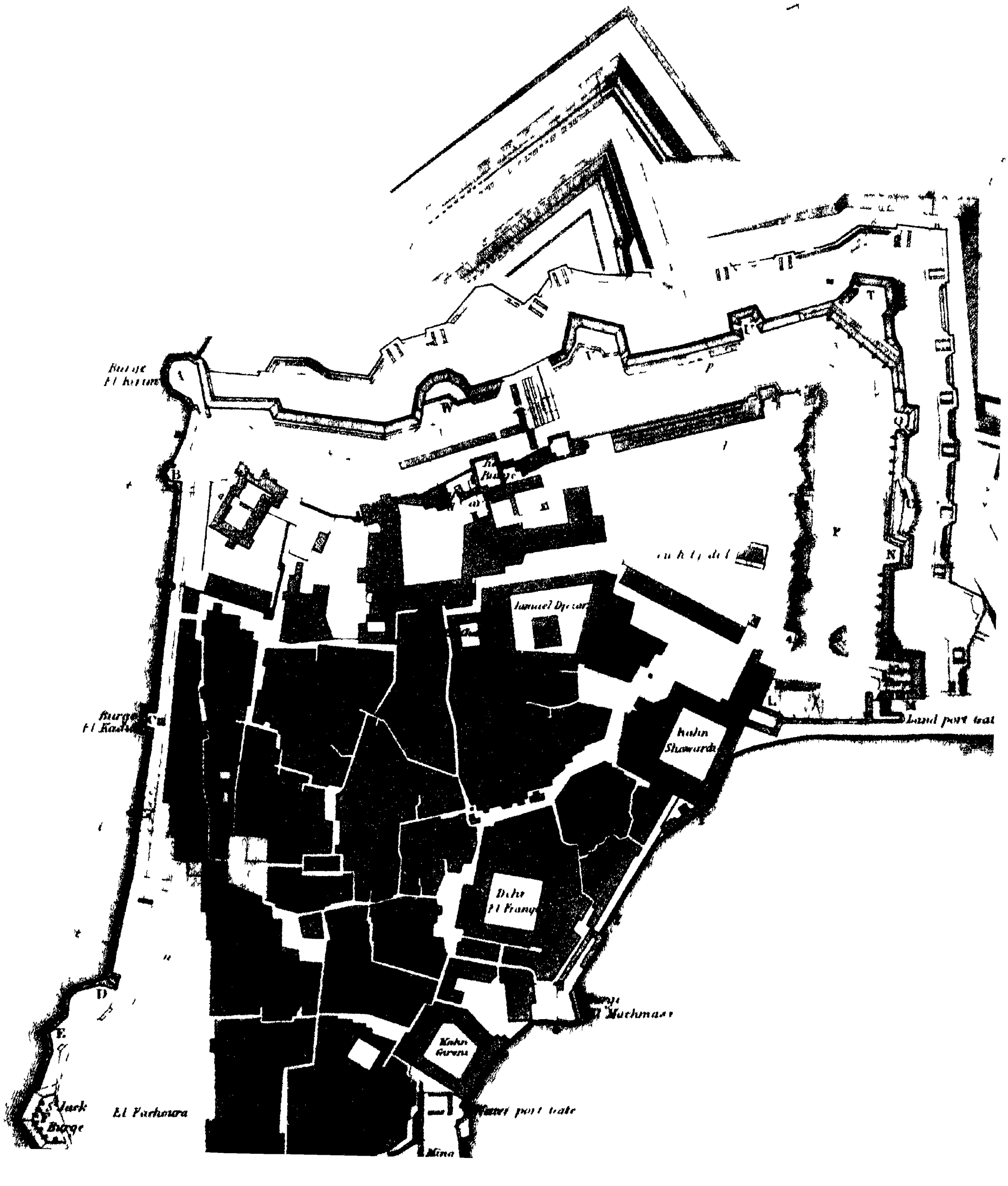
OF THE
wn & Defences
of
JEAN D'ACRE.

Note The line dotted thus shews the site of
The breaches on each side of the Bastion M and
siege of Ibrahim Pasha



by four. On this latter, to the north-east, and on the inner line, was a high citadel or tower, commenced by Abdallah, but not finished.

Though the trace of these several works was far from good, they were revetted, and their profile was very respectable. There were only two gates, the land port and water port, the former of which was on the east front, close to the beach, and the latter communicating direct with the harbour. To the north there were only sally-ports, or posterns. Plate IX.

The fortifications were in good order, and all the public buildings were capable of defence, being surrounded by high walls.

In the autumn of 1831, Mohammed Ali, Pacha of Egypt, in order to relieve the commerce of the Egyptians in Syria from the impediments thrown in its way by Abdallah, the Pacha of Acre, assembled 3500 cavalry and 18,000 infantry, including a battalion of sappers and one regiment of artillery, with twenty pieces of heavy ordnance, four field-pieces, and eight howitzers, on his eastern frontier.

In October, this force moved on Gaza, where no opposition was offered, the fortifications having been destroyed by the French in 1799.

Having remained a day in Gaza, the Egyptians marched on Jaffa; and Ibrahim Pacha, to whom Mohammed Ali had given the command of the whole force, appearing before the place in a frigate, at the same time that the troops approached on the land side, the garrison, consisting of 100 artillery and 1000 irregular cavalry, capitulated.

Ibrahim then sailed to Caiffa, and, after a slight skirmish between some troops which he landed and the irregular cavalry which had escaped from Jaffa, Caiffa opened its gates.

Here Ibrahim established his head-quarters, and received the submission of the chiefs of the mountain tribes of Naplouse, Tabaria, and Jerusalem; he received reinforcements of troops and supplies of ammunition and stores, and made his arrangements for the investment of Acre.

On the 20th November, Ibrahim sent the irregular cavalry, which, after the surrender of Jaffa, had entered into his service, together with 3000 infantry, to make a reconnoissance, and Acre was summoned to surrender. On the summons being rejected by Abdallah, several of the inhabitants quitted the place, in order to escape the miseries of a siege.

On the 27th, Ibrahim invested the place with his whole force, and cut off all communication with the country by land.

The town at this time was well supplied with all kinds of stores and provisions, and, including those mounted on the ramparts and in the arsenal, had 400 pieces of ordnance.

The garrison, consisting of Delhis, or irregular cavalry, artillery, Albanians and Arabs who formed the body-guard of the Pacha, amounted in all to 3000 men.

The attack embraced the two land fronts; the right flank of the besieging army rested on the sea to the north of the city, and the left on the small river anciently called Belus, which empties itself into the bay at about a quarter of a league from Acre; the rear guard remained at Caiffa.

The parallel, as well as the batteries, which were carried on under a brisk fire from the place, occupied the same site nearly as those of the French in 1799.

Ibrahim had fixed his head-quarters at Abdallah's country palace, near to which an hospital was established for the reception of the dangerously wounded. Another building on Mount Carmel was appropriated to the sick and to those who were slightly wounded. A bazaar was soon established by the country people in the neighbourhood, in rear of the camp.

On the 2nd December, a body of cavalry issued from the gate of Acre to attack a work thrown up by the Egyptians within musketry fire of the east front, at the tomb of the Sheik Mubarek; they spiked two guns and took twenty prisoners.

The besieging army was strengthened on the 6th by the arrival from Egypt of the 6th regiment of light cavalry.

On the 8th, Ibrahim bombarded the town.

On the 9th, the Egyptian fleet appeared before Acre with a favourable wind. Five frigates anchored in front of the port. The gun-boats remained under sail: four corvettes and two brigs anchored on the north-western side of the town. At 9 o'clock the ships, as well as the land batteries, opened their fire simultaneously; the latter were armed with sixty guns and fourteen mortars.

The firing continued till four o'clock in the afternoon; during which time 10,000 shot and 2000 shells were thrown into the town, which kept up a spirited fire in return, so as to sink one gun-boat and injure the masts and rigging of the frigates.

The squadron retired to the roadstead of Caiffa, with a loss of 30 killed and 135 wounded.

The viceroy's nephew, Abbas Pacha, arrived in the camp during the firing, with the remainder of the regular cavalry and the Bedouins.

On the next day Ibrahim detached 4000 men, both infantry and cavalry, to occupy Sidon, Beyrout, Tyre, Tripoli, and Latakia, along the coast.

The besiegers' batteries kept up an almost uninterrupted fire till the 19th of December. On that day Ibrahim offered Abdallah advantageous terms; amongst others, to go out free. The latter had a conference alone at the gate with the Egyptian envoys. Nothing, however, was agreed upon, and Abdallah retired, declaring he would sooner blow up the place than surrender it.

The breaching batteries opened a spirited fire; and on the 23rd the breach on the eastern rampart, near the gate, was reported practicable.

Meanwhile the Porte ordered Mohammed Ali to raise the siege of Acre and to evacuate Syria, and took measures to force him to do so, if he should refuse. Notwithstanding this, Ibrahim persevered in the attack of Acre, which still continued to defend itself.

The Egyptian squadron had suffered some loss, and the besiegers' stores were nearly expended, so that the attack only advanced slowly.

The outer wall near the land gate was now breached, but the interior wall was scarcely injured, and the Bosmiques obtained decisive advantages over the Arabs in the single combats which took place in the breach.

When Mohammed Ali, on the return of his Admiral, Osman Pacha, to Alexandria, learnt the state of affairs, he issued, with the advice of his minister, on the 3rd of February, an order to take Acre by assault.

At the end of the month, however, Acre still held out. The hopes of relief entertained by the besieged were the better founded, as the besiegers had not yet made a practicable breach.

Abdallah had shown throughout the siege both valour and judgment, but the conduct of the Porte, from whom he had neither received assistance nor encouragement since its commencement, now alarmed him, and caused him to entertain fears for the fidelity of his troops, whom he knew to be only mercenaries, and not attached to him; and he dreaded lest they should sacrifice him, to obtain possession of his treasure.

The Egyptians had for some time hemmed in both the land fronts by four large works. At this period they received a reinforcement of sixteen field-pieces and twelve mortars, so that they had in the camp ninety-six pieces of ordnance, of which seventy-six were guns and twenty were mortars and howitzers.

To these the besieged could only oppose thirty-six pieces of ordnance, because the ramparts on the fronts attacked did not permit them to establish more.

On the 9th March the breach was practicable. Ibrahim gave orders for the assault to take place next day.

The Arab battalions crossed the ditch and attacked the Bosmiques courageously; they mounted the breach, and took two guns placed to defend it; they escaladed the interior wall, and began to spread all over the town.

Their progress was now stopped by a coupure, and they were saluted with volleys of musketry from the houses, and thrown into disorder by the explosion of barrels of powder under their feet. They were forced to retire after losing 200 men: they crowned, however, the exterior wall, and made themselves masters of the land port gate, from whence they could take the town in detail.

Ibrahim, on hearing that a collision had taken place between some of his troops at Tripoli and the Turks under Osman Pacha, converted the siege of Acre, which place still held out, into a blockade, and advanced with 10,000 men to their relief.

It forms no part of this Paper to enter into the history of the war which took place between the Porte and Mohammed Ali, except so far as relates to Acre. I will only add, therefore, that after some successes on the part of Ibrahim, he saw from the dilatoriness of the Turks that he should have time to return and reduce Acre before they could assemble in force; and, leaving an army of observation of 15,000 men in a retrenched camp at Baalbec, to keep in check the Pacha of Aleppo, who was at Homs with 20,000 men, he returned once more to the siege. From the duration of the close blockade which the place had suffered, its ammunition and provisions had been much reduced, as well as its garrison, and it despaired of any assistance from the Porte.

Ibrahim had only left about 10,000 men before Acre, but they had not been idle. Two more breaches had been effected; the last was in the bastion (T) on the right of the attack, in which the mine had also been employed; whilst the shot, shell, and rockets thrown from the fleet had done much execution in the town.

Abdallah had been obliged to quit his palace and take refuge in the arched tower of Khazneh and bastion (W), built by Djezzar: here he was kept in continual alarm, lest he should be assassinated by his own people.

The garrison was reduced to about 2000 men, suffering much from fatigue. Nevertheless, with their usual intrepidity, they repulsed a fresh attack, and continued to repair the breaches, in spite of the heavy fire of the besiegers.

The siege appeared to have recommenced, when, on the 26th May, Ibrahim arrived before the place. He immediately called together his generals and principal officers, and, giving to each of them his instructions, he informed them he had determined on a general assault on the following morning.

Desiring to avoid a useless effusion of blood, he again summoned Abdallah to surrender. Abdallah refused to listen to any terms, and in his usual boasting manner replied, "Acre has not yet been besieged six months. It is provided with ammunition and provisions for five years, and it will be time enough, at the end of that period, to talk of surrendering, should our differences not be previously adjusted."

The batteries were now ordered to continue their fire without ceasing, to render the last made breach more practicable. Ladders were carried into the trenches opposite the west bastion on the north front (A). A battalion was told off for the escalade of this work, and one to each of the three breaches on the east front.

The battalion told off for the storming party of bastion (M) was commanded by Kutchuk Ibrahim Pacha, who had another battalion in reserve, whilst two others served as a reserve for the storming party at bastion (T).

27th May.—At daylight the signal for the assault was given by the discharge of three mortars, and the escalading party in front of bastion (A) advanced and planted their ladders, under a heavy fire of musketry and grape, which soon obliged them to retire. Whilst this false attack attracted the attention of the garrison, the three storming parties on the east front debouched from the trenches. That on the right advanced and seized on the retrenchment. The centre column met with little opposition in the breach, and easily established itself on the crest, whilst the left column carried bastion (M) by escalade on the side next the harbour.

At 5 o'clock A. M. the Egyptian troops had crowned the parapet and had hoisted their standards. The enemy immediately attacked them, and so successfully on the left at (M), that they were obliged to give way, when Kutchuk Ibrahim brought up his reserve battalion and rallied the troops; on which the besieged fired three mines, placed under the bastion, and the Egyptians were a second time forced to retire.

The besieged now left this point to assist in the defence of the other points attacked. The Arabs, seeing this, again advanced, and possessed themselves of the bastion, and hastily threw up a retrenchment to the right, and armed it with a gun found in the tower, with which they could fire on the town. Here they were ordered to maintain themselves without advancing, as it was ascertained from some deserters that there were other mines in the immediate neighbourhood.

Whilst this was going on, the storming party on the right, at bastion (T), had been equally successful. After a severe struggle, and being joined by the battalion which had established themselves in the centre bastion (N), they drove the besieged to a postern near the Khazneh tower and bastion (W); on which, Abdallah, at the head of a numerous escort, sallied out and fell on the Egyptians. The whole garrison appeared to concentrate themselves on this point, and drove the besiegers from the rampart and across the ditch again; and then, sallying out of the place, completed their defeat by driving them once more into their trenches.

Encouraged by this success, they turned to the Egyptians, who still retained possession of their retrenchment in the Kapt Burge (M). For an hour and a half the struggle continued with alternate success: but though the Egyptian colonel, Ishmail Bey, was killed, the besieged were ultimately obliged to retire behind the second line.

Ibrahim, seeing his troops flying before the enemy, hastened to the spot, and, sword in hand, endeavoured to rally them. The panic, however, was so great that his voice was not attended to; even his standard-bearer twice refused to obey his orders and advance, when Ibrahim seized the standard himself, and led the way. His example was soon followed; and his troops, thus recovered from their panic by the energy of their chief, drove the besiegers back to the foot of the breach. Here the contest continued for some time; at last the besiegers gained the parapet, and forced the besieged to retire behind the small bastion (U), where Abdallah hoisted his standard and maintained himself.

The Egyptians constructed a retrenchment in front of the tower.

A suspension of arms now took place during the heat of the day. At five in the evening Ibrahim caused the battery at (L), facing the port, to be escaladed. After some little resistance it was carried, and they made themselves masters of Khan Djenëin adjoining; thus becoming possessed of the most important positions on the land front.

A deputation of the principal inhabitants of the place now waited on Ibrahim, and throwing themselves on his generosity, pleaded for the preservation of the city from pillage. This he immediately granted, and forbid it under the severest penalties.

Shortly after, a second deputation from the civil and military authorities, and clergy, implored the clemency of Ibrahim in favour of Abdallah and the garrison.

Ibrahim granted to all who had taken part in the struggle their lives and property, and even their wives, excepting Abdallah, to whom he granted life alone. In proof of his clemency to the city, he hoisted a white flag.

Abdallah was received by Ibrahim with every mark of respect due to his rank and misfortunes, and the two generals repaired to the Pacha's country house for the night.

Notwithstanding Ibrahim's orders that the city should be spared, the troops were too irritated at the duration of the siege to be restrained, and the pillage lasted from midnight till daybreak. On the following day order was restored, and Ibrahim authorized those who had lost their property to seize it wherever it could be found.

Abdallah was sent to Egypt at his own request.

In Acre were found large stores of powder, shot, and shell, and numerous pieces of artillery, besides provisions, sufficient, with the exception of meat, for a two years' siege.

The Egyptians had, during the six months' siege, 4000 men placed *hors de combat*, of whom 500 were killed and 1400 wounded in the last day's assault. Besides this, 2000 men died of fever, after the place was taken, from the effluvia arising from the dead bodies of upwards of 7000 camels which had perished for want of food, and which had been merely thrown into a ditch.

The besieged had suffered much less than the besiegers: the garrison, the day after its fall, mustered only 1000 short of its complement at the commencement of the siege.

The possession of Acre by Mohammed Ali, who immediately commenced the repairing and strengthening of its works, placed him in a position highly favourable to the ultimate success of his views; and the victories of Homs, Baylen, and Konieh, which followed, put him in possession of the whole of Syria and a portion of Asia Minor. He fortified the passes of the Taurus, and gave just ground of alarm to the Porte, which finally led to the treaty of the

15th July, the bombardment and fall of Acre, and of Mohammed's sway in Syria in 1840.

The great advantages of the naval co-operation possessed by the besieged in 1799 were in this siege transferred to the besiegers. It enabled them to prevent the garrison receiving any supplies or assistance from without. It also enabled the besiegers to embrace both the land fronts in their attack, and being well provided with heavy artillery, to make three breaches in the east front; and whilst these were simultaneously assaulted, the besieged were called on to repel an attempt at escalade on their extreme left, or north-west angle, being the point furthest removed from the principal attack. By this judicious arrangement the garrison were obliged to distribute their comparatively small force over as extended a front as that of the besiegers; and thus, though the former appear to have exerted themselves to the utmost, and to have even driven the assailants from the ramparts after they had carried the breaches, numbers ultimately prevailed.

The results of these two sieges show the advantage, if not the necessity, of a naval co-operation to insure success either in the attack or defence of Acre, and that on whichever side this co-operation exists, success will probably be the result.

It will also explain the motive of the French in confining their operations to the salient point or angle furthest removed from the sea, and account in some measure for their failure; and it points out the advantage of gun-boats in the defence of Acre against any land attack.

By the terms of the treaty of the 15th July, 1840, between England, Russia, Austria, and Prussia, on the one part, and the Ottoman Porte on the other, certain conditions were dictated to Mohammed Ali, the principal of which were, that to him and his descendants, in the direct line, should be granted the Pachalic of Egypt, and also that of Acre, which included the southern part of Syria.

These terms were to be accepted within ten days; a delay of above ten days was to involve the forfeiture of the Pachalic of Acre, and a further delay of ten days carried with it the loss of Egypt.

Mohammed Ali having allowed the time to elapse without notifying his compliance with the terms of the treaty, offensive operations were immediately resorted to, for the purpose of compelling him to evacuate Syria.

This led to the capture and occupation by the marines and seamen of the fleet, under the orders of Admiral Sir R. Stopford, of the fortresses along the coast of Syria, viz.: Gebail, Beyrout, Tyre, Sidon, and Caiffa.

Having carried these with comparatively little resistance, a force of 3000 Turkish troops, under Selim Pacha, and small detachments of British artillery and sappers, under the command of Major Higgins, of the artillery, and Lieutenant Aldrich, of the engineers, were in consequence embarked on board the fleet. At the same time a force of 2000 Turkish troops was sent to occupy the pass of the White Mountain, to be ready to advance and co-operate with the troops on board the fleet, in the event of their being landed to assault the place.

The fleet appeared off Acre on the 2nd of November, and anchored in the bay. On the following day, the 3rd, as soon as the sea-breeze set in, the fleet got under weigh: the following ships took up a position against the west front of the fortress, at the distance of about 700 yards, viz.: [14]

Princess Charlotte,
Powerful,
Bellerophon,
Revenge,
Thunderer, and
Pique;

and against the south front, where the anchorage is more contracted, the British vessels

Edinburgh,
Benbow,
Castor,
Carysfort,
Talbot,
Wasp, and
Hazard.

The Turkish 84, *Mookuddimay-i-hive*, and the Austrian frigate *Medea*, with the flag of Rear-Admiral Bandiera; the *Guerriera*, under the command of His Imperial Highness the Archduke Frederic of Austria, and the corvette *Lipsia*, ranged themselves within about 600 yards of the walls.

[14] *Vide* Admiral Sir R. Stopford's and Sir Charles F. Smith's dispatches of the 4th, 5th, and 8th of November, 1840.

The British steamers *Gorgon*, *Vesuvius*, *Phœnix*, and *Stromboli*, were kept under weigh outside the line of the other vessels.

The position of each of the ships is shown upon the plan with sufficient accuracy.

The boats of the *Pique* and *Talbot* had buoyed off the shoal to the westward, as well as ascertained the soundings close to the walls without molestation from the garrison; and the vessels, having taken up their positions with little opposition, opened a heavy fire upon the works and town at 2 P.M., which they kept up without intermission till 5 P.M. About 4 P.M. the principal magazine on the east front of the town exploded: its position is shown in the plan. This not only destroyed two entire regiments drawn up on the ramparts, but also formed a practicable breach in each of the lines between which it was situated; and the remainder of the garrison evacuated the town in the night, and the troops were landed from the fleet, and took possession of the place at daylight on the 4th.[15]

After the first successes on the coast of Syria, and prior to the fall of Acre, small reinforcements of artillery and sappers and miners, together with artillery, engineer, and staff officers, were ordered out to that country. They arrived at Beyrout on the 13th December, about six weeks after the bombardment of Acre.

At this time Ibrahim Pacha was at Damascus in great force, so much so that the Turkish army then in Syria was unable to cope with him in the field.

His intentions with reference to the pending negotiations were not known; and as the explosion of the magazine at Acre had made practicable breaches in the land front of that place, which were only in progress of repair, I was, in conjunction with an artillery officer, immediately ordered to proceed to that fortress, and ascertain the state of its defences, and its capabilities of resisting a *coup de main* in the event of Ibrahim's attempt to recover it.

We arrived on the 18th of December, and found a party of seamen, assisted by large Turkish military working parties, busily engaged in closing the outer breach. The necessity of additional force was immediately reported, and the detachments of artillery and sappers just arrived were ordered to Acre,

[15] His Imperial Highness the Archduke Frederic, who commanded the *Guerriera*, and had been actively engaged during the bombardment, was, I believe, the first to enter the town.

to assist in completing this repair, as well as others which appeared to be requisite and within the means at our disposal.

The present fortress of Acre may be thus described. It is situated on a small peninsula forming the northern horn of the semicircular bay which takes its name, the southern horn being formed by the western termination of the Mount Carmel range.

The fortifications are of an irregular figure, presenting three fronts, A F, F H, and H M, towards the sea and bay, and two towards the land, M T and T A. Plate IX.

The sea fronts consist principally of a single escarp or wall of masonry, varying from 27 to 31 feet in height, armed with guns of heavy calibre, mounted on stone platforms and in embrasures. The only exceptions to this are the Jack Burge or bastion (F), and the upper tier of the semicircular bastion (G), where the armament consists of 8-inch shell guns, placed *en barbette*.

On reference to the plan it will be seen that the western or principal of these fronts, A F, is of considerable extent, and presents a formidable battery, but may be easily enfiladed from the bay. The other two, F H and H M, are also liable to enfilade from the west and south-west.

These fronts had suffered much from the bombardment; and the heavy sea which rolled in upon them during the severe south-west gale of the 2nd of December, had brought down large masses of the outer facing of the masonry that had been shaken by the fire of the fleet.

The two land fronts, M T and T A, have a double escarped enceinte; the inner one consists of small towers connected by curtains, with a keep or castle on the latter front, having an escarp of 90 feet, which commands and takes in reverse the ramparts to a certain extent, not only of its own, but of the outer line. The remaining portion of this front has an escarp from 35 to 40 feet high, with stone parapets. The outer, and that which may be considered as the principal line on the land side, is separated from the inner by a dry ditch whose counterscarp forms the retaining wall of the rampart of this line. It may be designated as consisting of two bastioned fronts with escarps of between 30 and 40 feet to the cordon and earthen parapets.

The ditch is dry, and has a revetted counterscarp of 21 feet in height, with a covered way tolerably well traversed, but in an unfinished state. The front facing the east, M T, is enfiladed from the bay, and T A from the sea. This outer line was planned and partly built by Djezzar Pacha after the siege in 1799, and completed by Abdallah, his successor.

In addition to these defences, Ibrahim Pacha had commenced extensive outworks on the east and north fronts, which were in an unfinished state and not very judiciously laid out. Their object, besides that of keeping the enemy at a distance, appears to have been, from their ditches sloping up to and uniting with the glacis of the body of the place, to facilitate sorties, particularly of cavalry, a species of warfare well adapted to the Arabs and Egyptians, and for which the plain round Acre affords great facilities. They are at present only field works, though of considerable profile; but I understood it was the intention of the engineer to give them counterscarps of masonry.

On the east front, in the ditch between the two lines, was placed the principal magazine (P), the explosion of which, during the bombardment, proved so disastrous to the garrison, and to which I shall have occasion to refer.

A slight reference to the plan of Acre will at once show the imperfect nature of its trace, both on the sea and land fronts,—the great want of flanking fire, and of a second enceinte or citadel, to retire to in the event of the first line being carried by assault, as well as to command and control the town.

To the west, the long straight line of sea battery, A F, so open to enfilade from the bay, is wholly unprovided with permanent traverses; whilst the bastion (C), on this front, is so small as to afford little flanking fire.

Had a large tower bastion been erected at this place, and another at F (the Jack Burge), many of the objections to this front would have been removed.

A great addition too might have been made to the strength of this front by opening embrasures in the eight large and commodious casemates at (*c*), used as workshops. Armed with 8-inch guns, they would have formed a powerful battery *à fleur d'eau.*

All the preparation which appeared to have been made for the coming struggle was the construction of three temporary traverses; two on the west and one on the south-west front: they were formed of the rough timber intended for palisades, laid crosswise and covered with a few sand bags. These were, however, low, and wholly inadequate for the purpose.

With such great defects in the trace of their works, the Egyptians ought to have exerted their utmost to have crippled the ships whilst taking up their positions, instead of withholding the greater portion of their fire until they were about to anchor.

By the few shots which were so fired, one ship, the *Edinburgh,* a short time before she reached her position, was struck by a shell which killed 4 men and wounded 10 others, besides disabling a gun; thus showing the effect that might have been produced, had the whole of the batteries opened their fire as the ships came within range.[16]

Another fatal error was committed by the garrison of Acre. They mistook the buoys laid down by Captain Boxer, of the *Pique*, and Captain Codrington, of the *Talbot*, on the shoal to the westward, for the positions intended to be taken up by the fleet, and elevated their guns for them; and, with a view of preserving their carriages and covering their men, raised the soles of the embrasures with sand bags.

This error was not discovered till too late; for as soon as the ships opened their fire, the shot from the southern division ricochetted along the terreplein of the west front, and overturned or injured many of the guns and carriages; and this, added to a terrific and well-directed fire in their front, paralysed, as might be expected, the Egyptians, who were unaccustomed to witness the effect of such heavy artillery, and either drove them from their batteries or rendered their fire comparatively ineffective.

Whilst the garrison were suffering from this heavy cannonade on their front and flank, the explosion of the magazine (P), on their rear, took place.

Such was the effect on both assailants and defenders, that for a moment[17] the firing ceased on both sides, and though renewed again almost immediately, and continued until dusk, the garrison appear never to have recovered from the panic it occasioned.

At the north-west angle (B), however, where the guns were protected from the enfilade fire, the Egyptians returned the fire of the ships opposed to them till near six at night, when it ceased altogether.

The ships now weighed and stood off for the night, with the exception of the *Benbow* and *Edinburgh*, which were ordered to warp closer in, and to commence firing at daylight on the wall at (*ee′ ff′*), which is only from 18

[16] The same error was committed at Algiers in 1816, and in a much greater degree. On that occasion the flag-ship of Lord Exmouth was permitted to anchor within 60 yards of the mole-head battery without a shot being fired; and the whole fleet took up their positions equally unopposed.

The delay was fatal to the Algerines, although they had two tier of guns, one of them in casemates, to oppose to the fire of the ships.

[17] This is perhaps the first opportunity, on a large scale, for testing the merits of the new system of gunnery introduced into the British navy by Sir Thomas Hastings, on board the *Excellent*, at Portsmouth, and it will not easily be forgotten. The impression was as vivid at Damascus, the head-quarters of Ibrahim Pacha, as at Acre.

inches to 2 feet thick, in order to effect a breach. This portion of the enceinte was formerly covered by the mole and fort (K), commanding the entrance to the port; but the former being in ruins, and the latter too much out of repair to be armed, it was uncovered and exposed to the fire of the ships outside the mole.

The battery at (L) also, acting as a second line to the mole for the protection of the bay, had been early silenced by the enfilade fire from the west, which, passing over the town, had dismounted or disabled all its guns. There is no doubt, therefore, but that a breach would have been easily effected, and in a few hours, by these ships. This service, however, was rendered unnecessary by the occupation of the place at daylight, on the 4th, as before stated.

If we consider the loss sustained by the garrison in the explosion of the magazine, by which two extensive practicable breaches had been formed in the land front, the great injury the sea batteries had sustained, and that one large body of troops was ready to be disembarked, and another to cross the plain from the pass of the White Mountain, so far from being astonished at the abandonment of the place, the garrison appear to have deserved the credit given them for continuing to fight their guns under great disadvantages during so severe, though short, a struggle; and that they did not abandon the place, until, from the effects of the explosion, it was no longer tenable.[18]

On inspecting the batteries, the injury done to the guns and carriages, as I have before stated, was very great, and was principally caused by the enfilade fire, as the greater part of them were hit on the south side. Some of the guns, however, were injured in the muzzle from shot, which appeared to me to

[18] Mohammed Bey, a captain in the navy, and brought up in France, was the governor of Acre during the siege, having been appointed after the abandonment of Beyrout, where he had also been governor. He told me, at Gaza, in January, 1841, that when it became known the fleet intended to bombard the place, a conspiracy was discovered amongst the troops to make the officers prisoners, and to deliver up the place on the third morning of the attack; but it was too late then to do any thing, as the fleet were already in sight, and they were obliged to trust to chance;—that the explosion caused such a panic amongst the troops, they could not be persuaded to remain any longer in the place. He further stated, that many of the men who worked the guns were fellahs (peasants) pressed into the service.

I give this as I received it; it is, however, corroborated, to a certain extent, by a large portion of the garrison returning on the morning of the 4th, and laying down their arms on the beach. But the whole campaign shows the Egyptians were not earnest in the war, and Ibraham's inactivity, so at variance with his usual character, may in a great measure be attributed to this cause.

Outer Breach shewing the Palisades [illegible].

Inner Breach looking North [illegible]

have entered the mouth of the embrasure, and ricochetted from the cheek; and this must, I think, constantly be the case from the splay in embrasures, when exposed to so concentrated a fire as that of line-of-battle ships.

The inner part of the cheeks of the embrasures had, as usual, suffered from their own fire; not, however, so much as might have been expected, owing, probably, to the guns being elevated for the position it was supposed that the ships would have taken up, and which has been before alluded to; and, to this and the *enfilade* fire, which rendered the men unsteady, and caused the firing to be very wild and ineffective, may be attributed the few casualties which occurred in the fleet.

The outer part of the cheeks of the embrasures at the angles were much injured by the fire from the shipping, and the extensive escarp wall had received a severe skinning; still there was no appearance of a breach excepting at the salient angle (E), opposite to the position of the *Revenge*.

Here an 8-inch gun had been placed in embrasure, and had either burst during the action, or, as is more probably the case, had been hit on the muzzle and split down, and thus contributed to the destruction of the embrasure at this spot, whilst its salient angle, exposed to the fury of the gale in its crippled state, from the effects of the bombardment, had so far crumbled away as to enable a person to get up and down it. The escarp too is low at this point, not above 18 or 20 feet, with a higher wall in its rear, forming a trap for low Plate XI. fig. 4.
angle shells. In this rear wall the shot had, in one or two places, penetrated to the extent of 2 feet and upwards. At (*d d'*) also, on the front F I, a breach had been made in the foundation of the wall of considerable extent, by the heavy sea during the gale of the 2nd, which had completely undermined it; and in August, 1841, a boat could, in calm weather, pass through the opening and effect a landing within the walls. The material of which the whole of the escarps are repaired is a limestone of very recent formation, ill-adapted to resist shot; it is easily penetrated, but does not splinter.

I may here remark, that the whole of the stone used by Ibrahim Pacha in the repairs of Acre was obtained at Athlete, from the ruins of Castle Pelegrino, on the coast, about 7 leagues to the southward. At the time of the bombardment there were several thousand cubic feet of stone, squared and laid on the beach, ready to be transported by sea to Acre, where works to a great extent were contemplated.*

* See note at end of Paper.

In very fine weather, and with an off-shore wind, absolutely necessary on the whole coast of Syria in any attempt at disembarkation, the western front might, I think, be escaladed, as there is a horizontal ledge of rock running many feet from the foundation of its walls, on its whole length, just below the level of the sea.

Lieut. Symonds, R. E., who remained at Acre a considerable time, and had frequent opportunities of examining the walls and making inquiries of persons on the spot, states that the whole of the escarp from A to H had been refaced, as well as the parapet between A and *b*, and that from *b* to H the parapet had been entirely rebuilt by Ibrahim Pacha; that the Jack Burge and semicircular bastions were also new works, built between 1836 and 1840; the lower part of the exterior facing of these fronts was tied into the old masonry, and built of large blocks of stone, but that the upper portion had no tie whatever; and that having been much perforated with shot, and the sea having got behind it in the gale of the 2nd of December, it had peeled off in large flakes or masses. The south-west angle of the bastion A also had suffered so severely from the gales as to render it necessary to withdraw the guns from its terreplein, and if not soon repaired, would become a ruin.

At (*a*) a new casemate had been constructed, with an embrasure in it, but the platform had not been laid, and it was not, consequently, armed. The remainder of the south-west front, from H to I, had not been repaired, and was in a bad state. Ibrahim had intended to have reconstructed this part, and to have casemated it. The whole of the south front H I was much more injured than the west front A F, from the masonry being so old and rotten, as well as from the ships being nearer to it than they were to the western front; also, from being built at the extreme edge of the rock, instead of being protected as A F is, it had felt the full force of the sea in the late gale. All these repairs, together with the outworks on the land fronts, and the casemates at L, to defend the ditch of the inner eastern front, are the work of Ibrahim Pacha, under the superintendence of Colonel Schultz, a Polish engineer officer, who was highly spoken of as a gallant soldier. He was severely wounded at the bombardment, and made prisoner.[19]

I cannot avoid remarking here, that, from the general testimony given of the talents of this engineer officer, he must have been under a firm conviction that no attack would have been made on Acre until the following spring, if at all,

[19] *Vide* Admiral Sir R. Stopford's dispatch.

or he would not have been found so unprepared for the struggle. The almost total absence of traverses to protect the men and guns, of shot furnaces, as well as expense and portable magazines, and the insecure state of the powder generally,—for though only one magazine blew up, there were several others equally insecure, which, had vertical fire been employed at the attack, would probably have shared the fate of the principal magazine,—all combine to prove the confidence Colonel Schultz possessed in his own security; and, when the advanced state of the year was considered, and the severe gales that prevail on the coast at that season, the probability was certainly much in his favour.

The first explosion took place at 4 o'clock, during the bombardment of the 3rd; and on the 5th a second took place, both of which are recorded in the Admiral's dispatches. The first of these made the breach in the inner line, from S to tower No. 2, and injured the rest of the front, as well as the breach on the outer line, as represented in the plan, and caused great destruction to human and animal life.[20] The second explosion extended the breach to the 2nd and 3rd towers. Again, on the 12th of January, after a period of upwards of two months, the ruins smoking at intervals, and after, also, much of the rubbish had been removed, a *third explosion* took place: the sphere of its action was, however, considerably diminished, and the only injury sustained was at the square tower No. 4, which was so shaken as to render it necessary to remove a large portion of it.

These repeated explosions show that the powder and ammunition were separated in various compartments; indeed, a great proof of this exists in the discovery of a considerable quantity of loose powder buried under the rubbish, in a perfect state, when they excavated for the foundation of the retaining wall of the rampart of the outer line.

The building (P) was more properly an arsenal than a magazine, and contained a large quantity of arms taken from the Syrians when Ibrahim took possession of the country, numerous shot, in piles, which were still standing when the rubbish was cleared away, and various other ordnance stores, including a great number of loaded shells, many of which had exploded whilst soldiers and others were searching for booty amongst the bodies of the unfortunate men who were blown up on the 3rd. I regret much that I was unable to ascertain the quantity of powder, or even an approximation to it, in the great explosion.

[20] The number of men blown up is supposed to have been about 1600, besides 30 camels, 50 asses, 12 cows, and some horses.

about two hours and a half more before the firing ceased altogether. The action began at a quarter before 3 P.M. The Admiral, Lord Exmouth, states in his dispatch, that "about sunset I received a message from Rear-Admiral Milne, conveying to me the severe loss the *Impregnable* was sustaining, having then 150 killed and wounded, and requesting I would, if possible, send him a frigate, to divert some of the fire he was under. The *Glasgow*, near me, immediately weighed, but it being a calm, she was obliged to anchor again. I had by this time sent orders to the explosion vessel, under charge of Lieut. Fleming and Mr. Parker, by Captain Reed, R. E., to bring her into the mole; but the Rear-Admiral having thought that she would do him essential service, if exploded under the battery in her front, I sent orders to this vessel to that effect, which were executed."

The casualties at Algiers were 883, of whom 121 were killed, 762 wounded; of these 50 were killed and 160 wounded on board the *Impregnable*, at 700 yards distance, exactly the same distance as the western division at Acre, yet her individual loss was more than double that of the whole of the Acre fleet, and one-fourth of that of her own fleet.[22]

It would appear then from these facts, that the construction of the batteries at Algiers, which consisted of casemates below and embrasures above, was better than at Acre, where there were no casemates. This then must be considered as one cause of the superiority of the fire at Algiers. But there were others: the height and form of the works generally, which prevented the *enfilade*; the state of preparation for the attack in which Lord Exmouth found the Algerines on his arrival, and the determination to resist to the last; and, lastly, an immense garrison, capable of filling up vacancies the moment they occurred.[23]

At Acre, the extremely small number of casualties in the fleet may be attributed, in addition to the causes previously mentioned, to the little interest the Egyptian troops had in the struggle, as was shown by the surrender of the

[22] Some of these casualties were occasioned by the explosion of cartridge boxes between decks.

[23] Captain Dashwood had been sent forward to get off the Consul, if possible. The Admiral in his dispatch says, "Captain Dashwood further confirmed that about 40,000 men had been brought down from the interior, and all the janisaries called in from the distant garrisons, and that they were indefatigably employed in their batteries, gun-boats, &c., &c., every where *strengthening their sea defences*. The Dey informed Captain Dashwood he knew perfectly well the armament was destined for Algiers."

garrison on the morning of the 4th, and generally during the operations on the coast.

From actual experience, here quoted, some valuable deductions may, I think, be made; but they are deserving of a Paper to themselves, and I trust that some abler pen will be found in the Corps to take up this extremely interesting subject.

In the two instances of collision between sea and land armaments which have just been brought forward, it is evident the parties were not on equal terms; that the former had the advantage of all the improvements known at the time in the construction and use of their missiles, whilst the latter were more or less deficient in both. It is therefore not quite fair to draw an inference or to lay down rules from the results of these unequal contests.

The following general principles are submitted solely with a view of drawing the attention of the Corps to the subject, in the firm belief that by an improvement in the construction of sea defences, they will be found to share with the navy in an equal, if not superior degree, the advantages of the great improvements which have taken place in projectiles:[24]

1st. That sea fortresses should have the terrepleins of their *open* batteries not less than 40 and not more than 60 feet above the water line.

2nd. That these batteries should be well defiladed, and be *en barbette* in preference to the embrasure, and be armed with the heaviest and longest ranging guns, carrying shot and shell, as they are to be brought into use immediately the enemy is within their most distant range, and that they should be elevated on traversing or permanent platforms, so that men standing on the terreplein may be covered.

3rd. That some plan should be devised to withdraw these guns *en barbette* and place them in security, should the enemy succeed in bringing such a fire on the battery as to endanger them, and render the battery useless, *for the time*, as a work of *offence*, when recourse must be had to the guns in casemates.

[24] The Duke of Wellington's speech in the House of Lords, on the 4th February, 1840, when a vote of thanks was unanimously passed to those engaged in the bombardment of Acre, is well worth a perusal. He says, "He had had a little experience in services of this nature, and he thought it his duty to warn their Lordships, on this occasion, that they must not always expect that ships, however gallant their seamen might be, were capable of commonly engaging successfully with stone walls."

The *barbette* guns being thus preserved, will be ready to resume offensive operations, should the attacking force be obliged to retire.

4th. That batteries below the minimum height before mentioned should, perhaps, be in casemates.[25] It may here also be remarked, that an improved form of embrasure would be a great advantage to casemates. Embrasures in casemates have a minimum height also, if required to fire at long ranges, for it is essential that neither shot nor shell should ricochet on the water. The former lose their velocity, and, consequently, power of penetration; and the latter, in addition, destroy their fuze nine times in ten on the first graze.

5th. That the battery, if well constructed, has the advantage over the ships when the range exceeds 500 yards; and that that advantage diminishes as the ships advance, and soon changes sides, provided the ships arrive close to the battery *uncrippled*.

6th. That a well-built fortress ought, even when its guns are for the time silenced by the concentrated fire of the ships, to be still able to make a passive defence, sufficient to save it from capture, though not protect the post from insult.

7th. That the heaviest batteries should be so placed as to have a direct fire on the channel or line of approach; and that these batteries should consist principally of shell guns, and be easily traversed.

8th. That batteries without casemates, when it is possible, should have their escarps covered by a breakwater or glacis, as high as the outer crest of the superior slope of the parapet, and with casemates, as high as the soles of their embrasures.

R. C. ALDERSON,
Lieut.-Colonel, Royal Engineers.

[25] The advantages of casemated batteries *à fleur d'eau* are twofold:

1st. The battery *cannot* be enfiladed or injured by vertical fire.

2nd. The artillerymen serving the guns are protected from the fire of the marines and men in the tops of the vessels. The effect of this fire will be severely felt in *open* batteries, when there is sufficient water to enable the vessels to come to close quarters.

Casemates *open* to the rear, similar to those at Block-house Fort, Portsmouth Harbour, are much to be preferred; indeed they are the only ones recommended where a close direct fire can be brought on the battery.

Note, referred to p. 53.

Specimens of the stone of which the works of Acre are constructed, and which forms the foreshore of the coast of Syria from Beyrout to Jaffa, have been submitted to Sir H. De la Beche, the result of whose examination of them I am enabled to give in his own words.

" After careful examination of the Acre stone, dividing the specimens into numerous pieces for " the chance of finding a perfect shell, or even a characteristic fragment, I have been unable to " detect any thing affording any good evidence of its probable age. The stone is, in fact, little " else than an agglomeration of small fragments of shells, apparently both univalves and bivalves; " but as few or no specimens I have seen afford the requisite evidence, neither the species, nor " even the genera, can be determined. From its appearance it may be some testiary deposit, " perhaps even very modern, but this is mere conjecture.

" The specific gravity of its solid parts, as ascertained in our laboratory, is 2·63; this of course " does not give the specific gravity of the stone with the air in its interstices."

The specific gravity, by weighing specimens of known dimension, was 1632.

A 32-pounder shot penetrated 30 inches, and made few or no splinters.—W. D.

APPENDIX I.

Armament of the Sea Fronts, St. Jean d'Acre.

	Guns.			Mortars.		Shell Guns.		
	32-prs.	24-prs.	18-prs.	13-in.	10-in.	10-inch.	8-inch.	Remarks.
North bastion A. .	4	3	—	3	—	—	—	
Curtain between A & C	14	{ 5, 2 howitzrs }	—	—	—	—	—	
Bastion C. . . .	—	4	—	1	—	—	—	
Curtain from C to re-entering angle D .	8	5	—	—	—	—	—	
Lower battery to Jack Burge from D to F	8	—	—	1	1	—	1 *	* At salient E, and either burst or destroyed by the fire of the fleet.
Jack Burge F . .	—	3	—	—	—	—	4	
Lower batteries between Jack Burge & semicircular battery to H . . .	11	2	1 brass	—	2	—	—	
Semicircular battery	—	—	—	—	—	—	4	
From H to I . . .	8	9	—	—	5	—	—	Of these guns there were 6 in the south-west front that did not bear on the fleet.
	53	33	1	5	8	—	9	Total 109 ordnance.

The total armament of St. Jean d'Acre in December, 1840, was 162, including every description of ordnance mounted on the ramparts.

APPENDIX II.

Bombardment and Capture of Acre, 2nd November, 1840.

COMMANDERS.	SHIPS.	Armament of each ship.	Guns.							Carronades.	Number of guns in each broadside.	Total weight of each broadside in lbs.
			9-prs.	18-prs.	24-prs.	32-prs.	36-prs.	8-in.	10-in.	32-prs.		
Admiral Sir R. Stopford, G.C.B., Commander-in-Chief . . . . Captain Fanshawe, C.B.	Princess Charlotte flag-ship . .	104	—	—	—	44	—	2	—	6	52	1712
Commodre Napier, K.C.B.	Powerful	84	—	—	—	31	—	3	—	8	42	1416
Captain Berkley, C.B. .	Thunderer . . .	84	—	—	—	31	—	3	—	8	42	1416
Captain Austin, C.B. . .	Bellerophon . . .	80	—	—	18	12	—	4	—	6	40	1232
Captain Waldegrave, C.B.	Revenge	76	—	—	—	30	—	3	—	5	38	1288
Captain Stewart, C.B. .	Benbow	72	—	—	—	28	—	2	—	6	36	1200
Captain Henderson, C.B.	Edinburgh . . .	72	—	—	—	28	—	2	—	6	36	1200
Captain Collier, C.B. .	Castor frigate . .	36	—	—	—	16	—	2	—	—	18	624
Captain Boxer, C.B. . .	Pique do. . . .	36	—	—	—	16	—	2	—	—	18	624
Captain Martin, C.B. .	Carysfort	26	—	—	—	12	—	1	—	—	13	440
Captain Codrington, C.B.	Talbot	28	—	4	—	10	—	—	—	—	14	392
Comr Hon. C. Elliot . .	Hazard sloop . .	18	—	1	—	—	—	—	—	8	9	274
Commander Mansel . .	Wasp brig . . .	16	1	—	—	—	—	—	—	7	8	233
Captain Henderson, C.B.	Gorgon war steamer	2 & 4	—	—	—	4	—	—	2	—	6	296
Commander R. Stopford	Phœnix do.	2 & 4	—	—	—	2	—	1	1	—	4	204
Commander W. Williams	Stromboli do.	2 & 4	—	—	—	2	—	—	2	—	4	232
Commander Henderson .	Vesuvius do.	2 & 4	—	—	—	2	—	—	2	—	4	232
Rear-Admiral Walker, K.C.B. (Turkish flag-ship)	Mookuddimay-i-hive	84										1416
	Small cutter (captrd)	8										
Admiral R. Bandiera, (Austrian flag-ship) .	Medea	60	—	11	9	—	—	—	—	—	20	414
His I. H. Archduke Fredc	Guerriera	46	—	11	9	—	—	—	—	—	20	414
	Lipsia	20	—	2	—	—	11	—	—	—	13	432
										Total . .	437	15691

IV.—*Report of Experiments in Blowing in Gates, made at Quebec on the* 11*th and* 13*th July*, 1840, *by order of Lieut.-Colonel* Oldfield, K.H., *Commanding Royal Engineer in the Canadas.*

Their Excellencies the late and present Commander of the Forces being desirous of ascertaining the effect of a bag of powder applied to the door of a block-house, church, or any other building occupied for defence, I availed myself of the first favourable opportunity of causing the experiment to be made at Quebec: the results are detailed in the accompanying reports of Lieuts. Simmons and White, of the Royal Engineers; the arrangements were satisfactorily made by Captain Whitmore. The Major-General commanding was present at the experiment on the 13th, and directed a detachment of grenadier guards to pass the gateway immediately after the explosion. The quantity of powder used produced the desired effect; a larger quantity would probably have brought down the masonry, and impeded the advance of the troops.

(Signed) J. Oldfield,
Lieut.-Colonel, Commanding Royal Engineer in the Canadas.

Report of an experiment on the effect of a bag of powder suspended to the outside of a pair of sally-port gates, and exploded.

Royal Engineer Office, Quebec, 11th July, 1840.

The gates were 4 inches in thickness, being made of 2-inch oak doubled; they were fastened on the inside by an iron strap 18 inches long, $2\frac{1}{2}$ inches by $\frac{1}{2}$ an inch; they were likewise secured by two bars of $1\frac{1}{8}$-inch round iron, fixed at one end by staples to posts in rear of the gates; the other ends were attached to the gates near the centre. These gates were the same, and fastened in the same manner, as those now in use to close the sally-ports of the fortifications at Quebec.

The quantity of powder used was 50 lbs., sown up in a leathern bag; it was suspended to one of the gates on the outside near the centre, and exploded by means of a miner's fuze.

The explosion caused an effectual breach in the gates; one of the iron bars was broken off at the staple which secured it to the post, and blown about 9 yards to the rear.

The other iron bar was considerably bent, the hook which attached it to the gate being blown completely off.

The effect on the gates themselves was very great; that to which the powder was suspended was almost entirely destroyed,—the other did not receive so much damage. They were opened sufficiently to allow four or five men to pass in abreast; the fragments of the gate were scattered in every direction, some of the pieces being projected about 30 yards to the front.

The iron bar which fastened the gates together was projected from 200 to 300 yards to the rear.

In addition to the manner in which the gates were secured, they were considerably strengthened by being spiked with die-headed nails.

Although the walls in which the frames of the gates were built were green, they were not in the least damaged by the explosion.

(Signed) H. A. White,
Lieutenant, Royal Engineers.

Report of an experiment made at Quebec, July 13, 1840, *on the effect of gunpowder applied in a bag to the exterior of a barrier gate.*

The gate on which the experiment was made was exactly similar to those in use in the sally-ports of the fortress of Quebec. It was 8 feet high by 7¾ feet broad, made with 3-inch framed oak, planked diagonally with 2-inch oak in two thicknesses, and was hung to pine posts 1 foot square, built 6 inches into the walls on each side, with a strong beam framed into them on the top, to prevent them from collapsing.

It was fastened on the inside with an iron strap 2 feet 5 inches long, 3¾ inches broad, and ½ an inch thick, a sketch of which, after the explosion, is

Fig 1

Outside of Gate before explosion No 1

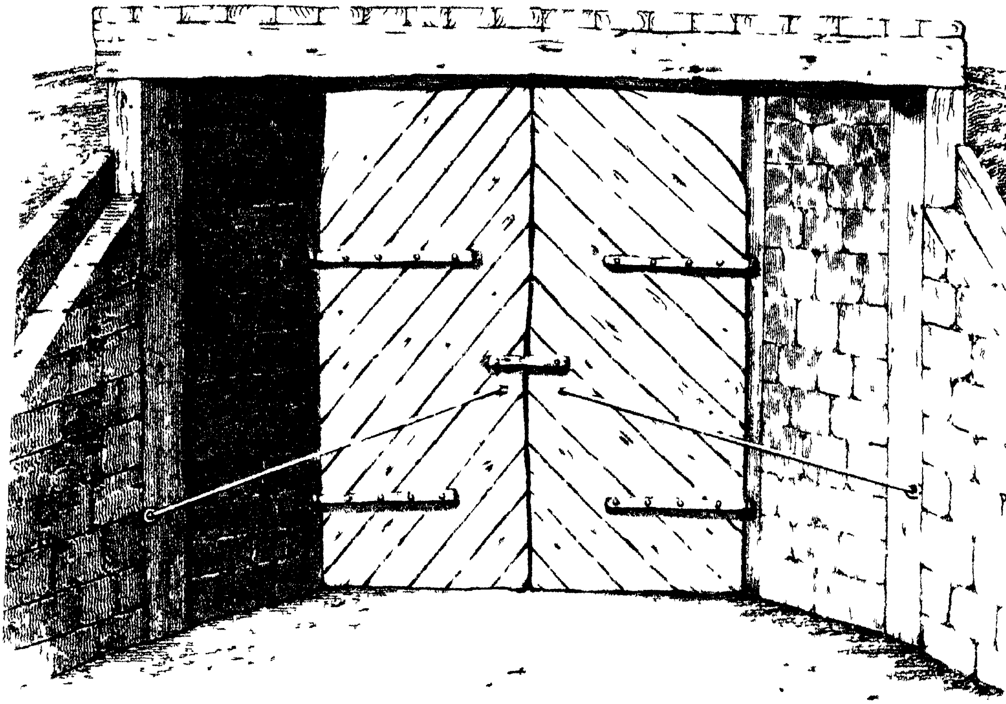


Fig 2

Outside of Gate before explosion No 2

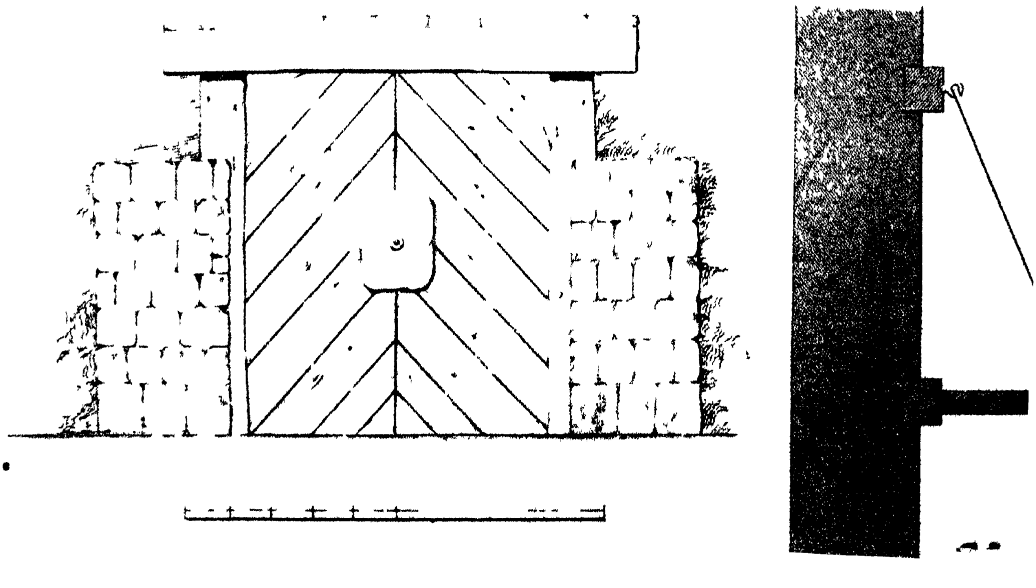
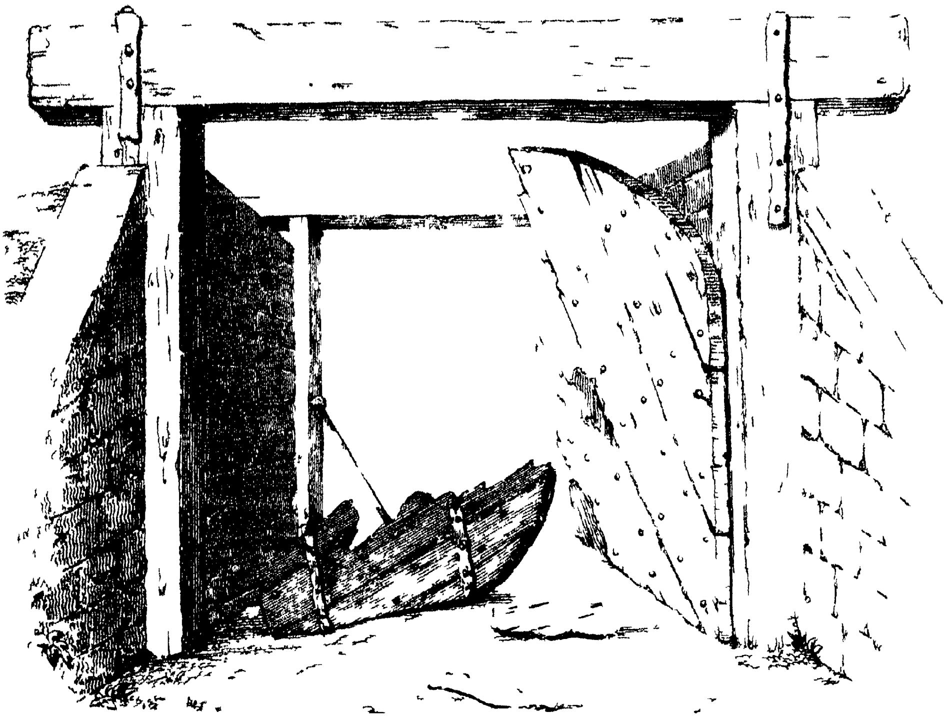


Fig 2



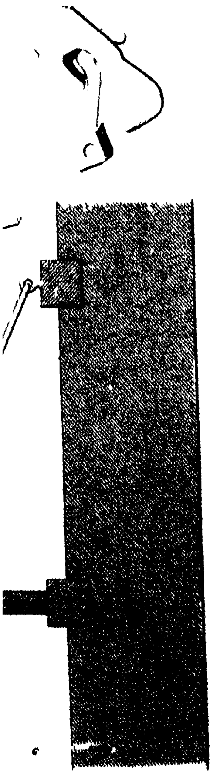
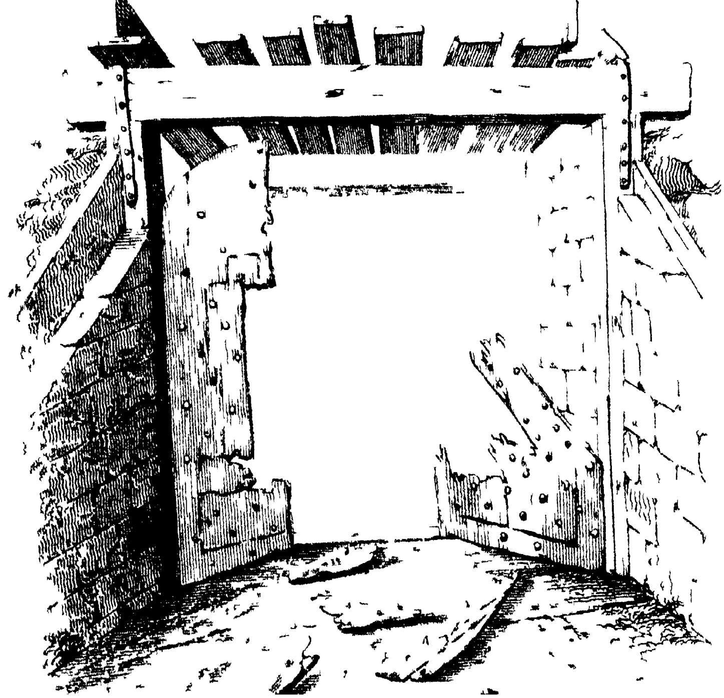


Fig ?



given. Besides this strap there were two round iron bars ($1\frac{1}{8}$ inch diameter) made fast by racked bolts to two upright posts 6 feet in rear, also built 6 inches into the wall; these bars had hooks which fitted into eye bolts fixed in the gate. Plate XII.

One of the racked bolts was driven into the face of the post; the other was driven into the side.

The bag containing the powder was made of leather, and was 2 feet $10\frac{1}{2}$ inches long by 1 foot $6\frac{1}{2}$ inches broad, with the corners rounded. It was stitched all round and a hole made in the centre, into which the head of a fuze (such as is used with shells) was fixed. A strap to serve as a sling for carrying the bag was also attached.

METHOD OF CHARGING, PRIMING, AND FIRING.

The charge was 50 ℔s., and was inserted into the bag by the fuze hole. When charged, a miner's fuze was forced through the fuze into the centre of the charge, after which it was tamped all round with clay. It was then suspended on a gimlet driven into the centre of the gate, about 5 feet from the ground, and the fuze lighted. In this experiment the length of fuze was sufficient to burn for $2\frac{1}{2}$ minutes, but this was not necessary; half a minute would have been ample.

EFFECT OF EXPLOSION.

The gates were instantaneously forced in, no particles being thrown more than a few feet to the front, but being all cast up the sally-port; proving that a storming party might have waited for the explosion, without risk, about 20 or 25 yards from the gate.

The storming party in this experiment was posted 40 yards in front.

The iron strap which fastened the gates was thrown about 86 yards towards the interior, and was bent in a most extraordinary manner.

The die-headed nails were cast to an equal distance, and some of the splinters of the door still further, and would have effectually cleared the sally-port.

The iron bars which fastened the gate on the inside had their hooks broken off, and that one which was fastened to the side of the post in rear of the gate drew its bolt; the other bolt, which was driven into the face of the other post, remained firm.

The gate was hung on reversed hooks. One-half of the gate was unhung and thrown down, breaking one of its hinges; the other was merely forced open.

The centre of the gate near the charge of powder was broken into numberless fragments, which were all thrown towards the interior of the sally-port. The gate posts and sill remained perfectly firm, and the wall, which was of green masonry, was unshaken.

From this and the former experiment of the same nature, made on the 11th July, it may be remarked, that in the first the gate was breached much more effectually than in the second experiment, owing to the gate in the latter case being 1 inch thicker than in the former, showing that in neither case a less charge than 50 lbs. ought to be used, but that, on the contrary, a larger charge by 10 or 15 lbs. would have been preferable for the second experiment.

(Signed) J. A. SIMMONS,
Lieutenant, Royal Engineers.

Quebec, July 17th, 1840.

SEA-WALL OR BREAKWATER
AT
HASLAR BEACH, PORTSMOUTH.

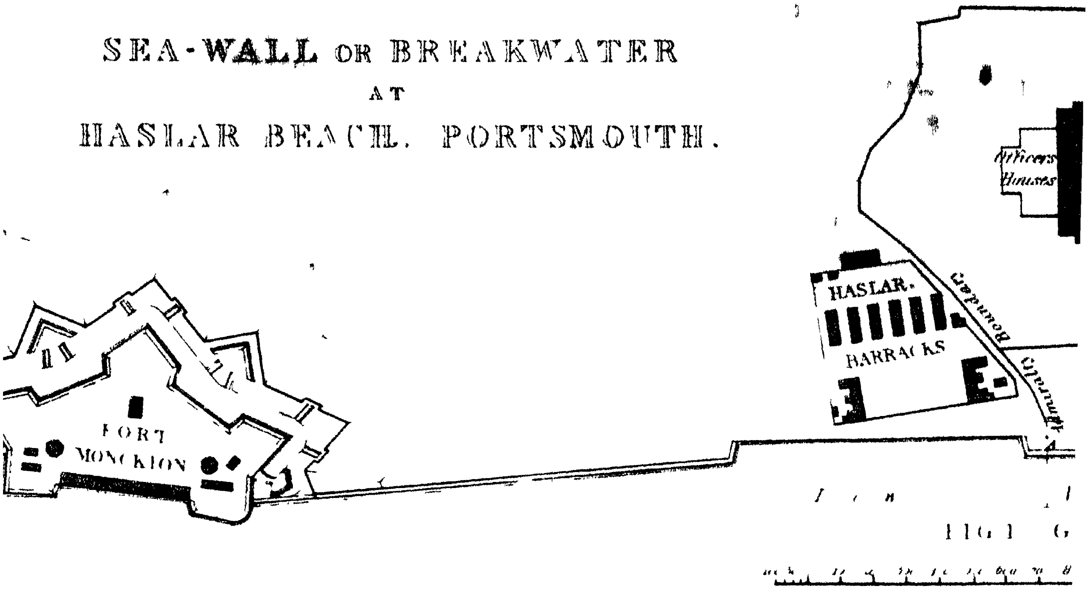


FIG I

FIG II

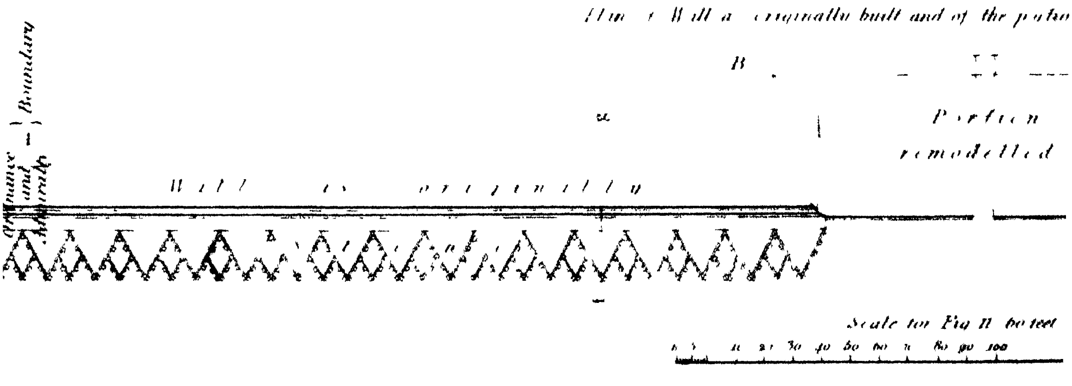
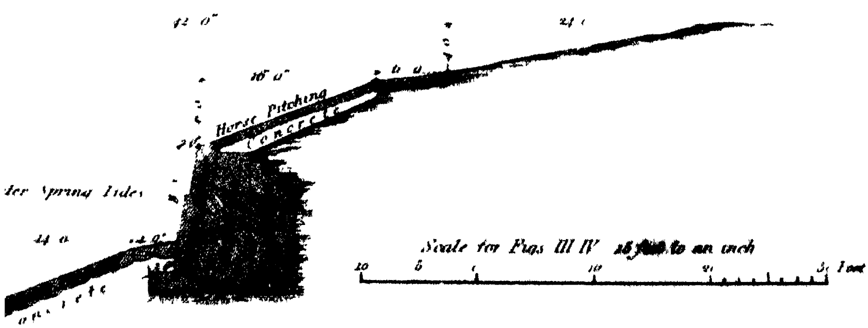
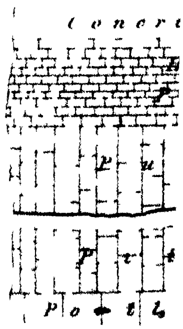


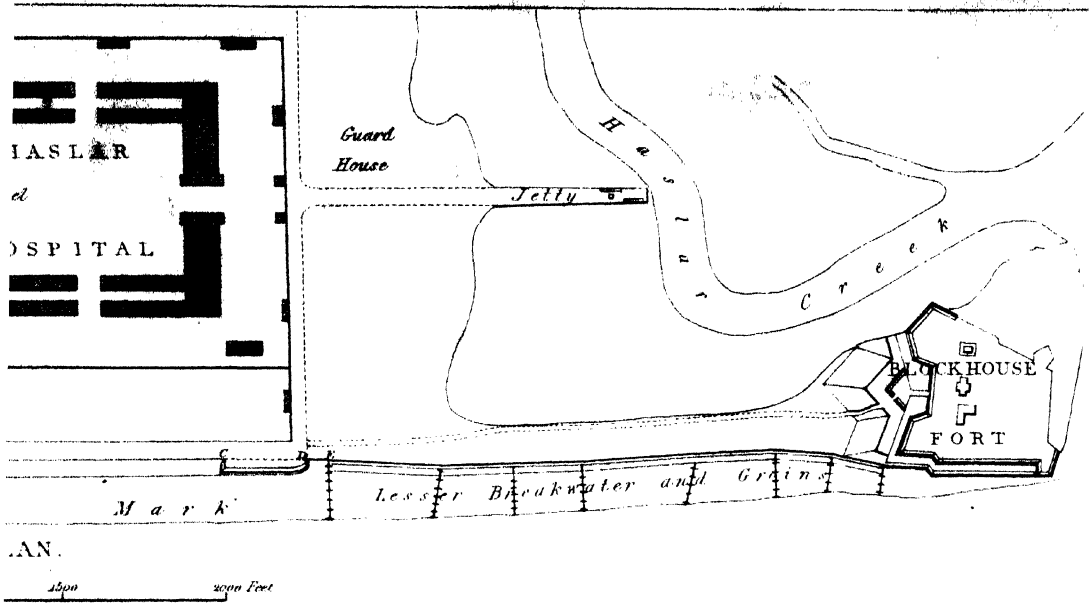
FIG III

Section at f g of original Wall and stone Groin



Plan of the work





.AN.

1500 2000 Feet

d 20 years ago.

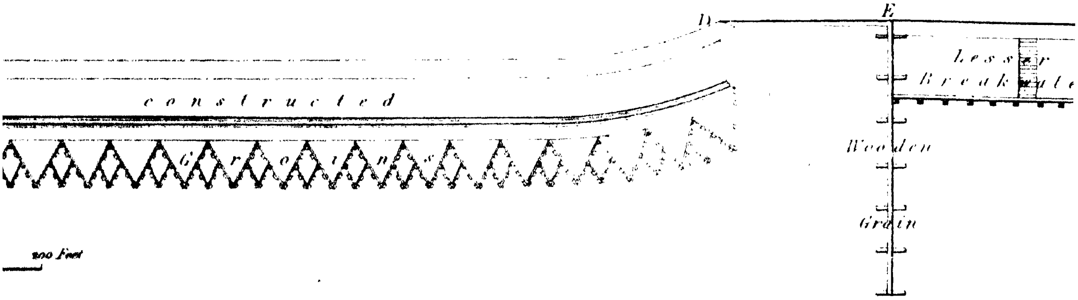
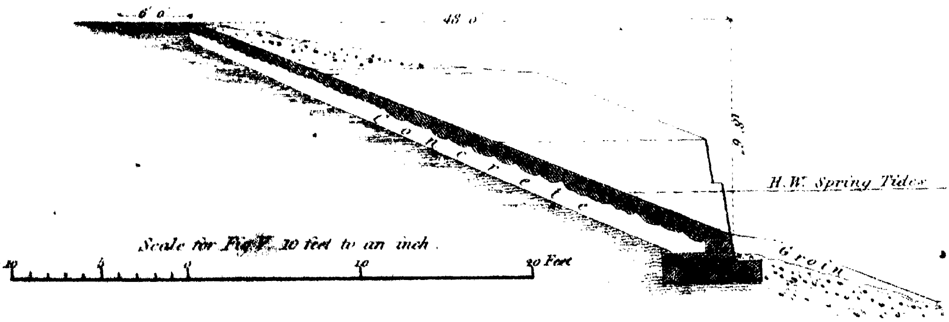
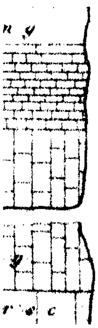


FIG IV

Section of h.i. Fig. II. of the portion remodelled with flank of original wall in Elevation.

rification.





V.—*Memoranda relative to the Reconstruction of certain portions of the Admiralty Sea Wall at Haslar Beach, Portsmouth. By Lieut.* Beatson, *Royal Engineers.*

During the very tempestuous winter of 1839-40, the then remaining portions (viz., from A to B, and from C to DE, *vide* figs. 1 and 2, being altogether about 800 feet in length,) of the original breakwater between Haslar Barracks and the front of the Royal Naval Hospital, suffered such extensive damage as to require reconstruction, and it became my duty to consider how that object might best be accomplished. Plate XII

The old wall had a batter of $\frac{1}{6}$th of its height, with an offset half-way up the face, and triangular-shaped groins of masonry covering and protecting its base. It was built upon the natural soil (a very tenacious red brick earth), with the exception of a portion of it about 90 feet in length, between C and D, where the presence of a quicksand had rendered planking and sheeting piles necessary.

The material chiefly used in its construction was the soft rubble stone of the Isle of Wight, which was faced with Purbeck ashlar; but between these there was not any bond, the ashlar being a mere superficial casing to the backing.

Composed of such indifferent materials, and so imperfectly put together, it might be supposed that the sea, acting as a battering-ram, would have had little difficulty in breaking it; but from all I have been able to learn on the subject, as well as from my own observation, I believe that, while it seldom escaped damage whenever an unusually severe south-easterly gale, accompanied by a high spring tide, set in, in no instance was the injury caused by the *direct* action of the waves, but that the destruction invariably commenced *behind* the wall. Neither do I think that the damage so frequently sustained by this breakwater furnishes any argument against the use of slightly battering or curved walls in similar situations: such walls stand very well on the neighbouring coast, but then they are much higher than this one was, the main defect of which, I suspect, was *want of elevation.*

Had it been of sufficient height, the waves would have lost their impetus, or power of doing harm, before they could have reached its crest, and would have fallen back upon themselves. As it was, the wall was just enough above high-water mark to oppose an abrupt and violent check to the angry element that assailed it, which, baffled in its advance, glanced upwards, and almost instantly surmounting the obstruction, resumed in a certain degree its onward, while it continued its upward, course; and having attained a greater or less height according to its impetus, fell upon and behind the wall with proportionate force; the effect of which was, by first loosening and removing the pitching, and then scooping out the soil, to leave the wall unsupported; after which, unless a fortunate subsidence of the gale, or a change of wind took place, the next flood tide generally completed the mischief.

But as on sandy or shingly coasts such violent results rarely, if ever, take place, it occurred to me that the more nearly the section of the breakwater could be made to conform with the line of beach, the greater would be the probability of its answering effectually the purposes for which it was intended; and that, instead of attempting to resist and repel the violence of the sea, my endeavours might be more advantageously directed by leading it on until friction and gravity should wear out its impetuosity, and the subdued and baffled element should harmlessly retrace its career.

This idea was strengthened by my having observed how comparatively slight an effect was produced on the stone glacis on the two seaward sides of Southsea Castle, as well as on a considerable portion (from B to C) of this very breakwater, which had been remodelled about twenty years previously, and which, though defective at a most essential point, viz., at its *base*, which rested on the footings of the former wall, without any thing to prevent it from striking, and, moreover, very indifferently executed, had withstood uninjured the same influences which had produced failure in the upright wall on either side of it.

A design, of which the particulars are given in the accompanying drawings and specification, was accordingly submitted for the consideration of the Lords Commissioners of the Admiralty, and, having received their approbation, the

SEA WALL OR BREAK

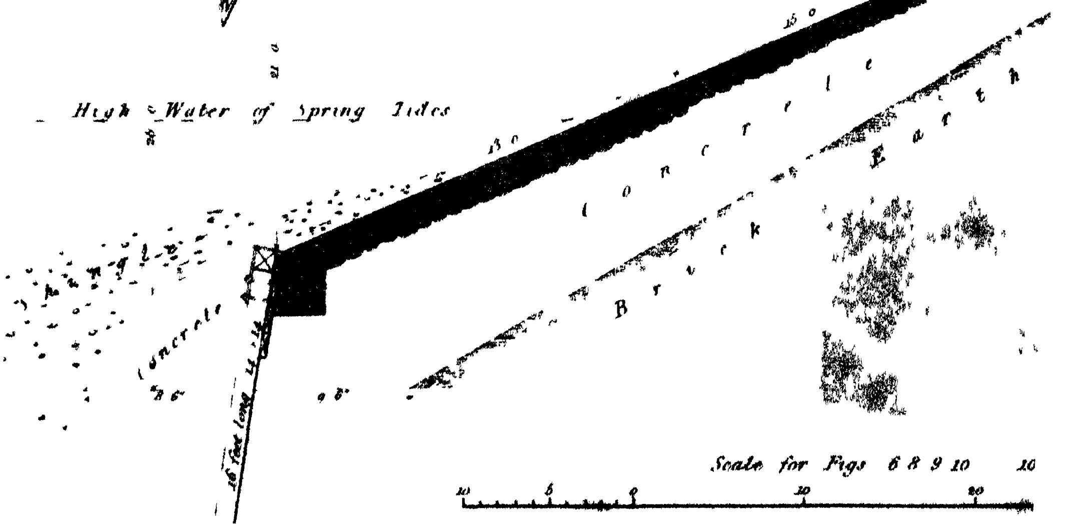
SECTIONS *and* ELEVATION *of* BR

FIG VI

FIG IX

SECTION OF BREAKWATER

as executed in 1841



Scale for Figs 6 8 9 10 10

Scale for Fig 6 _ 5 fe

AT HASLAR BEACH.

according to SPECIFICATION

FIG VII

Shewing lower part of Fig VI on a larger scale

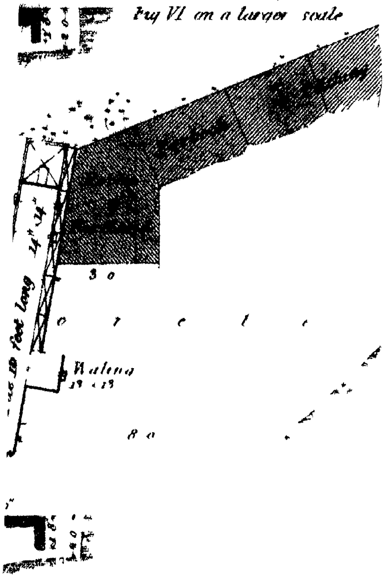
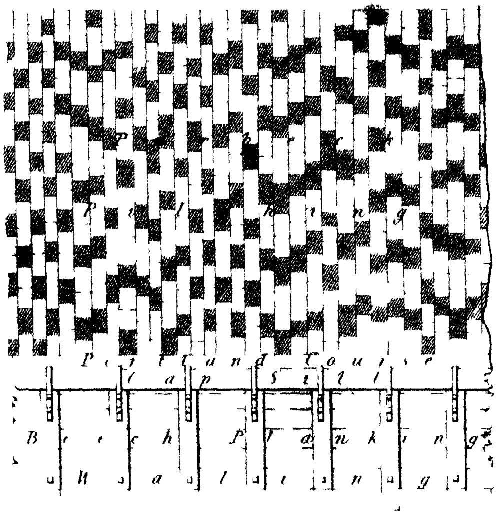


FIG VIII

ELEVATION *of Fig VI*



The stones shaded in Fig VIII are to be of greater depth than the rest so as to bond into the ... as shewn in Fig VI

FIG XI

Shewing in Perspective the closing block of the Portland course and plug

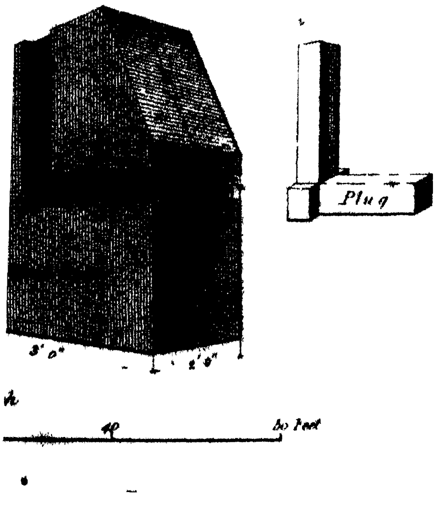
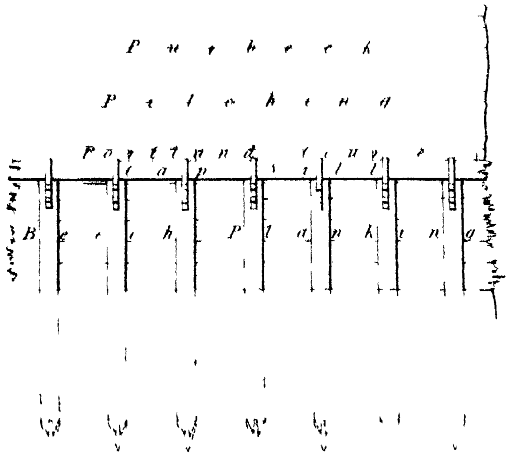


FIG X

ELEVATION *of lower part of Fig IX*



work was commenced by contract early in the spring of 1841. But as, during its progress, the drawings and specification were not exactly adhered to, I shall briefly mention the alterations that were made, and the reasons which led to them.

1. The waling was omitted, because, being under low-water mark of spring tides, it would have been very difficult to have fixed it properly; and the soil into which the piles were driven proved so much firmer than was anticipated, that I considered the waling unnecessary. Plate XIV. figs. 6, 7, and

2. It was suggested to me to have a certain proportion of the stones in each course of greater depth than the rest, so that by forming keys to the masonry they might prevent its slipping; and a clause to this effect was inserted in the specification. Figs. 6 and

On subsequent reflection, however, it was evident that any tendency to slip must commence at the *toe* of the wall; and I had no misgivings as to any want of strength or stability at that point, for the size, number, and stiff driving of the piles, their firm connexion with each other by means of the sill, straps, and planking, the massive packing of concrete outside of them, and the weight of the beach beyond and upon that, left no doubt in my mind respecting the adequacy of their combined resisting power to counteract any outward effort of the wall and its concrete bed. Besides, by disuniting the concrete, they would have been detrimental to the work.

3. It will be easily understood, that if a stratified stone, whose several laminæ are of various degrees of hardness, be so placed as that those laminæ shall be in vertical planes, and if a slope, or inclined plane, be formed of several series of such stones similarly placed, up and down which slope any small hard bodies are very frequently, if not constantly moving, the softer parts of the stones will be worn into channels, and the harder veins will become protuberant; and this effect will be greater in proportion as the stones are lower down the slope.

In that portion of the breakwater which was remodelled about twenty years ago, this detrition had taken place to such an extent as to have reduced the lower stones to mere ridges, and to have left them with scarcely any side joints. I was, therefore, prepared to see the beauty of the new work soon effaced; but I could not have believed, had I not witnessed it, that hard as the stones were, the action of the shingle upon them would have been so great as to render it scarcely possible, after only a few tides, to distinguish one week's work from that which had been done during two or three preceding weeks.

Foreseeing the certain destruction of the work at no distant period, if this evil remained unobviated, I caused the mode of setting the pitching to be reversed; that is, the longer joints and veins of the stones, instead of being
9 and 10. directed *down* the slope, were laid parallel with the top and bottom of the breakwater,—an arrangement which, I hoped, would not only render the wear more uniform, but greatly diminish it; as the retardation caused by the longitudinal joints would prevent the sea and shingle from reaching as high up the slope as they would if there were no such obstructions, while the frequent recurrence of those joints directly across the retrograde path of the shingle, by making it virtually recommence its descent at each, would prevent its acquiring any very hurtful degree of velocity. It was, in fact, dividing one long slope into as many distinct inclined planes as there were courses of stone in it.

For a time the result was sufficiently discouraging, for there seemed to be hardly any difference between the wear of the stones thus laid, and of those that had been previously set; but this equality of wear lasted only until the former were worn smooth and had become slightly convex, and the period of eighteen months that has since elapsed has fully proved the superiority of the second mode, which has also the advantages of being more easily set and kept in place, and of affording greater facility for the detection of any imperfection in the work.

4. Having commenced working towards the centre from each extremity of the eastern division of the work, the closing block of the Portland course could not be connected with the blocks on either side of it by oak dowels, as the rest of the stones in the same course were, and the following substitute was therefore adopted:

The three stones being mortised as if to receive the dowels, vertical and
Fig. 11. horizontal grooves, 4 inches wide and 2 inches deep, (so that, when brought together, each corresponding set might form channels 4 inches square,) were cut in each stone leading to the mortises. The grooves and mortises were then rendered with cement, the stones set, the joints of the grooves, &c., made good with cement by means of a long narrow spatula, the ends of the horizontal channels closed, and lead was run in at the vertical ones, thus forming a sort of double ⊥ plug, as shown at fig. 11.

5. It was specified that the Purbeck stones should be square-jointed throughout; but as the stone merchants at Sivanage would not supply stone so prepared, this condition was modified. In no instance, however, was any stone squared to less than two-thirds of its depth, and the stones were set as close as regular cubes could be. These were details on which the efficiency of the work so essentially depended, that their strict observance was much insisted on; and it is but justice to say, that I never saw any other than the most praiseworthy disposition on the part of Mr. Bramble, the contractor, to fulfil these and every other condition of his contract. The work does him very great credit, and is perhaps as fine a specimen of its kind as can be found.

In cutting down the bank at A, several human skeletons were exhumed; in the eye-sockets of one of which were two half-pence of the reign of George the Second,—one coined in 1731, the other in 1740. This ancient Saxon practice is not yet extinct, I believe, in some parts of England.

Note on Groins.—The large timber-framed groins which form various angles with the general direction of the beach between Haslar Hospital and Blockhouse Point, answer very imperfectly, if at all, their intended purpose. On their weather sides, or rather just where their weather sides meet the breakwater, some accumulation of shingle certainly takes place; but as there is generally a corresponding deficiency on the opposite sides, it seems doubtful whether, on the whole, they tend to raise the level of the beach.

In proceeding with the works to which the foregoing Paper has reference, the debris of the old wall was, for greater convenience, thrown promiscuously on the beach, outside of the line of excavation for the new work; where it so effectually served as a trap for the shingle, that I have no doubt that if large quantities of rough stone were strewn triangularwise along an exposed beach, between high and low-water marks, they would prove the cheapest and most effectual barrier to the passage of the shingle, and would always maintain a very high average line of beach.

It is probable, however, that they would eventually find their way towards low-water mark; but their tendency to do so would be less in proportion as they might happen to be larger and flatter.

R. Stewart Beatson,

Lieutenant, Royal Engineers.

Specification of Works to be performed and Materials to be used in the Reconstruction of certain portions of the Sea Wall at Haslar Beach, according to the Drawings hereto annexed.

Taking down old wall, &c.—The present breakwater, or sea wall, including the stone groins at the foot of the wall, is to be taken down to the extent of from 700 to 800 lineal feet, or to such extent, greater or less, as may be directed. The ashlar to be properly cleaned and stacked, if required; and such of it as may be considered fit for the purpose, to be used in the construction of the new breakwater. The rubble to be deposited in heaps near the works.

Excavation.—The excavation to be taken out to the depth of 29 feet, measured in a perpendicular direction below the line carried out horizontally from the point C, as shown on the section, and to such distance as may be necessary to insure the slope of the new wall being in the same plane with that of the remodelled portion of the breakwater at B and C; and all soil, clay, gravel, concrete, or other materials whatsoever, that may be taken out, are to be considered as *excavation*. It must also be distinctly understood that all slips or founders of ground, shingle, concrete, &c., that may occur, are to be cleared away at the contractor's expense; as only the actual measurements, once taken, will be allowed.

Filling in ground.—All ground that may require to be made good, such as levelling the road at the summit of the breakwater, filling in behind the new work, &c., is to be properly rammed, and any surplus earth or soil that may be taken out, if fit for this purpose, is to be again used; and all other required to complete the said work, is to be brought to the spot by convict labour. All filling in and ramming of ground is to be performed by measurement.

Carpentry, pile-driving, &c.—The piles at the foot of the wall are to be of the best Riga or Dantzic timber, 16 feet long, and from 13 to 14 inches square; properly hooped, and shod with wrought iron shoes, each weighing from 26 to 28 lbs.: each shoe to be firmly secured to its pile by four 4-inch dog nails. The piles to be driven 4 feet apart, from centre to centre, with a batter of 2 inches in every foot, and in a straight line with each other; so that the tenons formed on the heads of the piles may exactly fit into the mortises prepared to receive them in the cap-sill.

The piles being driven, a layer of concrete, 1 foot in depth, will then be put into the trench; and on this concrete the waling will be placed, which will be of the same material and scantling as the piles, properly scarfed, and bolted to the piles by wrought iron screw bolts 1¼ inch in diameter, and nuts 3½ inches square and 1 inch thick. Under each head and nut there will be a wrought iron plate, 6 inches square and ¾ of an inch thick. Each scarf shall be behind a pile, and be well secured by the bolt and nut.

The cap-sill upon the pile heads to be 21 feet perpendicularly under the level of the point C; to be of Riga or Dantzic timber, from 13 to 14 inches square, and in such lengths as that each piece shall receive the tenons of at least five piles; to be properly scarfed (each scarf to be over a pile) and framed to the head of each pile by a mortise 6 inches deep, 4 inches wide, and as long as the pile is thick; to be well secured to each pile by a wrought iron strap 3½ inches wide, ¾ of an inch thick, and 2 feet 9 inches long on each side, and two wrought iron screw bolts, 17 to 18 inches long, by 1⅛ inch diameter, and nuts of the size already described for fixing the waling.

At the back of the piles, from the upper side of the waling to the top of the cap-sill, beech or oak planking, 3 inches thick, and close jointed, is to be secured to the piles by means of 7-inch wrought iron spikes, two in each plank at every pile. The butts to be secured to each pile by two spikes in each; and the planks are to be so disposed as to break joint with each other.

Concrete.—The remainder of the concrete in front of the piles and framing to be then got in, and to be covered with shingle before the tide overflows it; the concrete foundations and backing to be at the same time, if possible, put in as high as may be necessary for setting the blocks of Roche Portland.

The concrete to be mixed in the following proportions, viz.: six measures of clean shingle, two measures of sharp sand, and one measure of freshly burnt Petersfield gray lime, or other lime of equal quality; and to be made in such quantities as shall be directed, so as to be used while in a hot state. The ingredients are to be well mixed without water; after which a sufficiency of water is to be added, and the whole thoroughly incorporated. As soon as the concrete is put into its place in the work, it is to be closely packed with shovels; and should its surface become deteriorated by the action of the sea or weather before the masonry has been set upon it, the damaged part must be removed, and fresh concrete be substituted for it; but no allowance will be made to the contractor, either for the removal of such damaged concrete, or for the new concrete required to make good the deficiency.

As large quantities of shingle have been collected at some distance from the site of the proposed works, the same will be conveyed thither at the expense of the Crown.

Masonry.—The concrete being put in to a sufficient height (as has been specified), the footing or lower course of the masonry is then to be got into its place. This course is to be of Roche Portland stone, in blocks containing not less than 24 cubic feet each. Each block to be dressed fair, so as to make a close and uniform joint throughout; the upper side to be dressed to the same inclination as has been determined on for the slope of the wall. The back to be squared from this bevelled end to a depth of at least 22 inches, so as to form a square abutment for the lower course of the Purbeck pitching, and an oak dowel, 6 inches long by 4 inches square, to be let into each stone 3 inches. The joints to be well grouted with mortar composed of gray lime and sharp sand, until every interstice be filled.

The concrete bed for the Purbeck pitching will then be got in, and each stone is to be prepared and set in the following manner: the upper surface is to be drove round the edge 2 inches in breadth, and to be scappled between; the stone to be square-jointed throughout; to have a bond of not less than 9 inches, and not be shorter than 2 feet, nor less than 9 inches in width; to be well bedded in gray lime mortar upon the concrete, and set with a close joint never exceeding a quarter of an inch; the whole of the joints to be well grouted in, as described for the Portland course.

The first 23 feet, measured upwards on the slope from the back of the Portland blocks, to be not less than 2 feet in depth; the next 15 feet, measured in the same direction, to be 18 inches deep; and the remainder to be 12 inches in depth.

To prevent the masonry from sliding, there shall be in each course a certain proportion of stones whose depth shall exceed that of the rest of the course in which they are placed, by 12 or 15 inches, as shown in the section. The number of such stones shall be from ten to twelve in every 100 square feet.

On arriving at the summit of the breakwater, a space 4 feet wide, and extending the whole length of the new work, is to be paved with Purbeck horse pitchers, averaging 7 inches in depth; the outer course to be bevelled on one side, in order that it may form a close joint with the upper course of the masonry of the breakwater. The inner side of this horse pitching will be confined by a Purbeck curb 6 or 7 inches thick, and 20 inches deep; and to prevent the back of this curb-stone being laid bare at any time by the washing away of the soil near it, a packing of concrete, as deep at least as the stone, and about 2 feet wide, will be put in behind it.

Mortar.—All the mortar required for the work to be made in the presence of the overseer of the works, and to be composed of freshly burnt gray lime, or other lime of equal quality, and clean sharp sand, in the proportion of one of lime to two of sand; or in such other proportions as may be directed. The whole to be well tempered.

The lime to be kept from exposure to the weather, at the contractor's expense.

The Crown will provide the whole or such portions of the timber for piles, waling, and sills, as the superintending officer may think expedient; the rest (if any) to be furnished by the contractor.

The contractor will supply all the wrought iron straps, bolts, nuts, plates, spikes, &c.

He will perform all the works by measurement, under a schedule of prices, except where such a mode cannot be adopted; and then the work will be executed by day-work, according to the rates stated in the schedule.

He will be responsible for his work in every respect, and for all accidents or losses that may take place during its progress.

In the preceding works, labour, scaffolding, shoreing, pile engines, all requisite implements, and every other expense attending the same, are to be considered as included.

The whole of the materials and labour are to be of the best description of their respective kinds.

The superintending officer of Royal Engineers shall be the referee in all questions that may arise respecting the works, and his decision shall be final and binding.

The works shall commence as soon as the contract is signed; and the whole must be completed by the end of October of the present year, to the entire satisfaction of the civil architect of the Admiralty, and of the superintending officer of Royal Engineers.

Note.—Labour in removing old stones and materials to the works is to be included in the contract.

May, 1841.

Abstract of the actual Cost of the Work.

	£.	s.	d.
1. Taking up old masonry	547	15	7
2. do. timber	89	9	9½
3. Excavating	845	19	3½
4. Dantzic timber in piles	530	6	7¼
5. Wrought iron pile shoes	70	11	7½
6. do. spikes	26	8	0
7. Hooping, shoeing, driving, and preparing piles to receive cap-sill	186	13	9
8. Riga timber in cap-sill	135	6	4
9. Labour in preparing and fixing ditto	38	3	9
10. Wrought iron straps	79	2	3½
11. do. screw bolts, nuts, and plates	30	19	3
12. 3-inch beech plank	115	19	9
13. Labour in fixing ditto	63	5	4
14. Concrete	1697	15	10½
15. Roche Portland blocks, worked and set	755	5	0
16. Cutting mortises in ditto for dowels	5	15	8
17. Oak dowels	3	12	3½
18. Purbeck pitching	4778	0	2½
19. Old stone re-set	11	0	0
20. Cutting on ridge formed by the meeting of the two slopes at the east end	9	6	3
21. Rubble masonry in retaining walls at A and E	17	5	1
22. Horse pitching in footpath	73	8	0
23. Filling in and ramming ground	92	17	4
24. Day-work	0	13	1½
Total expense of reconstructing 801 lineal feet of the breakwater	£ 10,205	0	2¼

Cost of 1 lineal foot of it. £ 12. 14*s*. 9½*d*.

Note on pile driving.—The ordinary method of hooping square piles often causes great waste of material, and is always productive of much loss of power and time.

A pile head being trimmed *round*, in order that it may receive the hoop, while the rest of the pile remains square, the parts of the rectangle without this circle become so many shoulders on which the hoop is violently forced at each blow of the ram; and its tendency is, of course, to split the pile at those points. Should this happen before the pile is driven to its full depth, it must be hooped again,—an operation of some trouble when the pile is under the engine,—and it may even be necessary to do so a third time.

Again, the round hoop being forced down upon the pile by repeated blows, the head of the pile becomes so bruised and spongy that the momentum is virtually lost. There being generally a good deal of pile driving going on either in this dock-yard or the mast pounds attached to it, it was worth consideration how these inconveniences might be avoided; and I have lately found considerable advantages arise from the use of *square* hoops for all isolated piles; (in coffer-dams, except for the gauge piles, they are inapplicable.) The head of the pile being very slightly tapered, the hoop is driven on by hand, just far enough to give it a firm hold; and a few gentle blows of the ram then send it down flush with the head of the pile, in which position it remains.

Piles so hooped, and driven from 15 to 20 feet in stiff clay, by a ram of 13 or 14 cwt., will be found, on removing the hoops, to be so little injured, as to admit of tenons being formed after about an inch of the tops of the piles has been sawn off. Square hoops, when equally thick throughout, are apt to break at the angles; for which reason I generally have double the thickness of metal at those parts.

R. Stewart Beatson,
Lieutenant, Royal Engineers.

H. M. Dock-yard, Portsmouth,
10th November, 1842.

VI.—*Practical Essay on the Strength of Cast Iron Beams, Girders, and Columns; in which the principles of calculation are exhibited in a plain and popular manner.* By WILLIAM TURNBULL.

INTRODUCTION.

THE want of some short and simple method of ascertaining the proper dimensions of cast iron beams of different sections, calculated to sustain any given weight, has been of late years often forced upon my notice. I have therefore gladly availed myself of the labours of Mr. Turnbull, who, taking Tredgold's experiments and formulæ as his guide, has deduced from them not only simple rules for numerical calculation, but has also formed sets of Tables extensive enough to take in nearly every case that may occur in practice, and by which, in many cases by simple inspection, the results required may be at once obtained.

I do not take upon myself any responsibility either as regards the correctness of the formulæ, or of the tabular results deduced therefrom; but I have every confidence in their accuracy, having compared the strengths calculated according to the rules here given with the results of a great number of experiments actually made upon iron girders cast by Messrs. Bramah and Cochrane, and proved by them. The following Table, which shows the lengths of the girders, the amount to which they were proved, the calculated strength, the average deflexion, and the number of each sort proved, will enable others to judge how far my confidence in the accuracy of the Tables is justified.

No.	Length of bearing.	Proof in tons.	Pressure from Tables.	Average deflexion in inches.	Deflexion in terms of length.	Number of beams proved.
	ft. in.					
1	28·3	30	30·8	·625	$\frac{1}{542}$	19
2	28·3	$31\frac{3}{4}$	32·55	·66	$\frac{1}{513}$	6
3	22·5	13	13·16	·519	$\frac{1}{518}$	8
4	13·10	6	6·64	·387	$\frac{1}{429}$	4
5	18·3	9	9·9	·55	$\frac{1}{380}$	2
6	16·9	$7\frac{1}{4}$	8·0	·458	$\frac{1}{439}$	6
7	17·0	$6\frac{1}{2}$	6·85	·466	$\frac{1}{438}$	124
8	15·2	$5\frac{1}{2}$	6·0	·412	$\frac{1}{442}$	3
9	23·3	$15\frac{1}{4}$	15·33	·55	$\frac{1}{507}$	4
10	10·11	4	4·38	·325	$\frac{1}{400}$	12
11	11·11	6	5·98	·366	$\frac{1}{391}$	80
12	9·1	$3\frac{3}{4}$	4·2	·241	$\frac{1}{452}$	18
13	12·8	$3\frac{1}{4}$	3·4	·275	$\frac{1}{552}$	2
14	12·10	$4\frac{1}{2}$	5·07	·4	$\frac{1}{385}$	3

In taking the forms of the girders, as given by Tredgold, and calculating the Tables by his rules, I have not lost sight of the experiments made by Mr. Hodgkinson, which appear conclusive in favour of increasing the width of the bottom flange in cast iron beams; but, as I am not aware that the results of these experiments have as yet been embodied into a form susceptible of calculation, I have thought it better not to delay the publication of the present Tables.

I have also availed myself of Mr. Turnbull's assistance in reducing the formulæ for the strength of iron columns into a simple form for computation, as also in preparing from these formulæ, Tables extensive enough to take in nearly every practical case: here, however, I have not been able to compare the tabular results with those derived from actual experiment; but I should have no hesitation in making use of the Tables, as I feel convinced that the error, if any, tends to an excess of strength.

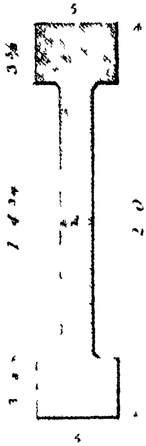
W. D.

Note.—The sections of the girders mentioned in the Table are given in Plate XV.

There are in the English language several distinct and valuable productions, which treat exclusively on the strength of materials, besides a great many detached essays and tracts, that have appeared at various times in the Encyclopædias, and other periodical publications; and it is now customary for every

SECTIONS

N° 1



N° 3

N° 4

N° 5

N° 10

N° 11

GIRDERS.

No 2

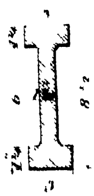
No 7

No 8

No 9

No 13

No 14



person who writes on the subject of mechanics, to introduce a chapter or section on the laws of resistance, as they are exhibited in the flexure and rupture of metals, timber, and other substances employed in the mechanical arts. Some of the treatises here alluded to contain a great variety of elegant and useful formulæ, intended to guide the mechanic to an approximate estimate of the strength of the materials which he employs; but unfortunately, as a consequence of the theory, these formulæ are expressed in algebraic symbols, which render them incomprehensible to ninety-nine out of every hundred of our most experienced artisans: and although in many instances, the algebraic equations are converted into rules in words at length, yet it does not appear, that those individuals for whom the rules are more particularly intended, have paid that attention to them which their importance would seem to demand. The fact is, that men in extensive practice will not take the trouble to study rules of calculation; they want the thing done to their hands, and expect that the man of science, who undertakes to draw up rules for their guidance, should divest the subject entirely of its mathematical character, and deliver the precepts in such a plain and simple manner, that even a child might understand them. Now this is asking too much, for there are many departments of science that will not admit of such extensive simplification, and among them is that of which we are now treating; for if taken in its full extent, and considered in all its bearings as applied to the arts of life, it would be difficult indeed, if not altogether impossible, to render it intelligible to those who are not acquainted with the principles of algebra. In the present instance, however, we have endeavoured to dispense with the aid of analysis, and in as far as we have proceeded, the rules for calculating the several sections are all deduced from principles of such easy comprehension that we anticipate no further objections on this head.

The several Tables have been expressly computed for this work; they are sufficiently extensive for every practical purpose, and the most scrupulous attention has been paid to their accuracy. The labour attending the computation has been very great, and it is hoped that the exemplifications are conducted in that plain and simple manner, so much desired by practical men; it being with a view to accommodate this class of individuals, and to remove the objections commonly raised against scientific works, that the present performance was undertaken.

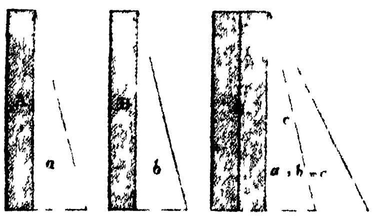
It is a law deducible from theory, and it has been abundantly confirmed by a multitude of very accurate experiments, that—

The lateral strength of any beam of timber or other material of which the transverse section is a rectangle, is directly as the breadth and square of the depth, and inversely as the length of the beam.

In the proposition here enunciated there are three elements upon which the strength of the beam depends; namely, the breadth and depth of the section, and the leverage, or distance between the fulcrum and the point where the force acts; and in order that the import of the proposition may be made clear to the ordinary reader, we shall consider these elements separately, as follows.

1 *The length of the beam and depth of the section being constant, the strength varies directly as the breadth* Let A and B, fig. 1, represent the transverse sections of two equal and similar homogeneous beams of the same material, placed under like circumstances, and strained by forces of equal magnitude or intensity; then it is manifest that the effect will be the same upon both the beams, and consequently, their strength will be measured by the same or an equal quantity.

Fig. 1.

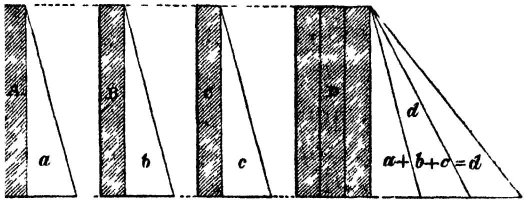


Let the strengths of the equal and homogeneous sections A and B be respectively denoted by the equal and similar triangles *a* and *b*, described upon the depth of the sections with a base of any convenient magnitude at pleasure; then it is obvious, that the strength of the sections will be the same, whether they are considered apart from each other, or are brought into immediate contiguity as represented at C, provided always that they are placed in similar positions and subjected to a similar strain.

Therefore, if the two sections A and B are made to coalesce and form a single section as indicated at C, the triangles *a* and *b*, when brought into one, will constitute the triangle *c*, containing an area equal to them both, so that the strength of the section C is equal to the united strengths of both the sections A and B, or it is double the strength of either, since the base of the triangle *c* is double the base of either *a* or *b*. Hence we infer, that *the strength varies directly as the breadth.*

Again, let there be three equal sections A, B, and C, fig. 2, and let their strengths be respectively denoted by the equal and similar triangles *a*, *b*, and *c*; then, if the sections A, B, and C be placed in immediate contiguity as represented at D, the triangles *a*, *b*, and *c*, which indicate the individual strengths, will constitute the triangle *d* which indicates the accumulated strength of all the three.

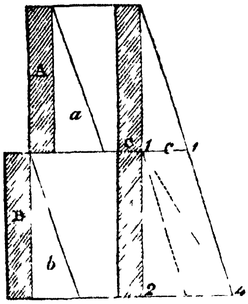
Fig. 2.



Hence it appears, that if the depth of the section remain the same, *the strength varies directly as the breadth;* for when the height of the triangle, which is constructed upon the depth of the section, and represents the aggregate strength, remains the same, the area varies directly as the base, and since the base of the triangle varies directly as the breadth of the section, the strength of the section must vary according to the same law.

2. *The length of the beam and the breadth of the section being constant, the strength varies directly as the square of the depth.* Let A and B, fig. 3, represent the transverse sections of two equal and similar homogeneous beams, placed under similar circumstances, and operated on by forces of equal magnitude; then it is obvious from the laws of mechanics, that the effect will be the same on both beams; consequently, the absolute strength of the beams will be measured by the same quantity.

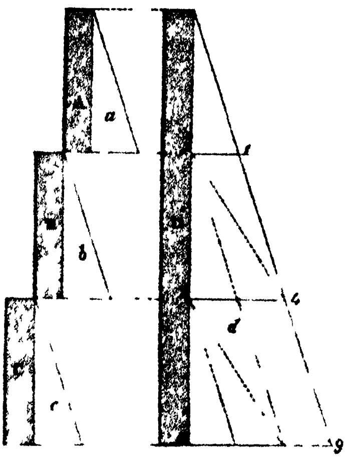
Fig. 3.



Let the equal and similar triangles *a* and *b*, constructed on the depth of the sections, represent their individual strengths; then we have seen in the preceding case, that if the sections be brought together between the same horizontal lines, the strength of both sections, when united in one, is precisely the same as when they are considered apart; but when placed in immediate contact with each other, the breadth, as well as the base of the triangle which indicates the strength, is doubled, and consequently the united strength is double the strength of either section when considered apart or by itself.

In the present case, however, the sections are brought into contact and blended together by being placed between the same vertical lines, as represented at C, and in consequence of this concentration, the depth of aggregate section is doubled, while the breadth remains the same as before; the strength of the composite section is therefore represented by the area of the triangle *c*, whose height and base are respectively double of those denoting the strength of either component section; and for this reason, the area of the triangle *c*, is quadruple the area of either *a* or *b*; and consequently, the strength of the section C, is quadruple the strength of either A or B when considered as a separate and independent section. Hence it appears, that by doubling the depth of the section, we quadruple its strength, admitting the breadth to remain invariable; that is, *the strength varies directly as the square of the depth.*

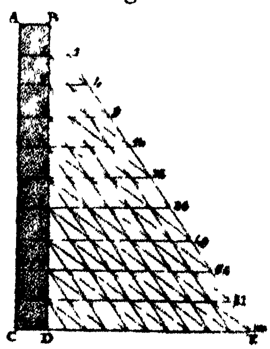
Fig. 4.



Again, let there be three equal and similar homogeneous sections A, B, and C, fig. 4, and let their individual strengths, when placed under the same or similar circumstances, be respectively denoted by the equal and similar triangles *a*, *b*, and *c*, constructed upon the depths; then, conceive the sections A, B, and C, to be brought into immediate contact and blended together, by being placed between the same vertical lines as represented at D. It will then be manifest, that the depth of the composite section D, as well as the base of the triangle which indicates its strength, is three times greater than the depth of either section A, B, or C; hence it follows, that the area of the triangle which indicates the aggregate strength, or strength of the section D, is equal to nine times the area of either of the triangles *a*, *b*, or *c*; that is, *the strength varies directly as the square of the depth.*

But for a general illustration, let A B D C, fig. 5, represent the transverse section of a beam, of which the breadth is A B and the depth A C or B D, and let the triangle B D E denote the strength of the section as dependent on the depth alone. Divide A C or B D, the depth of the section or perpendicular of the triangle, into any number of equal parts, say ten, in the points 1, 2, 3, 4, 5, &c.; then through each of these points of division, let straight lines be drawn respectively parallel to the base and hypothenuse of the triangle B D E; these will form a series of rhomboids, the bisection of which

Fig. 5.



divides the figure into a system of small triangles, corresponding to the square of the number of divisions in the perpendicular. These small triangles are all of the same area, and the number of them contained between any two lines which are parallel to the base, is equivalent to that term in the series of odd numbers, beginning at unity, whose index corresponds to the division of the lower line.

Thus, the number of the little triangles, comprehended between the parallel horizontal lines passing through the 6th and 7th divisions of the perpendicular, is 13, which corresponds to that term in the series of odd numbers whose index is 7. Now, the writers on the theory of numbers have shown, that the sum of any number of terms in the series of odd numbers, commencing at unity, is equal to the square of that number, which indicates the place of the final term from the commencement of the series.

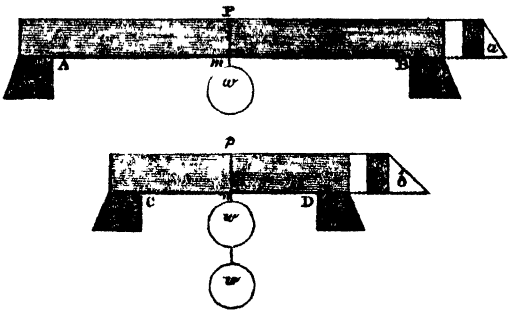
The series of little triangles corresponding to the several divisions in the above figure is 1, 3, 5, 7, 9, 11, 13, 15, 17, and 19; and the successive summation of these terms will give the whole number of little triangles, which stand above the horizontal line passing through any particular division of the perpendicular B D. The truth of this will be rendered manifest by means of the following Table.

1	1= 1=square of 1
2	1+ 3= 4= ,, of 2
3	1+ 3+ 5= 9= ,, of 3
4	1+ 3+ 5+ 7= 16= ,, of 4
5	1+ 3+ 5+ 7+ 9= 25= ,, of 5
6	1+ 3+ 5+ 7+ 9+11= 36= ,, of 6
7	1+ 3+ 5+ 7+ 9+11+13= 49= ,, of 7
8	1+ 3+ 5+ 7+ 9+11+13+15= 64= ,, of 8
9	1+ 3+ 5+ 7+ 9+11+13+15+17= 81= ,, of 9
10	1+ 3+ 5+ 7+ 9+11+13+15+17+19=100= ,, of 10

Hence it appears, that when the breadth of the section remains constant, *the strength varies directly as the square of the depth.* And if a greater number of divisions were assumed in the perpendicular, or depth B D, the successive summation of the terms of the series would still be equivalent to the square of the index, so that the law is general for all sections of the same form.

3. *The breadth and depth of the section remaining, the strength varies inversely as the length.* Let A B and C D, fig. 6, be two beams of the same material and

Fig. 6.



of equal section, supported horizontally at the extremities and loaded at the middle of the length; the forces by which the strains are produced being suspended at the points P and *p*.

Let E and F be the sections through P *m* and *p n* respectively, the triangles *a* and *b* denoting the measure of the strength in these sections; then, if the length of the beam A B be twice the length of C D, the leverage A *m* is also twice the length of C *n*, and consequently, the effect of the force on A B, is twice its effect on C D; but according to the writers on the resistance of solids, *the strength is inversely as the effect of the straining force;* therefore, the strength of the beam C D in the section *p n*, is twice the strength of A B in the section P *m*, and the area of the triangle *b* is double the area of *a*, or the strength of the beam is greater as its length is less. Hence generally, if the breadth and depth of the section remain constant, *the strength varies inversely as the length of the beam.*

By comparing the conclusions which we have drawn from the foregoing reasoning, it appears, that when the length of the beam and the depth of the section are constant, *the strength varies directly as the breadth:*—when the length of the beam and the breadth of the section are constant, *the strength varies directly as the square of the depth;* but when the breadth and depth of the section are constant, *the strength varies inversely as the length of the beam.* It therefore follows, that when all the three elements are found to change their magnitudes, the lateral or transverse strength of any section, *is directly as the breadth and square of the depth, and inversely as the length*, the same as announced in the proposition.

Fig. 7.

In order, therefore, to render this law available in practice, let A B C D, fig. 7, be the transverse section of a beam, of which the breadth is A B, and the depth A C or B D; then, by combining the several dimensions of length, breadth, and depth, according to the law which we have previously illustrated, the resulting equation in a specific form becomes,

$$\text{strength} = \frac{\text{breadth} \times \text{depth}^2 \times C}{\text{length}}$$

Here, then, we have obtained the fundamental equation, from which are derived the rules for calculating the transverse strength of beams, when supported horizontally after the manner of *girders, bressummers, cantilevers, joists, &c.*; but before we can apply it to practical inquiries, we must first determine the value of the constant symbol or quantity C, which being known, becomes a standard of comparison in all cases where the several circumstances and conditions of strain bear a resemblance to those adopted in its determination.

By an experiment, which appears, from the minuteness of its details, to have been performed with very great attention to accuracy, it has been found, that a bar of cast iron of a medium quality, 1 inch square, and 34 inches, or $2\frac{5}{6}$ feet in the length of bearing, will sustain a load of 300 ℔s. avoirdupoise applied at the middle of its length, while the elastic force of the material remains unimpaired, but if a few pounds more be added to the load, the bar will assume a permanent set; that is, the elastic power of the material will be exceeded by the effect of the straining force, and the bar will not be competent to restore itself on the removal of the load: 300 ℔s. must therefore be taken as the limit of elasticity for the bar in question, beyond which, in practical operations, it would not be proper or safe to extend.

Let this measure of elasticity be reduced to its equivalent value on a bar of 1 foot in length, which is very readily done, if we recollect that in the third division of the foregoing illustrations, it has been shown, that the strength is greater as the length is less; therefore we have

$$1 : 2\tfrac{5}{6} :: 300 : C = 850 \text{ ℔s. avoirdupoise};$$

that is, a bar of cast iron 1 inch square, and 1 foot or 12 inches in the length of bearing, will sustain a load of 850 ℔s. at the middle of its length without losing any part of its elastic force; our fundamental equation, therefore, when adapted to practice becomes,

$$\text{strength} = \frac{850 \times \text{breadth} \times \text{depth}^2}{\text{length}}. \qquad \text{(A)}$$

This equation is very elegant, and it is sufficiently simple in its form to be generally understood; it expresses the fundamental law of resistance as enunciated in our proposition, and applies to the case, where the bar or beam is loosely supported at its ends in a horizontal position, and strained in the direction of gravity at the middle of its length.

In practice, the breadth and depth of the section may always be estimated in inches, and the length of the bearing in feet; it is not, however, necessary that this should be the case, but it is most convenient to do so, as the absolute constant 850 has been deduced from these dimensions.

These particulars being attended to, the rule for reducing the equation may be expressed in words at length as follows:

RULE 1.—*Multiply* 850 *times the breadth of the section in inches by the square of the depth in inches, and divide the product by the length of bearing in feet, for the load to be suported in pounds avoirdupoise.*

Then, divide the weight or load in pounds by 2240, *the number of pounds in a ton, and the result will be the strength of the beam in tons.*

EXAMPLE.—A cast iron beam, of which the section is a rectangle, is 46 feet long between the supports, $2\frac{1}{2}$ inches broad, and 28 inches deep; how much will it bear at the middle of its length without destroying the elastic force?

Here by the rule we get,

$$\text{strength} = \frac{850 \times 2\frac{1}{2} \times 28^2}{46} = 36217{\cdot}49 \text{ lbs. and } 36217{\cdot}49 \div 2240 = 16{\cdot}162 \text{ tons very nearly;}$$

and in this way were the numbers in Table I. computed.

Table of the Strength of Cast Iron Beams within the Limits of Elasticity.

Depth.	TABLE I.—Argument.—Length in feet—Breadth or thickness 1 inch.									
	1	2	3	4	5	6	7	8	9	10
in.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.
1	0·3795	0·1897	0·1265	0·0949	0·0759	0·0632	0·0542	0·0474	0·0422	0·0379
2	1·5179	0·7589	0·5059	0·3795	0·3036	0·2529	0·2168	0·1897	0·1686	0·1518
3	3·4152	1·7076	1·1384	0·8538	0·6830	0·5692	0·4879	0·4269	0·3795	0·3415
4	6·0714	3·0357	2·0238	1·5179	1·2143	1·0119	0·8674	0·7589	0·6746	0·6071
5	9·4866	4·7433	3·1622	2·3717	1·8973	1·5811	1·3552	1·1858	1·0541	0·9487
6	13·6607	6·8304	4·5536	3·4152	2·7321	2·2768	1·9514	1·7076	1·5179	1·3661
7	18·5938	9·2969	6·1979	4·6484	3·7188	3·0989	2·6562	2·3242	2·0659	1·8594
8	24·2857	12·1429	8·0952	6·0714	4·8571	4·0476	3·4694	3·0357	2·6984	2·4286
9	30·7366	15·3683	10·2455	7·6842	6·1473	5·1227	4·3909	3·8421	3·4152	3·0737
10	37·9466	18·9732	12·6488	9·4866	7·5893	6·3244	5·4209	4·7433	4·2163	3·7947
11	45·9160	22·9580	15·3053	11·4790	9·1832	7·6526	6·5593	5·7395	5·1018	4·5916
12	54·6429	27·3214	18·2143	13·6607	10·9286	9·1071	7·8061	6·8304	6·0714	5·4643
13	64·1295	32·0647	21·3765	16·0324	12·8259	10·6882	9·1613	8·0162	7·1255	6·4129
14	74·3750	37·1875	24·7917	18·5937	14·8750	12·3958	10·6250	9·2969	8·2639	7·4375
15	85·3795	42·6897	28·4598	21·3449	17·0759	14·2299	12·1970	10·6724	9·4866	8·5379
16	97·1429	48·5714	32·3809	24·2857	19·4286	16·1904	13·8775	12·1429	10·7936	9·7143
17	109·6652	54·8326	36·5551	27·4163	21·9330	18·2775	15·6665	13·7081	12·1830	10·9665
18	122·9461	61·4730	40·9820	30·7365	24·5892	20·4910	17·5638	15·3682	13·6607	12·2946
19	136·9864	68·4932	45·6621	34·2466	27·3973	22·8310	19·5695	17·1233	15·2207	13·6986
20	151·7857	75·8928	50·5952	37·9464	30·3571	25·2976	21·6836	18·9732	16·8651	15·1786
21	167·3438	83·6719	55·7813	41·8359	33·4688	27·8906	23·9063	20·9179	18·5938	16·7344
22	183·6607	91·8303	61·2202	45·9151	36·7321	30·6101	26·2379	22·9575	20·4067	18·3661
23	200·7365	100·3682	66·9122	50·1841	40·1473	33·4561	28·6766	25·0920	22·3041	20·0736
24	218·5714	109·2857	72·8571	54·6428	43·7143	36·4285	31·2245	27·3214	24·2857	21·8571
25	237·1652	118·5826	79·0551	59·2913	47·4330	39·5275	33·8808	29·6456	26·3517	23·7165
26	256·5179	128·2589	85·5059	64·1294	51·3036	42·7529	36·6454	32·0647	28·5019	25·6518
27	276·6295	138·3147	92·2098	69·1573	55·3259	46·1049	39·5186	34·5786	30·7366	27·6629
28	297·4999	148·7499	99·1666	74·3749	59·5000	49·5833	42·5000	37·1874	33·0555	29·7500
29	319·1295	159·5647	106·3765	79·7823	63·8259	53·1882	45·5900	39·8911	35·4588	31·9129
30	341·5179	170·7589	113·8393	85·3794	68·3036	56·9196	48·7882	42·6897	37·9464	34·1518
31	364·6652	182·3326	121·5551	91·1663	72·9330	60·7775	52·0952	45·5831	40·5184	36·4665
32	388·5714	194·2857	129·5238	97·1428	77·7143	64·7619	55·5101	48·5714	43·1746	38·8571
33	413·2366	206·6184	137·7455	103·3092	82·6473	68·8727	59·0331	51·6546	45·9152	41·3237
34	438·6607	219·3303	146·2202	109·6651	87·7321	73·1101	62·6659	54·8325	48·7401	43·8661
35	464·8436	232·4218	154·9479	116·2109	92·9687	77·4739	66·4063	58·1054	51·6493	46·4844
36	491·7855	245·8927	163·9285	122·9463	98·3571	81·9642	70·2352	61·4731	54·6428	49·1785

Table of the Strength of Cast Iron Beams within the limits of Elasticity.

Depth.	Table I.—Argument.—Length in feet—Breadth or thickness 1 inch.									
	11	12	13	14	15	16	17	18	19	20
in.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.
1	0·0345	0·0316	0·0292	0·0271	0·0253	0·0237	0·0223	0·0211	0·0200	0·0189
2	0·1380	0·1264	0·1167	0·1084	0·1012	0·0948	0·0893	0·0843	0·0779	0·0759
3	0·3105	0·2846	0·2627	0·2439	0·2277	0·2134	0·2009	0·1897	0·1797	0·1707
4	0·5519	0·5059	0·4670	0·4337	0·4048	0·3794	0·3571	0·3373	0·3195	0·3035
5	0·8624	0·7905	0·7297	0·6776	0·6324	0·5929	0·5580	0·5270	0·4993	0·4743
6	1·2419	1·1384	1·0508	0·9757	0·9107	0·8538	0·8036	0·7589	0·7190	0·6830
7	1·6903	1·5494	1·4303	1·3281	1·2396	1·1621	1·0938	1·0329	0·9786	0·9297
8	2·2079	2·0238	1·8681	1·7347	1·6190	1·5178	1·4286	1·3492	1·2782	1·2143
9	2·7942	2·5113	2·3644	2·1954	2·0491	1·9210	1·8080	1·7076	1·6177	1·5368
10	3·4497	3·1622	2·9190	2·7104	2·5298	2·3716	2·2320	2·1081	1·9972	1·8973
11	4·1741	3·8263	3·5320	3·2796	3·0611	2·8697	2·7009	2·5309	2·4166	2·2958
12	4·9675	4·5535	4·2033	3·8030	3·6429	3·4152	3·2143	3·0357	2·8759	2·7321
13	5·8299	5·3441	4·9330	4·5806	4·2753	4·0081	3·7723	3·5627	3·3752	3·2065
14	6·7614	6·1979	5·7212	5·3125	4·9583	4·6484	4·3750	4·1319	3·9145	3·7188
15	7·7618	7·1149	6·5677	6·0985	5·6920	5·3362	5·0223	4·7433	4·4928	4·2690
16	8·8312	8·0952	7·4725	6·9387	6·4762	6·0714	5·7143	5·3968	5·1128	4·8571
17	9·9696	9·1387	8·4358	7·8333	7·3110	6·8540	6·4509	6·0915	5·7718	5·4833
18	11·1769	10·2455	9·4575	8·7819	8·1964	7·6841	7·2322	6·8303	6·4709	6·1473
19	12·4533	11·4155	10·5374	9·7847	9·1324	8·5616	8·0581	7·6103	7·2098	6·8493
20	13·7987	12·6488	11·6758	10·8418	10·1190	9·4866	8·9286	8·4325	7·9886	7·5893
21	15·2131	13·9453	12·8726	11·9531	11·1563	10·4589	9·8438	9·2969	8·8076	8·3672
22	16·6964	15·3050	14·1278	13·1189	12·2440	11·4787	10·8036	10·2033	9·6664	9·1830
23	18·2488	16·7280	15·4413	14·3383	13·3824	12·5460	11·8081	11·1520	10·5651	10·0368
24	19·8701	18·2142	16·8132	15·6122	14·5714	13·6607	12·8571	12·1428	11·5038	10·3286
25	21·5604	19·7637	18·2431	16·9404	15·8110	14·8228	13·9509	13·1758	12·4824	11·8583
26	23·3193	21·3764	19·7321	18·3227	17·1012	16·0323	15·0893	14·2509	13·5009	12·8259
27	25·1482	23·0524	21·2792	19·7593	18·4419	17·2893	16·2723	15·3683	14·5588	13·8315
28	27·0454	24·7916	22·8846	21·2500	19·8333	18·5937	17·5000	16·5277	15·6571	14·8750
29	29·0117	26·5941	24·5484	22·7950	21·2753	19·9455	18·7723	17·7294	16·7963	15·9565
30	31·0470	28·4598	26·2706	24·3941	22·7679	21·3448	20·0892	18·9732	17·9746	17·0759
31	33·1513	30·3887	28·0512	26·0476	24·3110	22·7915	21·4509	20·2592	19·1929	18·2333
32	35·3246	32·3809	29·8902	27·7550	25·9048	24·2857	22·8572	21·5873	20·4511	19·4286
33	37·5669	34·4363	31·7874	29·5165	27·5491	25·8273	24·3084	22·9576	21·7492	20·6618
34	39·8782	36·5550	33·7432	31·3329	29·2440	27·4162	25·8036	24·3700	23·0873	21·9330
35	42·2584	38·7369	35·7573	33·2031	30·9896	29·0527	27·3436	25·8246	24·4654	23·2422
36	44·7078	40·9821	37·8297	35·1176	32·7857	30·7365	28·9287	27·3214	25·8835	24·5893

Table of the Strength of Cast Iron Beams within the limits of Elasticity.

Depth.	TABLE I.—Argument.—Length in feet—Breadth or thickness 1 inch.									
	21	22	23	24	25	26	27	28	29	30
in.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.
1	0·0181	0·0172	0·0165	0·0158	0·0152	0·0146	0·0141	0·0135	0·0131	0·0127
2	0·0723	0·0690	0·0660	0·0632	0·0607	0·0583	0·0562	0·0542	0·0523	0·0506
3	0·1626	0·1557	0·1485	0·1423	0·1366	0·1313	0·1265	0·1219	0·1178	0·1138
4	0·2891	0·2759	0·2640	0·2529	0·2429	0·2335	0·2249	0·2168	0·2094	0·2024
5	0·4517	0·4312	0·4125	0·3952	0·3795	0·3648	0·3514	0·3388	0·3271	0·3162
6	0·6505	0·6209	0·5939	0·5692	0·5464	0·5254	0·5059	0·4878	0·4711	0·4554
7	0·8854	0·8451	0·8084	0·7747	0·7438	0·7151	0 6886	0·6640	0·6412	0·6198
8	1·1565	1·1039	1·0559	1·0119	0·9714	0·9340	0·8995	0·8673	0·8374	0·8095
9	1·4636	1·3971	1·3364	1·2556	1·2295	1·1822	1·1384	1·0977	1·0599	1·0246
10	1·8069	1·7248	1·6498	1·5811	1·5179	1·4595	1·4054	1·3552	1·3085	1·2649
11	2·1864	2·0870	1·9963	1·9131	1·8366	1·7660	1·7006	1·6898	1·5833	1·5305
12	2·6020	2·4837	2·3758	2·2767	2·1857	2·1016	2·0238	1·9015	1·8842	1·8214
13	3·0538	2·9149	2·7882	2·6720	2·5652	2·4665	2·3752	2·2903	2·2114	2·1377
14	3·5417	3·3807	3·2337	3·0989	2·9750	2·8606	2·7546	2·6562	2·5647	2·4792
15	4·0657	3·8809	3·7122	3·5574	3·4152	3·2838	3·1622	3·0492	2·9441	2·8460
16	4·6258	4·4156	4·2236	4·0476	3·8857	3·7362	3·5979	3·4693	3·3498	3·2381
17	5·2222	4·9848	4·7681	4·5693	4·3866	4·2179	4·0610	3·9166	3·7816	3·6555
18	5·8546	5·5884	5·3455	5·1227	4·9178	4·7287	4·5536	4·3909	4·2395	4·0982
19	6·5232	6·2266	5·9560	5·7077	5·4795	5·2687	5·0736	4·8923	4·7237	4·5662
20	7·2279	6·8993	6·5994	6·3244	6·0714	5·8379	5·6217	5·4209	5·2340	5·0595
21	7·9688	7·6065	7·2758	6·9726	6·6938	6·4363	6·1979	5·9765	5·7705	5·5781
22	8·7459	8·3482	7·9853	7·6525	7·3464	7·0639	6·8022	6·5594	6·3331	6·1220
23	9·5589	9·1244	8·7277	8·3640	8·0295	7·7206	7·7347	7·1691	6·9220	6·6912
24	10·4082	9·9350	9·5031	9·1071	8·7429	8·4066	8·0952	7·8061	7·5370	7·2857
25	11·2936	10·2802	10·3116	9·8818	9·4866	9·1215	8·7839	8·4702	8·1781	7·9055
26	12·2151	11·6596	11·1529	10·6882	10·2607	9·8660	9·5006	9·1610	8·8454	8·5506
27	13·1729	12·5741	12·0274	11·5262	11·0652	10·6396	10·2455	9·8796	9·5390	9·2210
28	14·1667	13·5227	12·9348	12·3958	11·9000	11·4423	11·0188	10·6250	10·2586	9·9167
29	15·1967	14·5058	13·8753	13·2970	12·7652	12·2742	11·8196	11·3975	11·0043	10·6377
30	16·2627	15·5235	14·8487	14·2299	13·6607	13·1353	12·6488	12·1970	11·7765	11·3839
31	17·3651	16·5756	15·8550	15·1943	14·5866	14·0256	13·5061	13·0238	12·5746	12·1555
32	18·5034	17·6623	16·8943	16·1904	15·3429	14·4451	14·3915	13·8775	13·3989	12·9524
33	19·6777	18·7834	17·9668	17·2181	16·5295	15·8937	15·3051	14·7582	14·2495	13·7746
34	20·8886	19·9391	19·0722	18·2175	17·5464	16·8716	16·2467	15·6664	15·1262	14·6220
35	22·1354	21·1292	20·2106	19·3684	18·5937	17·8786	17·2164	16·6015	16·0291	15·4948
36	23·4118	22·3539	21·3820	20·4910	19·6714	18·9148	18·2143	17·5588	16·9582	16·3929

Table of the Strength of Cast Iron Beams within the limits of Elasticity.

Depth.	Table I.—Argument.—Length in feet—Breadth or thickness 1 inch.									
	31	32	33	34	35	36	37	38	39	40
in.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.
1	0·0122	0·0118	0·0115	0·0111	0·0108	0·0105	0·0103	0·0100	0·0097	0·0094
2	0·0490	0·0474	0·0460	0·0446	0·0434	0·0422	0·0410	0·0389	0·0383	0·0379
3	0·1102	0·1067	0·1035	0·1004	0·0976	0·0948	0·0923	0·0898	0·0876	0·0853
4	0·1958	0·1897	0·1839	0·1785	0·1735	0·1686	0·1641	0·1597	0·1557	0·1517
5	0·3060	0·2964	0·2875	0·2790	0·2710	0·2635	0·2564	0·2496	0·2432	0·2371
6	0·4407	0·4269	0·4139	0·4018	0·3903	0·3794	0·3692	0·3595	0·3503	0·3415
7	0·5998	0·5810	0·5634	0·5469	0·5312	0·5164	0·5025	0·4893	0·4768	0·4648
8	0·7834	0·7589	0·7359	0 7143	0·6939	0·6746	0·6564	0·6391	0·6227	0·6071
9	0·9915	0·9605	0·9314	0·9040	0·8782	0·8538	0·8307	0·8088	0·7881	0·7684
10	1·2241	1·1858	1·1499	1·1160	1·0842	1·0540	1·0256	0·9986	0·9730	0·9486
11	1·4812	1·4348	1·3914	1·3504	1·3119	1·2754	1·2410	1·2083	1·1773	1·1479
12	1·7627	1·7076	1·6558	1·6071	1·5612	1·5178	1·4768	1·4379	1·4011	1·3660
13	2·0687	2·0040	1·9433	1·8861	1·8323	1·7813	1·7332	1·6876	1·6443	1·6032
14	2·3992	2·3242	2·2538	2·1875	2·1250	2·0659	2·0101	1·9572	1·9071	1·8594
15	2·7542	2·6681	2·5873	2·5111	2·4394	2·3716	2·3076	2·2464	2·1892	2·1345
16	3·1336	3·0357	2·9437	2·8571	2·7755	2·6984	2·6255	2·5564	2·4908	2·4285
17	3·5376	3·4270	3·3232	3·2254	3·1333	3·0457	2·9639	2·8859	2·8119	2·7416
18	3·9660	3·8420	3·7256	3·6161	3·5128	3·4151	3·3229	3·2354	3·1525	3·0736
19	4·4189	4·2808	4·1511	4·0290	3·9139	3·8051	3·7024	3·6049	3·5125	3·4246
20	4·8963	4·7433	4·5996	4·4643	4·3367	4·2162	4·1023	3·9943	3·8919	3·7946
21	5·3982	5·2294	5·0710	4·9219	4·7813	4·6484	4·5228	4·4038	4·2909	4·1836
22	5·9245	5·7393	5·5655	5·4018	5·2476	5·1016	4·9638	4·8332	4·7093	4·5915
23	6·4754	6·2730	6·0829	5·9040	5·7353	5·5760	5·4253	5·2825	5·1471	5·0184
24	7·0507	6·8303	6·6234	6·4285	6·2449	6·0714	5·9073	5·7519	5·6044	5·4643
25	7·6505	7·4114	7·1868	6·9754	6·7762	6·5879	6·4099	6·2412	6·0810	5 9291
26	8·2748	8·0161	7·7731	7·5446	7·3291	7·1254	6·9329	6·7504	6·5774	6·4129
27	8·9235	8·6446	8·3827	8·1361	7·9037	7·6841	7·4765	7·2794	7·0931	6·9157
28	9·5968	9·2968	9·0151	8·7500	8·5000	8·2638	8·0405	7·8285	7·6282	7·4375
29	10·2945	9·9727	9·6706	9·3861	9·1180	8·8647	8·6251	8·3981	8·1828	7·9782
30	11·0167	10·6724	10·3490	10·0446	9·7576	9·4866	9·2302	8·9873	8·7569	8·5379
31	11·7634	11·3957	11·0504	10·7254	10·4190	10·1296	9·8558	9·5964	9·3504	9·1166
32	12·5345	12·1428	11·7749	11·4286	11·1020	10·7936	10·5019	10·2255	9·9634	9·7143
33	13·3302	12·9136	12·5223	12·1542	11·6066	11·4788	11·1686	10·8746	10·5958	10·3309
34	14·1503	13·7081	13·2927	12·9018	12·5332	12·1850	11·8557	11·5436	11·2477	10·9665
35	14·9949	14·5263	14·0861	13·6718	13·2813	12·9123	12·5633	12·2327	11·9191	11·6211
36	15·8641	15·3682	14·9026	14·4643	14·0471	13·6607	13·2915	12·9417	12·6099	12·2946

Table of the Strength of Cast Iron Beams within the limits of Elasticity.

Depth.	TABLE I.—Argument.—Length in feet—Breadth or thickness 1 inch.									
	41	42	43	44	45	46	47	48	49	50
in.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.
1	0·0093	0·0090	0·0088	0·0086	0·0084	0·0082	0·0081	0·0079	0·0074	0·0076
2	0·0370	0·0361	0·0353	0·0345	0·0337	0·0330	0·0326	0·0316	0·0310	0·0304
3	0·0833	0·0813	0·0794	0·0776	0·0759	0·0742	0·0727	0·0711	0·0697	0·0683
4	0·1481	0·1445	0·1412	0·1379	0·1349	0·1320	0·1292	0·1264	0·1239	0·1214
5	0·2314	0·2258	0·2206	0·2156	0·2108	0·2062	0·2018	0·1976	0·1936	0·1897
6	0·3332	0·3252	0·3177	0·3104	0·3036	0·2969	0·2907	0·2846	0·2788	0·2732
7	0·4535	0·4427	0·4324	0·4225	0·4132	0·4042	0·3956	0·3873	0·3795	0·3719
8	0·5923	0·5782	0·5648	0·5519	0·5397	0·5279	0·5167	0·5059	0·4956	0·4857
9	0·7497	0·7318	0·7148	0·6985	0·6830	0·6682	0·6540	0·6278	0·6273	0·6147
10	0·9255	0·9034	0·8825	0·8624	0·8433	0·8249	0·8074	0·7905	0·7744	0·7589
11	1·1199	1·0932	1·0678	1·0435	1·0204	0·9981	0·9769	0·9565	0·9370	0·9183
12	1·3328	1·3010	1·2707	1·2418	1·2143	1·1879	1·1626	1·1383	1·1152	1·0929
13	1·5642	1·5269	1·4914	1·4574	1·4251	1·3941	1·3645	1·3360	1·3088	1·2826
14	1·8140	1·7708	1·7297	1·6903	1·6528	1·6168	1·5825	1·5994	1·5179	1·4875
15	2·0824	2·0328	1·9856	1·9404	1·8973	1·8561	1·8166	1·7787	1·7424	1·7076
16	2·3693	2·3129	2·2591	2·2078	2·1587	2·1118	2·0669	2·0238	1·9825	1·9429
17	2·6748	2·6111	2·5504	2·4924	2·4366	2·3840	2·3333	2·2846	2·2381	2·1933
18	2·9987	2·9273	2·8592	2·7942	2·7321	2·6727	2·6159	2·5613	2·5091	2·4589
19	3·3411	3·2616	3·1857	3·1133	3·0441	2·9780	2·9147	2·8538	2·7957	2·7397
20	3·7021	3·6139	3·5315	3·4496	3·3730	3·2997	3·2295	3·1622	3·0977	3·0357
21	4·0816	3·9844	3·8917	3·8032	3·7188	3·6379	3·5605	3·4863	3·4152	3·3469
22	4·4795	4·3729	4·2712	4·1741	4·0813	3·9926	3·9077	3·8262	3·7482	3·6732
23	4·8960	4·7794	4·6683	4·5622	4·4608	4·3638	4·2711	4·1820	4·0967	4·0147
24	5·3310	5·2041	5·0831	4·9675	4·8571	4·7515	4·6505	4·5535	4·4606	4·3714
25	5·7845	5·6468	5·5155	5·1401	5·2703	5·1558	5·0461	4·9409	4·8401	4·7433
26	6·2565	6·1075	5·9655	5·8298	5·7004	5·5764	5·4579	5·3441	5·2351	5·1304
27	6·7486	6·5864	6·4333	6·2870	6·1473	6·0137	5·8858	5·7631	5·6455	5·5326
28	7·2561	7·0833	6·9186	6·7613	6·6111	6·4674	6·3299	6·1979	6·0714	5·9500
29	7·7836	7·5983	7·4216	7·2529	7·0918	6·9376	6·7901	6·6485	6·5129	6·3826
30	8·3297	8·1313	7·9423	7·7617	7·5893	7·4243	7·2664	7·1149	6·9698	6·8304
31	8·8943	8·6825	8·4806	8·2878	8·1037	7·9275	7·7589	7·5971	7·4422	7·2933
32	9·4774	9·2517	9·0366	8·8311	8·6349	8·4471	8·2676	8·0952	7·9300	7·7714
33	10·0789	9·8388	9·6102	9·3917	9·1830	8·9834	8·7924	8·6090	8·4334	8·2647
34	10·6989	10·4443	10·2014	9·9695	9·7480	9·5361	9·3333	9·1387	8·9523	8·7732
35	11·3364	11·0677	10·8130	10·5646	10·3299	10·1053	9·8904	9·6842	9·4866	9·2969
36	11·9948	11·7059	11·4390	11·1769	10·9286	10·6910	10·4635	10·2455	10·0365	9·8357

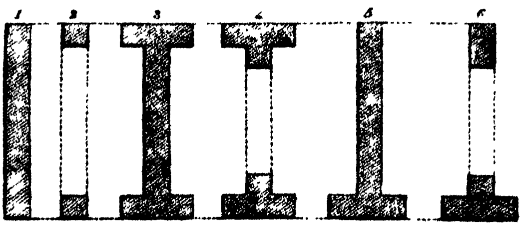
The numbers contained in Table I. are adapted to the calculation of cast iron beams of which the transverse section is a rectangle; they extend from 1 inch to 36 inches or 3 feet in depth, and from 1 foot to 50 feet in the length of bearing, the breadth of the section being constantly 1 inch. The results are estimated in tons and decimals of a ton, as being more convenient for large castings, and, in order to attain a sufficient degree of accuracy, the decimals are carried out to four places, the fourth or last place being always reckoned to the nearest unit.

It will readily appear to those who are in the least acquainted with the details of practical operations, that many of the tabulated numbers will never be applied, because the corresponding dimensions of the beams are totally inconsistent in their proportions for application to any useful purpose. Thus, for instance, all the numbers that fall below the zig-zag line on the left-hand side of the Table, at the commencement, belong to dimensions that would never be applied in practice; and those above the zig-zag line on the right-hand side of the Table, towards the end, correspond to dimensions that would render the beams incapable of sustaining even their own weight. All those numbers below and above the zig-zag lines are therefore superfluous, but we have retained them for the sake of comparison, when our inquiries happen to extend to extreme cases, and also for the purpose of preserving a full page.

The numbers, as thus arranged, are of the greatest utility in *Practical Architecture* and the various departments of *Civil Engineering;* for when the several dimensions of length, breadth, and depth are known, the strength of a beam can readily be ascertained by simple inspection, assisted occasionally by a little subsidiary calculation.

The forms of beams which are subjected to a transverse strain are very numerous, but in the general routine of practical operations, a few forms only have obtained a currency, and these, with a few slight modifications suggested by circumstances, are accordingly found to pervade almost the whole of our larger and more important constructions. The forms of section which have obtained a standing in modern practice, are those exhibited in fig. 8, and the names by which they are usually known, are as follow, viz.

Fig. 8.



No. 1. *The complete rectangular section.*

No. 2. *The open rectangular section.*

No. 3. *The complete double-flanged or* I *section.*

No. 4. *The open double-flanged or* I *section.*

No. 5. *The complete single-flanged or* T *section*, to which we have thought proper to add,

No. 6. *The open single-flanged or* T *section;* all of which we propose to calculate on the principles of the complete rectangular section alone.

For the purpose of more effectually illustrating the use of the numbers in Table I., we shall apply them to the resolution of a series of numerical examples, such as are likely to offer themselves in the practice of the *architect* and *engineer;* and if the reader carefully contemplates the manner of applying the numbers to these particular cases, he will find no difficulty in extending their application to any other case that may occur in the course of his practice.

EXAMPLE 1. A cast iron beam of the complete rectangular section, is 40 feet in length between the supports, 4 inches broad, and 30 inches deep; how much will it sustain with safety at the middle of its length, on the supposition that it is horizontal, with its extremities resting loosely on the supports?

The section which we have here proposed, is that represented by No. 1, fig. 8, and its solution is obtained from the Table in the following manner:

Look at the top of the columns for the length of bearing or distance between the supports in feet, and find the depth of the section in inches in the marginal column on the left-hand side of the page; then, under the length in feet, and opposite the depth in inches, we find 8·5379 tons, for the load that can be supported with safety, by a beam of the same length and depth of section, and only 1 inch in breadth; but the breadth of the beam in question is 4 inches, and we have shown, that *the strength increases directly as the breadth;* therefore we have

$$8{\cdot}5379 \times 4 = 34{\cdot}1516 \text{ tons,}$$

for the load with which the beam may be charged at the middle of its length, without impairing its elastic force.

It is, however, necessary to remark, that the load obtained in this way, includes the effect produced by the weight of the beam itself, a circumstance which must always be attended to in practical cases, for the omission of it may be attended with very serious consequences, especially when the weight of the beam is something considerable.

In the present instance, the weight of the beam is

$$30 \times 4 \times 40 \times 3{\cdot}2\,[1] = 15360 \text{ lbs., or } 6{\cdot}8572 \text{ tons very nearly,}$$

and the writers on mechanics have shown, that the whole weight of the beam, when considered uniform, produces the same effect in augmenting the strain, as would be produced by one-half of it if applied at the middle point; one-half the weight of the beam must therefore be deducted from the calculated strength, and the remainder will be the extraneous load with which the beam ought to be charged, in order to confine the effect of the strain within the limits of its elastic power. Now, half the weight of the beam, as we have just determined it, is 3·4286 tons; consequently, the proper extraneous load is 30·723 tons, a difference of sufficient magnitude to produce a very important effect.

Note. The formula for calculating this case, independently of Tables, has already been given at equation (A), and the practical rule for its reduction, is the same as we have there expressed it. The operation, when performed according to the rule, will be as below, viz.

$$\text{strength} = \frac{850 \times 4 \times 30^2}{40 \times 2240} = 34{\cdot}1516 \text{ tons.}$$

If the beam be loaded uniformly over the length, instead of being strained at the middle point, as we have supposed it to be in the question, then the strength will be doubled; that is, the beam will sustain twice the weight when uniformly diffused throughout the length, that it can sustain when applied at a single point equally distant from each support; and when the beam is fixed at both its extremities, and loaded uniformly over the length, it is generally estimated to sustain quadruple the central load. This, however, is in excess of what Mr. Barlow allows in similar circumstances; the results of his investigations pointing only to three times the central load, or one-half more than the load when uniformly distributed.

When the load is accumulated at any intermediate point other than the middle of the length, *the strain is proportional to the rectangle of the segments into which the point of application divides the length of bearing, and the strength*

[1] The number 3·2 which we have employed in calculating the weight of the beam, is the weight in pounds avoirdupoise of a bar of cast iron of a medium quality, 1 inch square, and 1 foot or 12 inches in length.

of the beam is inversely as the strain; hence, when the point of application is given relatively to the points of support, the rule for calculating the strength at the given point, may be expressed in words at length as follows:

RULE 2. *Calculate the strength of the beam on the supposition that the load is applied at the middle point; then multiply the load thus found, by the square of one-half the length of bearing, and divide the product by the rectangle of the given segments, for the strength required.*

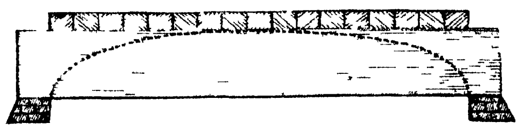
Thus, in the foregoing example, let the point at which the load is supposed to act, be 18 feet from one support and 22 feet from the other; then the operation, as implied in the above rule, is equivalent to the following proportional statement, viz.

$$22 \times 18 : 20 \times 20 :: 34{\cdot}1516 : 34{\cdot}7491 \text{ tons very nearly.}$$

It may be remarked that the difference between this and the central load is very small, being only 0·5975 of a ton, or nearly 12 cwt.; but then it must be recollected that the distance of the point of application from the middle of the beam is also very small, being only 2 feet, and the greater the distance, the greater would be the power of the beam to resist flexure or fracture. And the above rule answers for any of the six forms of section represented in fig. 8.

The preceding calculations and remarks apply to a beam of which the longitudinal outline and transverse section are rectangular; but in practice, especially when the load is uniformly diffused throughout the length, it would be advantageous to make the lower side of the beam, which is exposed to a tensile strain, a straight tie, and the upper side, which is exposed to compression, an elliptical arch; in this way the beam or girder would be equally capable of resisting the strain at every point of its length, and a great quantity of the material would be saved.

Fig. 9.

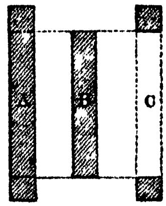


The marginal drawing, fig. 9, represents a beam or girder when loaded in the usual way, and the dotted line marks out the figure of equal strength, the extremities of the beam being so modified, as to give a proper bearing upon the walls. And these remarks are equally applicable to all the forms of section exhibited in fig. 8, and of which the calculations are given in the following pages.

EXAMPLE 2.—A cast iron beam of the open rectangular section, is 40 feet long between the supports, 4½ inches broad, and 30 inches deep; how much will it support at the middle of its length, the depth of the opening being 21 inches?

The transverse section of the beam propounded in this example, is that represented by No. 2, fig. 8, and its strength may be calculated by inspection from the following considerations, viz., that the strength of the open section C, fig. 10, is equal to the difference between the strengths of the two complete rectangular sections A and B, of equal breadth, and having the proposed depths; that is, the depth of the whole section, and the depth of the open part; the calculation is therefore reduced to that of the preceding case, and the process is as follows:

Fig. 10.



Look at the top of the columns for the length of bearing, or the distance between the supports in feet, and find each of the proposed depths in inches in the marginal column on the left-hand side of the Table; then, opposite the respective depths, and under the common length, we find for the whole depth, 8·5379 tons, and for the lesser depth, 4·1836 tons. These are the respective strengths for 1 inch in breadth; but the proposed breadth of section is 4½ inches, and *the strength is directly as the breadth;* the entire strengths of the sections A and B, considered as separate and independent beams, are therefore as follows:

For the larger section A, it is $8{\cdot}5379 \times 4\frac{1}{2} = 38{\cdot}4206$ tons nearly, and
for the lesser section B, it is $4{\cdot}1836 \times 4\frac{1}{2} = 18{\cdot}8262$ tons;

and consequently, the difference or strength of the section C, is $= 19{\cdot}5944$ tons.

In this, however, we have made no allowance for the effect of tension in the metal, which is of very great importance in a practical point of view, and is estimated in the following manner:

As the depth of the section A, *is to the depth of the section* B,
So is the strength of the section B, *as found above, to the strength to be subtracted.*

Thus we have $30 : 21 :: 18{\cdot}8262 : 13{\cdot}1784$ tons very nearly, which is the strength of the metal in B when forming a part of A, and consequently, is the quantity by which the strength of A must be diminished, to obtain the correct strength of the ultimate section C; hence we get $38{\cdot}4206 - 13{\cdot}1784 = 25{\cdot}2422$ tons for the correct strength, being $5{\cdot}6478$ tons more than the strength as obtained above.

We believe the effect of tension was first noticed by Dr. Thomas Young, and the correct mode of solution was first pointed out in his 'Elements of Natural Philosophy;' we may therefore infer, that before his very accurate and comprehensive mind was directed to the subject, the process of calculation was but very imperfectly understood. The equation which represents the strength of a beam of this form, is

$$\text{strength} = \frac{850 \times \text{breadth} \times (\text{greater depth}^3 - \text{lesser depth}^3)}{\text{greater depth} \times \text{length}}; \qquad \text{(B)}$$

and the rule for its reduction, when expressed in words at length, is as follows:

RULE 3.—*From the cube of the greater depth, subtract the cube of the lesser depth or opening; multiply the difference by 850 times the breadth, and divide the product by the greater depth drawn into the length, for the load in pounds avoirdupoise that the beam will bear with safety when applied at its middle point.*

Therefore, by using the data of the example, and proceeding according to the directions given in the rule, we shall have

$$\text{strength} = \frac{850 \times 4\tfrac{1}{2}\ (30^3 - 21^3)}{40 \times 30 \times 2240} = 25{\cdot}2422 \text{ tons.}$$

In the solution of this example, as given above, we have taken no notice of the effect produced by the weight of the beam, and under Example 1, we have stated that the effect thus produced, must always be allowed for in practical cases, otherwise the beam may be found deficient in strength. The weight of the beam is calculated thus:

$$(30 - 21) \times 4\tfrac{1}{2} \times 40 \times 3{\cdot}2 = 5184 \text{ lbs., or } 2{\cdot}3142 \text{ tons;}$$

and we have already intimated, that the effect produced by the whole weight, is the same as would be produced by one-half of it applied at the middle point; the total extraneous load with which the beam ought to be charged, is therefore $25{\cdot}2422 - 1{\cdot}1571 = 24{\cdot}0851$ tons, and if the load were uniformly diffused throughout the length of bearing, the beam would sustain twice as much, or 48·1702 tons, and if fixed at the extremities, the load would admit of another duplication. And furthermore, with respect to the form of equal strength, what we have said in reference to the beam of the complete rectangular form, is equally applicable here, and when the load is applied

40 feet between the bearings, we get 8·5379 and 4·1836 tons respectively, the same as before; but the breadth of the one section in this case is $4\frac{1}{2}$ inches, while that of the other is $2\frac{13}{16}$ inches; hence we have $8{\cdot}5379 \times 4\frac{1}{2} = 38{\cdot}4206$ tons, and $4{\cdot}1836 \times 2\frac{13}{16} = 11{\cdot}7663$ tons, and when reduced for the effect of tension, the latter strength becomes 8·2364 tons; therefore by subtraction we get $38{\cdot}4206 - 8{\cdot}2364 = 30{\cdot}184$ tons, the same as before.

The equation which expresses the central transverse strength for this case, as deduced from the above considerations, is as follows:

$$\text{Strength} = \frac{850\ (\text{whole breadth} \times \text{whole depth}^3 - \text{breadth of flanges} \times \text{middle depth}^3)}{\text{whole depth} \times \text{length}}. \quad \text{(C)}$$

And the rule which this equation supplies, when expressed in words at length, may be read as follows:

RULE 4.—*Multiply the cube of the whole depth by the whole breadth, and the cube of the depth between the flanges by the breadth of both flanges taken together; subtract the latter of these results from the former, and divide 850 times the remainder by the whole depth drawn into the length of bearing, and the quotient will express the central strength.*

Therefore, by using the data of the example, the strength as calculated by this rule will be as under.

$$30 \times 30 \times 30 \times 4\tfrac{1}{2} = 27000 \times 4\tfrac{1}{2} = 121500$$
$$21 \times 21 \times 21 \times 2\tfrac{13}{16} = 9261 \times 2\tfrac{13}{16} = 26046{\cdot}5625 \text{ subtract}$$
$$95453{\cdot}4375 = \text{remainder;}$$

therefore, by multiplication and division, we obtain

$$\text{strength} = \frac{95453{\cdot}4375 \times 850}{30 \times 40} = 67612{\cdot}8515 \text{ lbs., or } 30{\cdot}184 \text{ tons,}$$

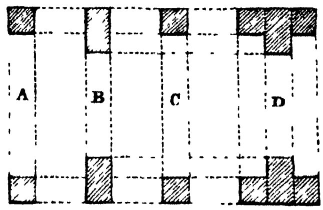
the same as we found it to be by the Table.

We may here remark, that the formula for this case, as it is generally represented by the writers on the strength of materials, is very complicated, and but rarely understood by practical men; but it is presumed, that in the form which it assumes above, its import may be more easily comprehended, and it is manifest from the process which we have just exhibited, that its application is as simple as can be wished for. With respect to the form of equal strength, and the effect of the load when applied at some intermediate point, the remarks already made are equally applicable here.

EXAMPLE 4.—A cast iron beam of the open I or double-flanged section, is 40 feet in length within the bearings, the whole breadth being $4\frac{1}{2}$ inches, and the breadth of the middle part $1\frac{11}{16}$ inches; how much will it bear with safety at the middle of its length, the whole depth being 30 inches, the depth between the flanges 21 inches, and the depth of the opening 14 inches?

In the preceding example for the complete I form, we have supposed the section to be composed of two open and one complete rectangular section, the two open sections being equal between themselves, as represented by fig. 11; and we have also shown that it is deducible from three complete rectangular sections, as exhibited in fig. 13. So, in like manner, we may suppose the open double-flanged or I section, to be constituted of three open rectangular sections, as shown in fig. 13, where it is obvious, that two of the sections are equal and similar in every respect. Consequently, the strength of the section D must be equal to the sum of the strengths of the three sections A, B, and C, determined in the same manner as we have already illustrated for the open rectangular section in fig. 10, Example 2. The process of calculation is therefore as follows, viz.:

Fig. 13.



Look in the Table for the length of bearing at the top of the columns, and find the several depths in the marginal column on the left-hand side of the page; then, under the common length, and opposite the respective depths, we have 8·5379, 4·1836, and 1·8594 tons, for the several strengths at 1 inch thick. But the breadth of the two equal sections A and C together, is $2\frac{13}{16}$ inches, and the breadth of the section B, considered individually, is $1\frac{11}{16}$ inches. Therefore, in order to correct the two lesser strengths for the effects of tension, we have

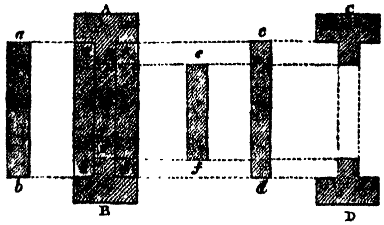
$$30 : 21 :: 4{\cdot}1836 : 2{\cdot}9285; \text{ and } 30 : 14 :: 1{\cdot}8594 : 0{\cdot}8677.$$

Consequently, by subtracting and multiplying by the appropriate breadths or thicknesses, we obtain for the strength of A and C together $(8{\cdot}5379 - 2{\cdot}9285) \times 2\frac{13}{16} = 15{\cdot}7764$ tons, and $(8{\cdot}5379 - 0{\cdot}8677) \times 1\frac{11}{16} = 12{\cdot}9434$ tons, and the sum of the two gives $15{\cdot}7764 + 12{\cdot}9434 = 28{\cdot}7198$ tons for the strength of the beam, including the effect of its own weight. Now the weight of the beam is $\{(30-21) \times 4\frac{1}{2} + (21-14) \times 1\frac{11}{16}\} \times 40 \times 3{\cdot}2 = 6696$ lbs., or 2·9892 tons; therefore, the effect produced by the weight of the beam is equivalent to 1·4946 tons applied at the middle of its length; hence, the greatest extraneous load with which it ought to be charged is $28{\cdot}7198 - 1{\cdot}4946 = 27{\cdot}2252$ tons;

but if the load be uniformly diffused over the length, it will support twice this quantity, or 54·4504 tons, and, if fixed at the extremities, it will support 108·9008 tons.

Another method of resolving this problem may be deduced from the consideration of four complete rectangular sections, as shown in fig. 14, viz., the whole section A B, the two equal sections *a b*, *c d*, and the smaller section *e f*. Calculating each of these by the rule for the complete rectangular section, and correcting *a b*, *c d*, and *e f* for the effect of tension; then the sum of the strengths of *a b*, *c d*, and *e f*, as thus corrected, being subtracted from the strength of the entire section A B, will manifestly leave the strength of the open I or double-flanged section C D. The calculation is as follows:

Fig. 14.



Look in the Table, under 40 feet at the top of the page, and opposite 30 inches in the left-hand column, and we find 8·5379 tons, for the strength of a beam whose breadth is 1 inch; but the whole breadth of the section A B, according to the question, is $4\frac{1}{2}$ inches; hence we have $8{\cdot}5379 \times 4\frac{1}{2} = 38{\cdot}4206$ tons for the strength of the section A B considered as entire.

Again, under 40 feet at the top of the page, and opposite the depths of 21 and 14 inches, being the depths of the sections *a b*, *c d*, which are equal, and of the section *e f*, we find 4·1836 and 1·8594 tons respectively for the strengths corresponding to the given depths, each 1 inch in breadth. But the breadth of the two equal sections when taken together is $2\frac{13}{16}$, and that of the lesser section *e f* is $1\frac{11}{16}$, and consequently, when these sections are modified for the effect of tension, the strengths become respectively 2·9285 and 0·8677 tons, which, being taken from the strength of the whole section A B, we have $38{\cdot}4206 - (2{\cdot}9285 \times 2\frac{13}{16} + 0{\cdot}8677 \times 1\frac{11}{16}) = 28{\cdot}7198$ tons, the same as before, including the effect produced by the weight of the beam. The formula for calculating the strength independently of the Table, when expressed in specific terms, is as follows, viz.:

$$\text{ntral strength} = \frac{850\,(\text{whole breadth} \times \text{whole depth}^3 - \text{breadth of flanges} \times \text{depth}^3 \text{ between flanges} - \text{breadth of opening} \times \text{depth}^3 \text{ of opening})}{\text{whole depth} \times \text{length}}. \text{ (D}$$

The rule which this equation supplies when adapted to practical operations, may be expressed in words at length in the following manner:

RULE 5.—*Cube the whole depth, the depth between the flanges and the depth of the opening; multiply each by its corresponding breadth; then, from the cube of the whole depth drawn into the whole breadth, subtract the sum of the other two depths drawn into their respective breadths, and multiply the remainder by 850; then divide the product by the whole depth drawn into the length, and the quotient will express the central strength of the beam.*

By using the data in the example according to the directions here given, the process of calculation will be as exhibited below:

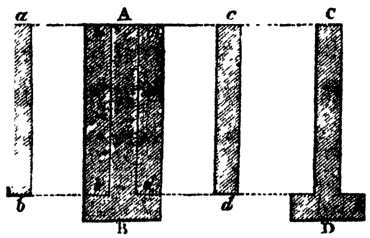
$$\{30 \times 30 \times 30 \times 4\tfrac{1}{2} - (21 \times 21 \times 21 \times 2\tfrac{13}{16} + 14 \times 14 \times 14 \times 1\tfrac{11}{16})\} \times 850 = 77199496{\cdot}875,$$

and the product of the length into the whole depth is $40 \times 30 = 1200$: therefore, by division, we have $77199496{\cdot}875 \div 1200 = 64332{\cdot}91406$ lbs., which being again divided by 2240, the number of pounds in 1 ton, we have 28·72 very nearly, for the load in tons, including the effect produced by the weight of the beam.

EXAMPLE 5.—A cast iron beam of the single-flanged or T section, is 40 feet in length between the points of bearing, the whole breadth being $4\frac{1}{2}$ inches, and the breadth of the lesser part $1\frac{1}{8}$ inches; how much will it bear with safety when applied at the middle of its length, the whole depth being 30 inches, and the depth from the flange to the upper side of the beam 28 inches?

The section which forms the subject of this example is represented by C D, fig. 15. We may conceive it to be formed by subtracting the two rectangles *a b* and *c d*, which are equal between themselves, from the rectangle A B which circumscribes the section, or that which is constructed upon the entire breadth and depth; and the method of determining its strength, is to subtract the strengths of *a b* and *c d*, when corrected for the effects of tension, from the strength of A B, considered as a complete section. It is, however, necessary to remark, that the effect of tension is not precisely the same in this as in the preceding cases, by reason of the neutral axis being differently posited; but, nevertheless, it is calculated in a somewhat similar manner, with this difference only, that in the single-flanged section, the quantity of reduction must be considered to amount to one-half of its value as derived from the proportion of the depth

Fig. 15.



of section. This allowance, although only approximative, will give the strength sufficiently near for every practical purpose, and it has the advantage of bringing the computation within the scope of the rectangular Table. The process of calculation is as follows:

Under the given length of bearing at the top of the page, and opposite to the given depths of 30 and 28 inches in the marginal column, we have 8·5379 and 7·4375 tons, for the strengths of two rectangular sections 1 inch broad, and of the respective depths of 30 and 28 inches. But the whole breadth of the section is $4\frac{1}{2}$ inches, and the breadth of *a b* and *c d* taken together is $3\frac{3}{8}$ inches; hence we have $8·5379 \times 4·5 = 38·4206$ tons for the strength of the entire section A B, and $7·4375 \times 3·375 = 25·1016$ tons for the strength of *a b* and *c d*, considered as one separate and independent section; therefore, by the law of tension, we have, 30 : 28 : : 25·1016 : 23·4282 tons; hence it is $38·4206 - \{23·4282 + \frac{1}{2}(25·1016 - 23·4282)\} = 14·1557$ tons, for the central strength of the section C D, including the weight of the beam.

But the weight of the beam, determined as in the preceding cases, is $(4·5 \times 2 + 28 \times 1\frac{1}{8}) \times 40 \times 3·2 = 5184$ lbs., or 2·3142 tons, and the half of this is 1·1571 tons; which, being taken from the above result, gives $14·1557 - 1·1571 = 12·9986$ tons for the extraneous load; and if this be doubled, it will express the load which the beam will bear when uniformly diffused throughout the length, or that which it will bear at the middle point, on the supposition that the extremities are firmly fixed in the wall. Or, if uniformly loaded and fixed at the extremities, it will bear 51·9944 tons.

The equation for calculating the strength of this section independently of Tables, is very complicated, and difficult to express in a specific form; it may, however, be represented approximately as follows, viz.:

$$\text{Strength} = \frac{850 \times (\text{twice whole breadth} \times \text{whole depth}^3 - \text{breadth of flange} \times \text{less depth}^2 \times \text{sum of greater and less depth})}{\text{twice whole depth} \times \text{length}}. \quad ($$

And the rule for reducing this equation, may be expressed in words at length in the following manner:

Rule 6.—*Add into one sum the whole depth of the section, and the depth of the narrow part or distance between the flange and upper side of the beam; then multiply the sum by the square of this distance drawn into the breadth of the flanges, and reserve the product. Multiply the cube or third power of the whole depth of the section by twice its greatest breadth, and from this latter product subtract the former and multiply the re-*

mainder by the general constant 850; *then, divide this last product by twice the whole depth of the section drawn into the length of bearing, and the quotient will express the strength of the beam in pounds avoirdupoise very nearly, the degree of accuracy thus obtained being quite sufficient for every practical purpose.*

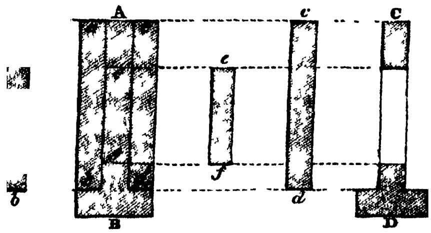
The calculation, when performed according to the directions contained in this rule, may be represented as below, viz.:

$(30+28) \times 28^2 \times 3\frac{3}{8} = 153468$; and $30^3 \times 4\frac{1}{2} \times 2 = 243000$; therefore, by the rule, it is $243000 - 153468 = 89532$, which being multiplied by 850, gives $89532 \times 850 = 76102200$, and, finally, by division, we have 76102200 — 2400 = 31709 lbs. very nearly, or 14·1557 tons, the same as before. The strength calculated in this way will generally err in excess, but the filling up of the angles in the casting will compensate for the excess.

If greater accuracy be required than that which is obtained by the above process, we would advise that the arithmetical mean between the strength as calculated above, and that found in the usual way, be taken; the result will then be a very close approximation to the true value, and all the other particulars may be deduced from it, as in the preceding cases.

Example 6.—A cast iron beam of the open single-flanged or T section, is 40 feet long between the points of bearing, the whole breadth being $4\frac{1}{2}$ inches, and the breadth of the narrow part $1\frac{1}{8}$ inches; how much will it support with safety at the middle of its length, the whole depth being 30 inches, the depth of the narrow part 28 inches, and the depth of the opening 20 inches?

Fig. 16.



The section which we have here described is that represented by C D, fig. 16. It is formed by deducting the sections *a b*, *c d*, and *e f*, from the section A B, constructed on the whole breadth and depth; and the strength may be calculated by taking the difference between the strength of the entire section A B, and the strengths of *a b*, *c d*, and *e f*, when corrected for the effect of tension; that effect, as referred to the sections *a b* and *c d*, being determined as in the last example, and the effect in reference to the section *e f*, as in all the foregoing cases.

In the above example the whole breadth of the section is $4\frac{1}{2}$, the breadth of the flanges $3\frac{3}{8}$, and that of the opening $1\frac{1}{8}$ inches, respectively; the corresponding depths being 30, 28, and 20 inches. Therefore, in the Table, under the common length of 40 feet, at the top of the page, and opposite 30, 28, and 20 inches, in the marginal column, we find 8·5379, 7·4375, and 3·7946 tons, for the strengths corresponding to 1 inch in breadth. Let these be respectively multiplied by the breadths as given in the question, and we get $8{\cdot}5379 \times 4\frac{1}{2} = 38{\cdot}4206$; $7{\cdot}4375 \times 3\frac{3}{8} = 25{\cdot}1016$, and $3{\cdot}7946 \times 1\frac{1}{8} = 4{\cdot}269$ tons, for the respective strengths, when considered as separate and independent sections; and when corrected for the effect of tension, the strengths of *a b*, *c d*, together, and of *e f*, considered by itself, become 24·2649 and 2·846 tons, and the sum of these being subtracted from the strength of the entire section, gives $38{\cdot}4206 - 27{\cdot}1109 = 11{\cdot}3087$ tons for the strength of the beam according to the conditions of the question.

The equation for calculating the strength of a beam of this form of section is still more complicated than that for the case immediately preceding, because it involves another term depending upon the breadth and depth of the opening. The equation in a specific form may be expressed approximatively as follows, viz.:

$$\text{strength} = \frac{850\ (\text{twice whole breadth} \times \text{whole depth}^3 - \text{breadth of flange} \times \text{less depth}^2 \times \text{sum of greater and less depth} - \text{twice breadth of opening} \times \text{depth}^3 \text{ of opening})}{\text{twice whole depth} \times \text{length}}.$$

And when this equation is translated into a rule in words at length, it may be read in the following manner:

RULE 7.—*Add into one sum the whole depth of the section and the depth of the narrow part, or the distance between the flange and the upper side of the beam; then, multiply the sum by the square of this distance drawn into the breadth of the flanges, and reserve the product.*

Again:—Multiply twice the breadth of the opening by the cube of its depth, and add the product to that obtained by the preceding process; then, subtract the sum from twice the whole breadth of the section drawn into the cube of its whole depth; multiply the remainder by 850, *and divide the product by twice the whole depth of the section drawn into the length of the beam, and the quotient will express the central strength within the limits of safety in pounds avoirdupoise.*

Taking the data as proposed in the example, the calculation, when performed according to the rule, will stand as below, viz.:

$(30+28) \times 28^2 \times 3\frac{3}{8} = 153468$; $20^3 \times 1\frac{1}{8} \times 2 = 18000$, and $30^3 \times 4\frac{1}{2} \times 2$

$= 243000$; then, from this last product subtract the sum of the other two, and we obtain $243000 - 153468 - 18000 = 71532$; therefore we get $71532 \times 850 \div 2 \times 30 \times 40 = 25334$ lbs., or 11·3087 tons, the same as before.

Now, the weight of the beam is $18 \times 40 \times 3{\cdot}2 = 2304$ lbs., or 1·0286 tons, the half of which is 0·5143; and, consequently, the greatest extraneous load that the beam can bear at the middle of its length, is $11{\cdot}3087 - 0{\cdot}5143 = 10{\cdot}7944$ tons. But when the beam is fixed at both its ends, or when merely supported and loaded uniformly over the length, it will, in both cases, bear a load of 21·5888 tons; and when fixed at both ends, and uniformly loaded, it will bear 43·1776 tons with safety.

In all the preceding sections, with the exception of the first, or the complete rectangular form, it is customary in practice, to construct the several parts in such a manner, as to bear a certain relation among themselves, by which means they are rendered more suitable for their intended purposes; and if those proportions were universally adhered to, we might have a separate Table for each particular form of section, which would very much facilitate the process of calculation; but even then, they may all be calculated by the rectangular Table, as we shall show a little further on.

The proportions here alluded to, and which have been found the most convenient in practice, are as follows, viz.: In the open rectangular section, No. 2, fig. 8, the depth of the opening should be seven-tenths of the whole depth, while the breadth of the section ought to be three-twentieths of its depth; these proportions render the solid parts on the upper and lower side of the section squares, which are equal between themselves; and with these proportions, the general formula (B) becomes transformed into that which follows, viz.:

$$\text{Central strength} = \frac{558 \times \text{breadth} \times \text{depth}^2}{\text{length}} = \frac{84 \times \text{depth}^3}{\text{length}}. \qquad \text{(G)}$$

Again, in the complete I section, the proportions are as follows, viz.: the breadth of the flanges is five-eighths of the whole breadth, and the distance between the flanges is seven-tenths of the whole depth; and, by adopting these proportions, the general formula (C) becomes,

$$\text{Central strength} = \frac{668 \times \text{breadth} \times \text{depth}^2}{\text{length}}. \qquad \text{(H)}$$

In the open I section, the proportions for the constant or solid part are the same as above; and, in addition, the depth of the opening is seven-tenths of the distance between the flanges, or forty-nine hundredth parts of the whole depth; therefore, by adopting these proportions, the general formula (D) becomes,

$$\text{Central strength} = \frac{630 \times \text{breadth} \times \text{depth}^2}{\text{length}}. \qquad \text{(I)}$$

In the complete single-flanged or T section, the proportions are such, that the depth of the narrow part is 828 thousandth parts of the whole depth, and its breadth one-fourth of the whole breadth; therefore, by adopting these proportions, the strength of the complete T section, is to the strength of its circumscribing rectangular section, as 1000 to 2326, or as 5 to 11·63 very nearly; hence we get

$$\text{Central strength} = \frac{365 \times \text{breadth} \times \text{depth}^2}{\text{length}}. \qquad \text{(K)}$$

In the open single-flanged or T section, the proportions for the constant or solid parts are the same as in the last case; but the depth of the opening is made two-thirds of the depth of the narrow part; consequently, if the equation (K) be diminished by the strength of the opening when corrected for the effect of tension, we obtain

$$\text{Central strength} = \frac{302 \times \text{breadth} \times \text{depth}^2}{\text{length}}. \qquad \text{(L)}$$

Admitting, therefore, that the proportions as specified for each of the above forms of section are the best that can be chosen, we see no reason why they should not be universally adopted in the construction of cast iron beams; and if this were to be the case, each equation might have a corresponding set of tabular numbers adapted to its appropriate constant, so that the strength, as well as the dimensions of each section, might be found by simple inspection; but since the computation of a separate set of tabular numbers for each constant would prove a very irksome and laborious task, we shall endeavour to avoid it, by deducing every particular from the use of the rectangular Table only.

Since the preceding particular equations are all of one form, differing only in the constant coefficients, and because 850 is the constant for the complete rectangular section; it follows, that the strength of any other of the sections that we have considered above, will be to the strength of its circumscribing rectangular section, in the same proportion as its appropriate constant is to 850; consequently, if each of the foregoing constants be divided by 850, the quotients will be the fractions by which the strength of the complete rectangular section, as found by the Table, must be multiplied to obtain the strength of the particular section under consideration. Thus we have

For the open rectangular section	558 ÷ 850 = 0·657 the fractional multiplier.[2]		
For the complete double-flanged or I section . .	668 ÷ 850 = 0·785625, or practically		0·7856
For the open double-flanged or I section . . .	630 ÷ 850 = 0·741506625	do.	0·7415
For the complete single-flanged or T section . .	365 ÷ 850 = 0·4298646	do.	0·4299
For the open single-flanged or T section . . .	302 ÷ 850 = 0·355791	do.	0·3558

The fractions which we have here obtained are of the greatest use in practice, and we earnestly advise our readers to render themselves familiar with their application, for by so doing, there will be no occasion to have recourse to the formulæ, unless in cases where the greatest accuracy is required; the rectangular Table alone being sufficient for all common purposes, as will appear from the following examples.

EXAMPLE 7.—A cast iron beam of the open rectangular section, is 40 feet long between the points of support, 4½ inches broad, and 30 inches deep; how much will it bear with safety at the middle of its length, the depth of the opening being 21 inches?

The data of this example are precisely the same as those in Example 2, the dimensions being in the exact proportion employed in forming equation (G), which is applicable to the solution of this example; but we propose to resolve it by having recourse to the Table as follows:

Look in the Table for 40 feet, the given length of bearing, at the top of the page, and for 30 inches, the given depth, in the left-hand column; then, under the one and opposite the other in the body of the page, we find 8·5379 tons for the strength of a solid rectangular beam 1 inch in breadth; but the breadth of the beam as proposed in the question is 4½ inches; hence we have 8·5379 × 4½ = 38·4206 tons for the strength of the circumscribing complete rectangular section. Consequently, multiplying by the fraction 0·657, we get 38·4206 × 0·657 = 25·2422 tons for the strength of the beam proposed, being precisely the same as was obtained by the resolution of the second example.

[2] The fractions here exhibited are not precisely what would arise from the respective divisions by which they are represented; but they are such as belong to the proportions that we have adopted, and ought therefore to be employed in practical operations; at least, in cases where a considerable degree of accuracy is a matter of importance.

Note.—To ascertain if any proposed beam of this form of section be constructed according to the specified proportions, it is only necessary to observe, that three times the whole depth divided by twenty, must be equal to the given breadth, and the depth of the opening divided by the whole depth, must be equal to the fraction ·7; and these are precisely the conditions which are satisfied in the above example. The practical rule for reducing the particular equation independently of Tables, may be expressed in words at length in the following manner:

RULE 8.—*Multiply* 558 *times the breadth of the section in inches by the square of the whole depth in inches, and divide the product by* 2240 *times the length of bearing in feet, for the load in tons.*

And the process of calculation is thus performed; $558 \times 4\frac{1}{2} \times 30^2 \div 2240 \times 40 = 2259900 \div 89600 = 25{\cdot}2221$ tons very nearly; differing from the tabular result by the small fraction 0·0201 of a ton, a difference which arises from having taken the constant coefficient 558 to the nearest unit, as being sufficiently accurate for every practical purpose; and we may further add, that the same plan has been adopted in the formation of all the other constants, which will account for the small differences that may show themselves in the results, as obtained from the Table and by calculation. This being understood, the observations need not be repeated in the following cases.

With respect to the effect produced by the weight of the beam, the uniform load, and fixing at the extremities, enough has already been said on these points to show how they are to be allowed for in all similar cases; and consequently, these several particulars will not in future be taken notice of in any of our calculations. We therefore proceed with the solution of the remaining cases.

EXAMPLE 8.—A cast iron beam of the double-flanged or complete I section, is 40 feet in length between the supports, $4\frac{1}{2}$ inches broad, and 30 inches deep; how much will it bear at the middle of its length, the depth between the flanges being 21 inches, and their breadth $2\frac{13}{16}$ inches?

The question, as here proposed, is manifestly the same as Example 3; but we have first to examine, if the dimensions of the parts bear to each other the proportions specified in the formation of equation (H); and for this purpose, we must divide the middle depth or distance between the flanges by the whole depth, and also the breadth of the flanges by the whole breadth; then, if the quotients come out 0·7 and 0·625 respectively, we may conclude that the dimensions are just, and therefore the results derived from them may be considered as correct.

Now $21 \div 30 = 0{\cdot}7$, and $2{\cdot}8125 \div 4{\cdot}5 = 0{\cdot}625$; hence we infer that the requisite proportions obtain amongst the parts, and the method of calculation is therefore as follows:

Look in the Table for 40 feet at the top of the page, and 30 inches, the whole depth, in the left-hand column; then, under the former and opposite the latter in the body of the page, we find 8·5379 tons for the strength of a beam of 1 inch in thickness or breadth, of which the length is 40 feet and depth 30 inches. But the breadth in the present instance is $4\frac{1}{2}$ inches; therefore we have $8{\cdot}5379 \times 4\frac{1}{2} = 38{\cdot}4206$ tons for the strength of the circumscribing rectangular beam; consequently, if we multiply by the appropriate fraction for this particular section, we obtain

$$38{\cdot}4206 \times 0{\cdot}7856 = 30{\cdot}184 \text{ tons.}$$

The practical rule for reducing equation (H) independently of Tables, may be expressed in words at length as follows:

RULE 9.—*Multiply* 668 *times the whole breadth in inches by the square of the whole depth in inches, and divide the product by* 2240 *times the length of bearing in feet, for the load in tons.*

EXAMPLE 9.—A cast iron beam of the double-flanged or open I section, is 40 feet in length between the points of support, $4\frac{1}{2}$ inches broad, and 30 inches deep; how much will it bear with safety at the middle of its length, the distance between the flanges being 21 inches, the breadth of flanges $2\frac{13}{16}$ inches, the depth of the opening 14·7 inches, and its breadth $1\frac{11}{16}$ inches?

To try if the parts of the section are here in the proper proportion, we must divide the distance between the flanges and the depth of the opening, respectively, by the whole depth of the section, and if the quotients come out 0·7 and 0·49, the proportions are just as regards the vertical dimensions. And, moreover, if the breadth of the flanges be divided by the whole breadth of the section, and the quotient come out 0·625, the conditions are also satisfied in respect of the lateral dimensions, and the method of solution is therefore as follows:

Look in the Table for the given length of bearing at the top of the page, and the whole breadth of the section in the left-hand column; then, under the one and opposite the other, we get 8·5379 tons for the strength of a rectangular beam 1 inch broad, 30 inches deep, and 40 feet in length. But the given breadth is $4\frac{1}{2}$ inches; therefore we have $8{\cdot}5379 \times 4\frac{1}{2} = 38{\cdot}4206$ tons for the strength of the circumscribing rectangular beam; consequently, if we multiply by the appropriate fraction for this particular section, the strength of the beam in question becomes

$$38 \cdot 4206 \times 0 \cdot 7415 = 28 \cdot 489 \text{ tons.}$$

The practical rule for reducing equation (I) independently of Tables, may be expressed in words at length as follows:

RULE 10.—*Multiply* 630 *times the whole breadth of the section in inches by the square of the whole depth in inches, and divide the product by* 2240 *times the length of bearing in feet, for the load in tons.*

EXAMPLE 10.—A cast iron beam of the complete single-flanged or T section, is 40 feet in length between the supports, 4½ inches broad, and 30 inches deep; how much will it support at the middle of its length within the limits of safety, the depth of the middle part being 24·84 inches, and its breadth 1⅛ inches?

The proportional quotients in this example are respectively 0·828 and 0·75, so that the sectional dimensions are correct as proposed in the question, for $24 \cdot 84 \div 30 = 0 \cdot 828$, and $3 \cdot 375 \div 4 \cdot 5 = 0 \cdot 75$; the method of solution is therefore as follows:

In the Table, under 40 feet, the length of the beam, at the top of the page, and opposite 30 inches, the whole depth of the section, in the left-hand column, we have 8·5379 tons for a beam 1 inch broad; but the breadth is 4½ inches; therefore, the strength of the circumscribing rectangular beam is $8 \cdot 5379 \times 4\frac{1}{2} = 38 \cdot 4206$ tons; consequently, if we multiply by the appropriate fraction for this particular section, the strength of the beam becomes

$$38 \cdot 4206 \times 0 \cdot 4299 = 16 \cdot 5155 \text{ tons.}$$

The practical rule for reducing equation (K) independently of Tables, may be expressed in words at length as follows:

RULE 11.—*Multiply* 365 *times the whole breadth of the section in inches by the square of the whole depth in inches, and divide the product by* 2240 *times the length of bearing in feet, for the load in tons.*

EXAMPLE 11.—A cast iron beam of the open single-flanged or T section, is 40 feet in length between the points of support, 4½ inches broad, and 30 inches deep; how much will it support with safety at the middle of its length, on the supposition that the parts of the section bear to each other the relation stated in the formation of equation (L)?

In the Table, under the given length at the top of the page, and opposite the given depth in the left-hand column, we find a load of 8·5379 tons for the strength of a rectangular beam 1 inch broad; but the breadth of the beam whose strength is here required is $4\frac{1}{2}$ inches, and the strength increases directly as the breadth; hence we get $8{\cdot}5379 \times 4\frac{1}{2} = 38{\cdot}4206$ tons for the central strength of the circumscribing rectangular beam; and if this be multiplied by the appropriate fraction for the beam under consideration, we obtain $38{\cdot}4206 \times 0{\cdot}3558 = 13{\cdot}6696$ tons, the load required.

The rule for reducing equation (L) independently of Tables, may be expressed in words at length in the following manner:

Rule 12.—*Multiply* 302 *times the whole breadth of the section in inches by the square of the depth in inches, and divide the product by* 2240 *times the length, for the load in tons.*

In concluding this part of our subject, it may be proper to remark, that since the equations (A), (G), (H), (I), (K), and (L), are all of the same form with the exception of the constant numbers or coefficients, it follows that they can all be expressed by the following very simple and general rule:

Rule 13.—*Multiply the breadth of the section in inches by the square of the depth in inches, and again by the constant number adapted to the particular case, and divide the product by* 2240 *times the length of bearing in feet, for the load to be supported in tons.*

Admitting the foregoing formulæ to be generally adopted in practice, the most important inquiry to which they can be applied is that which has reference to the construction of beams that shall be competent to sustain a given load. If the problem requires that the depth of the section be found, when the length of the beam and the greatest breadth of section, together with the load to be sustained, are known, the solution requires the extraction of the square root: the process, however, is unnecessary when the Table is employed.

The following rules, expressed in words at length, will apply to the two cases of the problem; that is, when the length of the beam, the depth of the section, and the load are given, to find the breadth, and when the length, the load, and the breadth of section are given, to find the depth.

First case. When the load, the length of the beam, and the depth of the section are given, to find the breadth.

Rule 14.—*Multiply the load, when reduced to pounds avoirdupoise, by the length of the beam in feet, and divide the product by the square of the depth in inches, drawn into the constant coefficient peculiar to the form of* *section under consideration, and the quotient will be the greatest breadth of the section in inches, which must be reduced according to the specified proportions, in order to obtain the required form of section.*

Second case. When the load, the length of the beam, and the greatest breadth of the section are given, to find the depth.

RULE 15.—*Multiply the given load, when reduced to pounds avoirdupoise, by the length of the beam in feet, and divide the product by the breadth of the section drawn into the appropriate constant; then the square root of the quotient will give the greatest depth of the section, which must be reduced according to the specified proportions to obtain the required form.*

Since these rules are alike applicable to each of the forms of section which we have already illustrated, we shall apply them to a single example for each case, which, being the same for each of the sections, will show the advantages or disadvantages to be derived from their adoption.

EXAMPLE 13.—In the floor of a certain building which is 60 feet long and 32 feet broad, there are fifteen cast iron joists or girders, all of them 15 inches in the depth of section; what must be the breadth of each beam to support a load of 720 tons when uniformly distributed over the surface of the floor, the ends of the beams being merely placed into openings in the walls, and not fixed there to give them the advantage of double strength?

Since the load is uniformly distributed over the floor, we have $720 \div 15 = 48$ tons for the uniform load on each of the beams, and this is equivalent to 24 tons, or 53,760 lbs. applied at the middle of the length; and we may here observe, that in all practical cases it is convenient to consider the load as being concentrated in that point, because in that case it corresponds to the conditions upon the existence of which the numbers in the Table have been computed.

Look in the Table under 32 feet, at the top of the page, and opposite 15 inches in the left-hand column, and we get 2·6681 tons for the central strength of a beam of the same length and depth, and 1 inch broad; therefore, if the given load in tons be divided by this tabular number, we shall have $24 \div 2{\cdot}6681 = 8{\cdot}995$ inches, the required breadth.

If the second form of equation (G) be employed, a depth will be found such as shall be competent to sustain the given load, while at the same time, the parts of the section will have the specified proportions; but it is not proper to perform the process in this place, as the depth is given by the question, and consequently, its value as found by the calculation is inadmissible.

For the open rectangular section the process will be as follows:

Look in the Table under the given length of bearing, at the top of the page, and opposite the given depth of section, in the left-hand column, and we get 2·6681 tons for the central strength of a beam of the complete rectangular section 1 inch broad. The total breadth would therefore be 8·995 inches, the same as in the last case; but, by reason of the form of section, this result must be increased in the proportion of the fraction 0·657 to unity; that is,

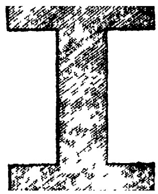
0·657 : 1 :: 8·995 : 13·691 inches.

For the complete I or double-flanged section, the process is as follows:

Take out the quantity corresponding to the given length and depth, and let this be reduced in the proportion of unity to the fraction 0·7856, which is the constant adapted to this form of section; then, the given load in tons being divided by this reduced number will give the breadth of the section sought.

Now the tabular number is 2·6681 tons; therefore it is 1 : 0·7856 : : 2·6681 : 2·096; consequently, by division we have 24 ÷ 2·096 = 11·45 inches. The parts of the section will therefore be as follows:

Fig. 17.



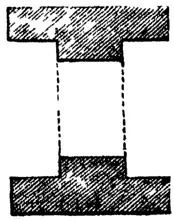
The whole depth		15 inches.
Distance between the flanges . . .	15 × ·7 =	10·5
The whole calculated breadth		11·446
The breadth of the flanges . .	11·446 × ·625 =	7·154
The breadth of the middle part	11·446 × ·375 =	3·846

The section, when constructed according to these dimensions, will therefore be as represented by the marginal drawing.

For the open double-flanged or I section, we have the following operation:

The constant fraction for this case is 0·7415, and the tabular number corresponding to the given length of bearing and depth of section is 2·6681 tons; hence we have 24 ÷ 2·6681 × 0·7415 = 12·137 inches, and the parts of the section deduced from this breadth with the specified proportions are as follows:

Fig. 18.



The whole depth		15 inches.
Distance between the flanges . . .	15 × ·7 =	10·5
Depth of the open part	15 × ·49 =	7·35
The whole calculated breadth		12·137
The breadth of the flanges	12·137 × ·625 =	7·586
The breadth of the middle part	12·137 × ·375 =	4·551

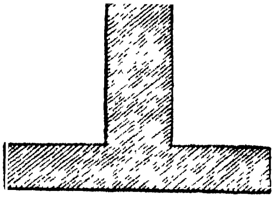
When the section is constructed according to these proportions, it will be as represented in the marginal drawing.

For the complete single-flanged or T section, the operation is as follows:

The number obtained by the inspection of the Table is 2·6681 tons, the same as before, and the constant fraction for the complete T section is 0·4299; hence we have 24 ÷ 2·6681 × 0·4299 = 24 ÷ 1·1468 = 20·927 inches; and the parts of the section deduced from this breadth are as below:

The whole depth	. . . .	15 inches.
Depth of the flange	. . . . . 15 × ·172 =	2·58
Depth of the narrow part	. . . 15 × ·828 =	12·42
The whole calculated breadth	. . . . . .	20·927
The breadth of the flange	. . 20·927 × ·75 =	15·695
The breadth of the narrow part	20·927 − 15·695 =	5·232

Fig. 19.



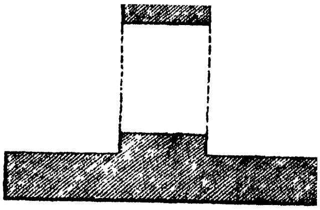
And the section, when constructed agreeably to these proportions, will be as exhibited in the marginal drawing.

For the open single-flanged or T section, the process is as follows:

The tabular number corresponding to the given length and depth is 2·6681 tons, and the constant fraction for the open single-flanged section is 0·3558; consequently the reduced divisor is 2·6681 × 0·3558 = 0·9492; hence by division we have 24 ÷ 0·9492 = 25·284 inches, and the parts of the section deduced from this breadth are as below:

The whole depth	. . . .	15 inches.
Depth of the flange	. . . . 15 × ·172 =	2·58
Depth of the narrow part	. . 15 × ·828 =	12·42
Depth of the opening	. . . 12·42 × $\frac{2}{3}$ =	8·28
The whole calculated breadth	. . . . .	25·284
The breadth of the flange	25·284 × ·75 =	18·963
The breadth of the narrow part	25·284 − 18·963 =	6·321

Fig. 20.



And the section, when constructed according to these dimensions, will appear as in the marginal drawing.

These sections are not at all graceful to the eye, but it is easy to perceive that their uncouth figure arises from the great breadth which they one and all assume in proportion to the depth. This disproportion, which is so very conspicuous in the figures, has been purposely adopted, in order to guard the architect against the absurdity of construction into which he is prone to fall, when his own better judgment fails to protect him from the consequences of such an important error. The following figures, which are derived from an assumed breadth, will be found much more elegant in appearance, and much more advantageous as regards economy and strength:

EXAMPLE 14.—Let the length of the beam, the load to be supported, and the conditions of strain, be precisely the same as in the last example, and assume the general breadth or greatest thickness to be 6 inches; it is required to determine the depth for each form of section, the strain being within the elastic power of cast iron?

For the complete rectangular section the process is as follows:

Divide the load in tons by the breadth in inches, and we get $\frac{24}{6} = 4$ tons for the strength of a beam of 1 inch in breadth. Find this quotient or the nearest to it in the column under the given length; then, opposite in the margin on the left hand, we find the depth in inches very nearly. Thus, in the present instance, the tabular number nearest to 4 is 3·8420, and opposite to this, in the left-hand column, is 18 inches, the approximate depth, and this in most practical cases may be considered as sufficiently correct; but when a greater degree of accuracy is desirable, it may be thus obtained. Take the difference between the next less tabular number to the above quotient, and the one adjacent to it, or the next greater; then say,

As the difference thus found is to unity, or 1 inch in depth;

So is the difference between the above quotient, and the nearest tabular number, to the required correction; which must be added to, or subtracted from, the depth first found, according as the nearest tabular number is less or greater than the quotient of the weight in tons divided by the given breadth in inches.

The nearest tabular number found above is 3·8420, corresponding to 18 inches, and the next greater is 4·2808, corresponding to 19 inches; hence we have

4·2808	19	4
3·8420	18	3·8420

0·4388 : 1 :: 0·158 : 0·36,

the correction to be added, because the nearest number is less than the quotient of the weight divided by the breadth; therefore it is $18 + 0·36 = 18·36$ inches, but greater correctness might be obtained by repeating the process. This method of approximation, however, cannot be accurate, in consequence of the effect produced by the second differences; and to correct for this effect would be much more tedious than to calculate by the formula itself.

We may therefore observe, and once for all, that in finding the required depth from the inspection of the Table the results will only be approximative, but they will be sufficiently accurate for every practical purpose.

In the case of the open rectangular section, the following is the process for determining the whole depth of the section according to the Table: the constant fraction for the open rectangular section is 0·657; and multiplying this by the given breadth, it becomes $0·657 \times 6 = 3·942$, which is the divisor for this form of section; hence, by division, we get $24 \div 3·942 = 6·0882$ tons for the load on a beam 1 inch in breadth. Then, in the Table, under 32 feet, the given length of bearing, the nearest and next less tabular number to 6·0882 is 5·7393, and opposite to this, in the marginal column, is 22 inches, the approximate depth. The next greater tabular number to 6·0882 is 6·2730; hence we get

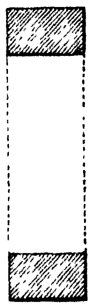
6·2730	23	6·0882
5·7393	22	5·7393

0·5337 : 1 : : 0·3489 : 0·654,

the correction to be applied additively to 22; therefore we have 22·654 inches for the depth very nearly.

The parts of the section as derived from this depth are as under:

The whole calculated depth	22·654 inches
The depth of the opening . .	$22·654 \times ·7 = 15·8578$
The depth of metal . . .	$22·654 - 15·8578 = 6·7962$
The depth on the upper side of the beam . .	3·3981
The depth on the lower side of ditto . . .	3·3981
The whole breadth or thickness	6



And the section constructed from these dimensions is as represented by the drawing in the margin.

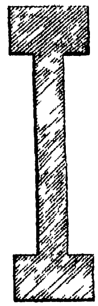
In the double-flanged or I section, we must recollect that the constant fraction is 0·7856, which being multiplied by the given breadth, becomes $0·7856 \times 6 = 4·7136$ inches for the reduced divisor; hence we get $24 \div 4·7136 = 5·0916$ tons for the tabular load corresponding to a beam of 1 inch in breadth. Therefore, under 32 feet, the given length of bearing, and opposite 4·7433, which is the next less tabular number to 5·0916, we find 20 inches for the approximate depth. The next greater tabular number is 5·2294; hence we have

5·2294	21	5·0916
4·7433	20	4·7433

0·4861 : 1 :: 0·3483 : 0·716 of an inch,

the correction to be applied additively; therefore, we have $20+0·716=20·716$ inches for the approximate depth of the section required. The parts of the section as derived from this depth are as under:

The whole calculated depth	20·716 inches.
The depth or distance between the flanges	$20·716 \times 0·7 = 14·5012$
The depth of the flanges . . .	$20·716 - 14·5012 = 6·2148$
The depth of the upper flange	3·1074
The depth of the lower flange	3·1074
Whole given breadth of the beam	6
The breadth of the flanges	$6 \times 0·625 = 3·75$
The breadth of the middle part	$6 \times 0·375 = 2·25$



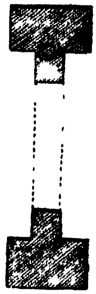
And the section constructed from these dimensions is as represented by the drawing in the margin.

For the open double-flanged or I section, the constant fraction for the tabular operation is 0·7415, which being multiplied by the proposed breadth, gives $0·7415 \times 6 = 4·449$ inches for the reduced divisor; consequently, by division, we get $24 \div 4·449 = 5·3945$ tons for the tabular number, answering to a breadth of 1 inch. Now, the next less number in the Table under the given length is 5·2294 tons, answering to a depth of 21 inches; and the next greater tabular number is 5·7393 tons, answering to a depth of 22 inches; hence we have

5·7393	22	5·3945
5·2294	21	5·2294

0·5099 : 1 :: 0·1651 : 0·324 of an inch,

the correction to be applied additively; therefore, by addition, we have $21+0·324=21·324$ inches for the approximate depth of the section. And the parts of the section derived from this depth are as follows:



The whole calculated depth	. . . .	21·324 inches.
The depth or distance between the flanges	21·324 × 0·7 =	14·9268
The depth of the opening	. . . . . . 14·9268 × 0·7 =	10·4488
The depth of the flanges	. . . 21·324 − 14·9268 =	6·3972
The depth of the upper flange	. . . . 6·3972 ÷ 2 =	3·1986
The depth of the lower flange	. . . 6·3972 − 3·1986 =	3·1986
The whole given breadth of the beam	. . . .	6
The breadth of the flanges	. . . . 6 × 0·625 =	3·75
The breadth of the middle part	. . . . 6 × 0·375 =	2·25

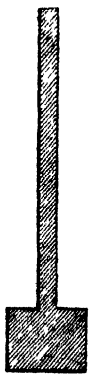
And the section constructed from these dimensions is as represented in the marginal drawing.

For the complete single-flanged or T section, the constant fraction is 0·4299, which being multiplied by the given breadth, becomes 0·4299 × 6 = 2·5794 inches, the reduced divisor; hence we get 24 ÷ 2·5794 = 9·3006 tons for the tabular number corresponding to 1 inch in breadth. Then in the Table, under 32 feet, the given length, the next less number to that above found is 9·2968 tons, corresponding to 28 inches; and the next greater is 9·9727 tons, corresponding to 29 inches; hence we get

9·9727	29	9·3006
9·2968	28	9·2968

0·6759 : 1 : : 0·0038 : 0·006 of an inch nearly,

the correction to be applied additively; therefore we have 28 + 0·006 = 28·006 inches for the approximate depth of the section required; and the parts of the section derived from this depth are as below:



The whole calculated depth	. . . .	28·006 inches.
The depth of the flange	. . . . 28·006 × ·172 =	4·817
The depth of the narrow part	. . . 28·006 − 4·817 =	23·189
The whole given breadth of the beam	. . . . . .	6
The breadth of the narrow part	. . . . . 6 × ¼ =	1·5
The breadth of the flange	. . . . 6 × ¾ =	4·5

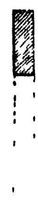
And the section constructed from these dimensions is represented by the marginal figure.

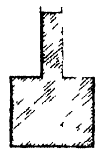
For the open single-flanged or T section, the constant fraction for the tabular operation is 0·3558, and consequently the reduced divisor is 0·3558 × 6 = 2·1348; therefore by division we get 24 ÷ 2·1348 = 11·2422 tons for the strength of a beam whose breadth is 1 inch. The next less tabular number under the given length of 32 feet is 10·6724 tons, which corresponds to a depth of 30 inches, and the next greater is 11·3957 tons, corresponding to a depth of 31 inches; hence we get

$$\begin{array}{lll} 11{\cdot}3957 & 31 & 11{\cdot}2422 \\ 10{\cdot}6724 & 30 & 10{\cdot}6724 \\ \hline 0{\cdot}7233 : & 1 :: & 0{\cdot}5698 : 0{\cdot}787 \text{ of an inch,} \end{array}$$

for the correction to be applied additively; therefore we get $30 + 0{\cdot}787 = 30{\cdot}787$ inches for the approximate depth of the section required; and the parts of the section derived from this depth are as follows:

The whole calculated depth		30·787 inches.
The depth of the narrow part	$30{\cdot}787 \times {\cdot}828 =$	25·492
The depth of the flange	$30{\cdot}787 \times {\cdot}172 =$	5·295
The depth of the opening	$25{\cdot}492 \times \frac{2}{3} =$	16·995
The depth of the part above the opening	$\frac{1}{2}(25{\cdot}492 - 16{\cdot}995) =$	4·2485
The depth of the part below the opening	$30{\cdot}787 - 21{\cdot}2435 =$	9·5435
The whole given breadth of the beam		6
The breadth of the flange	$6 \times 0{\cdot}75 =$	4·5
The breadth of the narrow part	$6 - 4{\cdot}5 =$	1·5





And the section constructed from these dimensions is as exhibited in the marginal diagram.

In all these examples we have taken no notice of the effect produced by the weight of the beam, presuming that what had previously been done on this head is quite sufficient to direct the inexperienced practitioner in all cases of a similar nature. And we may further observe, that in all that has hitherto been done, no notice whatever has been taken of the effect of flexure, which is a very important element in all delicate cases; and for this reason we mean to take a brief view of the deflexion as it affects the stability of a structure in what immediately follows.

It is a well-known and established principle in the doctrine of resistance as referred to the strength of materials, that if a beam of timber, iron, or any other substance of a fibrous compact and elastic nature, be supported at the ends and strained at the middle of its length by a force acting in the direction of gravity, it will suffer a certain degree of bending or flexure proportional to the power which produces it. Thus for example:

If a beam of any given dimensions be bent or deflected through a known space by a weight of 1 ton applied at its middle point, it will be deflected through twice that space with 2 tons; through three times the space with 3 tons; four times the space with 4 tons, and so on in proportion, until the elasticity of the substance is destroyed, when the quantity of deflexion becomes irregular; for beyond that point the variation does not appear to follow any determinate law.

When a beam of timber or any other material is strained to the full extent of its elastic force by a load applied at the middle of its length:

The square of the length in feet, divided by the depth in inches drawn into the deflexion, is constant for the same material, whatever may be the form of the transverse section.

This is the law upon which the theory of deflexion is founded, and being independent of every sectional dimension excepting the depth or that in the direction of gravity, it is equally applicable to every form of beam, provided the depth is uniform throughout the length of bearing or distance between the supports. This being the case, the subject may be very briefly discussed, because, whatever constant is found by experiment to obtain for one form of section, will answer for all the forms of which we have treated in the foregoing pages.

Reverting to Mr. Tredgold's experiment already alluded to, where a bar of cast iron, 1 inch square, and 34 inches in length, was found to support a load of 300 lbs. at its middle point without destroying the elastic force, and by this load it was found to be deflected through the space of 0·16 of an inch; consequently, by the above law, the constant for cast iron becomes

$$\frac{34 \times 34}{12 \times 12 \times \cdot 16} = 50 \cdot 1736,$$

and this, when referred to a bar of the same sectional dimensions, and 1 foot in length, gives a deflexion of 0·01993 of an inch; for we have

$$\frac{34 \times 34}{12 \times 12} : 0 \cdot 16 :: 1^2 : 0 \cdot 01993.$$

Consequently, when the beam is uniform in depth, supported at the ends, and loaded at the middle of its length, the specific expression for the central deflexion within the limits of elasticity becomes,

$$\text{central deflexion} = \frac{0 \cdot 01993 \times \text{length}^2}{\text{depth}}. \qquad \text{(M)}$$

This, as we have said, is the ultimate deflexion, or that which obtains at the instant when the elastic power of the material is about to fail; but it is often necessary in practice, and indeed it is the most useful case of the problem, to determine what degree of deflexion will be produced by a given load, and fortunately this is a point of very easy attainment, for we have already stated, that within the limits of elasticity, the deflexion is directly proportional to the load or force that produces it; hence by equations (A) and (M), we have

$$\frac{0\cdot01993 \times \text{length}^2}{\text{depth}} : \frac{850 \times \text{breadth} \times \text{depth}^2}{\text{length}} :: \text{deflexion} : \text{load};$$

and by working out the proportion, the expression for the load that will produce the required deflexion becomes,

$$\text{force or load} = \frac{42647\cdot57 \times \text{breadth} \times \text{depth}^3 \times \text{deflexion}}{\text{length}^3}. \qquad \text{(N)}$$

Consequently, by the transposition of this equation, any one of the parts can be found when all the rest are given; but in practice, it will be sufficiently accurate to drop the decimal in the constant number, and employ the whole number 42648 as a coefficient for the stiffness, in every case of the transverse section that has reference to the central strain.

Returning to equation (M), which gives the deflexion at the limit of elasticity, the practical rule which it affords may be expressed in words at full length as follows:

RULE 16.—*Multiply the square of the length in feet by the constant decimal* 0·01993, *or in practice* 0·02, *and divide the product by the depth of the section in inches, for the central deflexion in inches or parts of an inch.*

EXAMPLE 15.—A beam of cast iron of the complete rectangular section, is 40 feet in length between the supports, and 36 inches in depth; how much will it be deflected by a load applied at the middle of its length, supposing it to be strained to the full extent of its elastic power?

$$\text{Central deflexion} = \frac{40 \times 40 \times 0\cdot01993}{36} = 0\cdot886 \text{ of an inch nearly.}$$

We may therefore observe, that in the practice of proving beams when the quality of the material is well understood, the preferable mode of procedure would be to calculate the ultimate deflexion, and to strain the beams to that amount; for in this way, the required proof will be more easily applied and detected, than it can be by a force acting at the extremity of a lever when the effect of friction is unknown, which must always be the case with the hydraulic press. When the load is uniformly diffused throughout the length of the beam, the quantity of deflexion is the same as if $\frac{5}{8}$ths of the load were applied at the middle point, while the strain is the same as if one-half of it were applied there:—The constant for the deflexion in this case will therefore be 0·02491, or practically, 0·025, and the formula by which it is expressed is—

$$\text{central deflexion} = \frac{0{\cdot}025 \times \text{length}^2}{\text{depth}}. \qquad \text{(O)}$$

The practical rule for the reduction of this equation is the same, word for word, as that already given for the reduction of equation (M), and therefore it need not be repeated; but it must be borne in mind, that in this case the constant 0·02491, or rather 0·025, has to be employed instead of 0·01993, or rather 0·02, which is simpler, and sufficiently accurate for practice.[3] When the beam is supported at both ends, and strained at some other point than the middle of the length, the equation for the deflexion at that point is—

$$\text{central deflexion} = \frac{0{\cdot}07972 \times \text{less. seg.} \times \text{great. seg.}}{\text{depth}}. \qquad \text{(P)}$$

And if this equation be translated into words at length, it may be reduced as directed in the following rule:

RULE 17.—*Multiply* 0·07972 *times the lesser segment of the length in feet by the greater segment in feet, and divide the product by the depth in inches, for the deflexion in inches or parts of an inch.*

EXAMPLE 16.—A cast iron beam of the complete rectangular section, is 40 feet in length between the supports, and 36 inches in depth; how much will it be deflected by a load applied at a point, which is 16 feet distant from one support, and 24 feet from the other, supposing it to be strained to the full extent of its elastic power?

Here, by the rule, we have $0{\cdot}07972 \times 16 \times 24 \div 36 = 0{\cdot}07972 \times 32 \div 3 = 0{\cdot}85$ of an inch for the central deflexion, the point of application being 4 feet from the middle of the beam.

[3] When the outline of the depth is a parabola, the beam being supported at the ends and loaded in the middle, the constant for the ultimate central deflexion is 0·03986; and when the outline is elliptical, the other conditions being the same, the constant for the central deflexion is 0·0257; which constants must respectively be used in Rule 16, instead of the constant 0·01993, as there given.

There are many other circumstances under which the ultimate deflexion might be considered in a complete theory; but since the above are those which most frequently occur in practice, we shall not pursue this part of the subject farther, as from what has been already done, when viewed in connexion with the following particulars, the reader will be enabled to deduce whatever is necessary for his purpose. We therefore proceed to the consideration of the deflexion as dependent upon a given load.

The equation marked (N) expresses the load that a beam of given dimensions will bear at the middle of its length under any proposed degree of deflexion, and the practical rule which it supplies may be given in the following words:

RULE 18.—*Multiply the constant number* 42648 *by the breadth and cube of the depth both in inches, and again by the given deflexion; then divide the product by the cube of the length in feet, for the load in* ℔s. *avoirdupoise that will produce the deflexion.*

Since the depth of the section in inches, and the length of bearing in feet, are each of them raised to the cube or third power, it follows, that the operation by the rules of common arithmetic would be excessively tedious; it will therefore be advantageous in all cases which have a reference to stiffness, to perform the process logarithmically, and for this reason we shall express the rule as applicable to these numbers in the following manner:

RULE 19.—*From the logarithm of the depth in inches, subtract the logarithm of the length in feet, and multiply the remainder by* 3; *then, to the product add the logarithm of the breadth in inches, the logarithm of the given deflexion in inches or parts of an inch, and the constant logarithm* 1·279647, *and the natural number answering to the sum will be the load required expressed in tons. But if the load be required in* ℔s., *we must use the logarithm* 4·629895 *instead of* 1·279647.

The constant logarithm 1·279647, which is employed to determine the load in tons, is found in the following manner:

Constant coefficient	42648	log. 4·629895
Constant for tons	2240	log. 3·350248
The difference gives the constant log.		1·279647

EXAMPLE 17.—A beam of cast iron of the complete rectangular section, is 40 feet in length between the supports, 36 inches in depth, and 4½ inches broad;

what weight will it bear at the middle of its length, when the central deflexion is limited to $\frac{5}{8}$ths of an inch?

The logarithmic operation is as below:

The given depth in inches	36	log. 1·556303
The given length in feet	40	log. 1·602060
		9·954243
		3
Depth ^{3} ÷ length ^{3}	. . . . . .	log. 9·862729
The given breadth in inches . . .	4·5	log. 0·653213
The given deflexion in parts of an inch	0·625	log. 9·795880
Constant for tons	19·0391	log. 1·279647
The required load in tons	39·0363	log. 1·591469

A beam of the dimensions given in the above example will bear a much greater load within the limit of its elastic power; for by the Table, under 40 feet, the given length, and opposite 36 inches, the given depth, we have 12·2946 tons for a beam 1 inch broad; consequently, the entire load is $12{\cdot}2946 \times 4\frac{1}{2} = 55{\cdot}3257$ tons instead of 39·0363 tons; but it must be recollected that the deflexion will also be greater; for by Rule 16, we have

$$\text{central deflexion} = \frac{40 \times 40 \times 0{\cdot}01993}{36} = 0{\cdot}886 \text{ of an inch,}$$

whereas in the question the deflexion is limited to $\frac{5}{8}$ths or 0·625 of an inch, which manifestly requires a less load to produce it.

We have already stated, that when a load is uniformly diffused throughout the length of a beam, the quantity of deflexion is the same as would be produced by $\frac{5}{8}$ths of that load applied at the middle point; hence it follows, that the beam in question will bear 62·4581 tons uniformly distributed over its length, while the central deflexion is limited to $\frac{5}{8}$ths of an inch: this is obvious, for $\frac{39{\cdot}0363 \times 8}{5} = 62{\cdot}4581$ tons; but if the beam were loaded to the extent of its elastic power, it would bear $55{\cdot}3257 \times 2 = 110{\cdot}6514$ tons, and the deflexion would be 1·111 inches very nearly.

The equation marked (N) is that which applies to a beam of the complete rectangular form of section, and the rule and calculation deduced from it have also reference to that particular form; it is easy, however, to adapt the equation to the other forms of section which we have made the subject of our inquiry; for admitting the parts of the several sections to be related to each other in the manner already described, the equations will all assume the same form, but the constant coefficient will vary for each, according to the respective values in the equations (A), (G), (H), (I), (K), (L), and (N). Thus by proportion, the several coefficients become

850 : 42648 : : 558 : 27998
850 : 42648 : : 668 : 33517
850 : 42648 : : 630 : 31610
850 : 42648 : : 365 : 18314
850 : 42648 : : 302 : 15153

Let each of these constants, therefore, be substituted in equation (N), and we shall obtain, for the open rectangular section,

$$\text{load} = \frac{27998 \times \text{breadth} \times \text{depth}^3 \times \text{deflexion}}{\text{length}^3}. \qquad \text{(O)}$$

For the complete I section, it is

$$\text{load} = \frac{33517 \times \text{breadth} \times \text{depth}^3 \times \text{deflexion}}{\text{length}^3}. \qquad \text{(P)}$$

For the open I section, it is

$$\text{load} = \frac{31610 \times \text{breadth} \times \text{depth}^3 \times \text{deflexion}}{\text{length}^3}. \qquad \text{(Q)}$$

For the complete single-flanged or T section, it is

$$\text{load} = \frac{18314 \times \text{breadth} \times \text{depth}^3 \times \text{deflexion}}{\text{length}^3}. \qquad \text{(R)}$$

For the open single-flanged or T section, it is

$$\text{load} = \frac{15153 \times \text{breadth} \times \text{depth}^3 \times \text{deflexion}}{\text{length}^3}. \qquad \text{(S)}$$

And if these constants be respectively substituted in Rules 18 and 19, instead of 42648, the rules in all other respects will be the same for each form of section. And in this manner were the numbers in Table II. computed.

Table of the Strength of Cast Iron Beams corresponding to 1 inch Deflexion.

Depth.	TABLE II.—Argument.—Length in feet—Breadth or thickness 1 inch—Deflexion 1 inch.									
	21	22	23	24	25	26	27	28	29	30
in.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.
1	0·002	0·002	0·002	0·001	0·001	0·001	0·001	0·001	0·001	0·001
2	0·016	0·014	0·013	0·011	0·010	0·009	0·008	0·007	0·006	0·006
3	0·056	0·048	0·042	0·037	0·033	0·029	0·026	0·023	0·021	0·019
4	0·132	0·114	0·101	0·088	0·078	0·069	0·062	0·056	0·050	0·045
5	0·257	0·224	0·196	0·172	0·152	0·135	0·121	0·108	0·098	0·088
6	0·444	0·386	0·338	0·298	0·263	0·234	0·209	0·187	0·169	0·152
7	0·705	0·613	0·537	0·472	0·418	0·372	0·333	0·298	0·268	0·242
8	1·053	0·915	0·801	0·705	0·624	0·555	0·495	0·444	0·400	0·361
9	1·499	1·304	1·141	1·004	0·888	0·790	0·705	0·632	0·569	0·514
10	2·056	1·788	1·565	1·377	1·219	1·083	0·967	0·867	0·784	0·705
11	2·736	2·380	2·083	1·833	1·622	1·442	1·287	1·154	1·039	0·939
12	3·553	3·090	2·704	2·380	2·106	1·872	1·672	1·499	1·349	1·219
13	4·517	3·928	3·438	3·026	2·677	2·380	2·125	1·905	1·715	1·549
14	5·641	4·906	4·294	3·779	3·344	2·972	2·654	2·380	2·142	1·935
15	6·938	6·035	5·281	4·648	4·113	3·656	3·265	2·927	2·635	2·380
16	8·421	7·324	6·430	5·641	4·991	4·437	3·962	3·553	3·198	2·888
17	10·100	8·785	7·688	6·766	5·986	5·322	4·752	4·261	3·835	3·464
18	11·989	10·428	9·126	8·032	7·106	6·318	5·641	5·058	4·553	4·113
19	14·101	12·264	10·733	9·447	8·358	7·430	6·635	5·949	5·355	4·837
20	16·447	14·304	12·519	11·018	9·748	8·666	7·739	6·935	6·245	5·641
21	19·039	16·559	14·492	12·755	11·285	10·032	8·858	8·032	7·230	6·530
22	21·891	19·039	16·662	14·665	12·975	11·535	10·300	9·235	8·312	7·509
23	25·013	21·755	19·039	16·757	14·826	13·180	11·769	10·553	9·498	8·579
24	28·420	24·718	21·632	19·039	16·845	14·975	13·372	11·989	10·792	9·748
25	32·122	27·939	24·450	21·520	19·039	16·926	15·114	13·552	12·198	11·018
26	36·133	31·426	27·503	24·770	21·416	19·039	17·001	15·244	13·721	12·394
27	40·465	35·194	30·800	27·109	23·984	21·321	19·039	17·071	15·365	13·879
28	45·130	39·251	34·351	30·233	26·749	23·780	21·234	19·039	17·137	15·479
29	50·140	43·609	38·164	33·590	29·718	26·419	23·591	21·153	19·039	17·198
30	55·508	48·277	42·250	37·186	32·900	29·247	26·117	23·417	21·077	19·039
31	61·245	53·268	46·617	41·030	36·300	32·271	28·816	25·838	23·256	21·007
32	67·366	58·591	51·276	45·130	39·928	35·496	31·696	28·420	25·580	23·106
33	73·881	64·257	56·235	49·494	43·789	38·928	34·761	31·168	28·054	25·341
34	80·803	70·277	61·503	54·131	47·892	42·576	38·018	34·088	30·682	27·715
35	88·144	76·662	67·091	59·050	52·243	46·444	41·472	37·186	33·470	30·233
36	95·917	83·423	73·008	64·257	56·850	50·540	45·130	40·465	36·422	32·980

Table of the Strength of Cast Iron Beams corresponding to 1 *inch Deflexion.*

Depth.	Table II.—Argument.—Length in feet—Breadth or thickness 1 inch—Deflexion 1 inch.									
	31	32	33	34	35	36	37	38	39	40
in.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.
1	0·001	0·001	0·001	0·000	0·000	0·000	0·000	0·000	0·000	0·000
2	0·005	0·005	0·004	0·004	0·004	0·003	0·003	0·003	0·003	0·002
3	0·017	0·016	0·014	0·013	0·012	0·010	0·010	0·009	0·009	0·008
4	0·041	0·037	0·034	0·031	0·028	0·026	0·024	0·022	0·021	0·019
5	0·080	0·073	0·066	0·061	0·056	0·051	0·047	0·043	0·040	0·037
6	0·138	0·126	0·114	0·105	0·096	0·088	0·081	0·075	0·069	0·064
7	0·219	0·199	0·182	0·166	0·152	0·140	0·129	0·119	0·110	0·102
8	0·327	0·298	0·271	0·248	0·227	0·209	0·192	0·178	0·164	0·152
9	0·466	0·424	0·386	0·353	0·324	0·298	0·274	0·253	0·234	0·217
10	0·639	0·581	0·530	0·484	0·444	0·408	0·376	0·347	0·321	0·298
11	0·851	0·773	0·705	0·645	0·591	0·543	0·500	0·462	0·427	0·396
12	1·104	1·004	0·915	0·837	0·767	0·705	0·649	0·599	0·555	0·514
13	1·404	1·277	1·164	1·064	0·976	0·897	0·826	0·762	0·705	0·654
14	1·778	1·594	1·454	1·329	1·219	1·120	1·031	0·952	0·881	0·816
15	2·157	1·961	1·788	1·635	1·499	1·377	1·269	1·171	1·083	1·004
16	2·617	2·380	2·170	1·984	1·819	1·672	1·539	1·421	1·315	1·219
17	3·140	2·855	2·603	2·380	2·182	2·005	1·847	1·705	1·577	1·462
18	3·727	3·389	3·090	2·825	2·590	2·380	2·192	2·024	1·872	1·735
19	4·383	3·985	3·634	3·323	3·046	2·799	2·596	2·380	2·201	2·040
20	5·113	4·648	4·238	3·875	3·553	3·265	3·007	2·776	2·568	2·380
21	5·919	5·381	4·906	4·486	4·113	3·779	3·481	3·288	2·972	2·755
22	6·805	6·187	5·641	5·158	4·728	4·345	4·002	3·695	3·417	3·168
23	7·776	7·069	6·446	5·894	5·403	4·965	4·573	4·222	3·905	3·619
24	8·835	8·032	7·324	6·696	6·139	5·641	5·196	4·797	4·437	4·113
25	9·986	9·079	8·278	7·569	6·938	6·376	5·873	5·422	5·015	4·648
26	11·233	10·212	9·312	8·514	7·805	7·172	6·606	6·098	5·641	5·229
27	12·579	11·436	10·428	9·535	8·740	8·032	7·398	6·829	6·318	5·855
28	14·029	12·755	11·630	10·634	9·748	8·858	8·251	7·617	7·046	6·530
29	15·587	14·171	12·921	11·814	10·830	9·953	9·167	8·462	7·828	7·255
30	17·255	15·688	14·304	13·079	11·989	11·018	10·149	9·368	8·666	8·032
31	19·039	17·309	15·783	14·431	13·229	12·157	11·198	10·337	9·562	8·862
32	20·941	19·039	17·360	15·873	14·551	13·372	12·317	11·370	10·518	9·748
33	22·967	20·880	19·039	17·408	15·958	14·665	13·508	12·469	11·535	10·691
34	25·119	22·837	20·823	19·039	17·453	16·039	14·773	13·638	12·615	11·692
35	27·401	24·912	22·715	20·769	19·039	17·496	16·116	14·876	13·761	12·755
36	29·817	27·109	24·718	22·600	20·718	19·039	17·537	16·188	14·975	13·879

Table of the Strength of Cast Iron Beams corresponding to 1 inch Deflexion.

Depth.	TABLE II.—Argument.—Length in feet—Breadth or thickness 1 inch—Deflexion 1 inch.									
	41	42	43	44	45	46	47	48	49	50
in.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.
1	0·000	0·000	0·000	0·000	0·000	0·000	0·000	0·000	0·000	0·000
2	0·002	0·002	0·002	0·002	0·002	0·002	0·001	0·001	0·001	0·001
3	0·007	0·007	0·006	0·006	0·006	0·005	0·005	0·005	0·004	0·004
4	0·018	0·016	0·015	0·014	0·013	0·013	0·012	0·011	0·010	0·010
5	0·035	0·032	0·030	0·028	0·026	0·024	0·023	0·022	0·020	0·019
6	0·060	0·056	0·052	0·048	0·045	0·042	0·040	0·037	0·035	0·033
7	0·095	0·088	0·082	0·077	0·072	0·067	0·063	0·059	0·056	0·052
8	0·142	0·132	0·123	0·114	0·107	0·101	0·094	0·088	0·083	0·078
9	0·201	0·187	0·175	0·163	0·152	0·143	0·134	0·126	0·118	0·111
10	0·276	0·257	0·239	0·224	0·209	0·196	0·183	0·172	0·162	0·152
11	0·368	0·342	0·319	0·298	0·278	0·260	0·244	0·229	0·215	0·203
12	0·477	0·444	0·414	0·386	0·361	0·338	0·317	0·298	0·280	0·263
13	0·607	0·565	0·526	0·491	0·459	0·429	0·403	0·378	0·356	0·335
14	0·758	0·705	0·657	0·613	0·573	0·537	0·503	0·472	0·444	0·418
15	0·932	0·867	0·808	0·754	0·705	0·660	0·619	0·581	0·546	0·514
16	1·131	1·053	0·981	0·915	0·836	0·801	0·751	0·705	0·663	0·624
17	1·357	1·263	1·176	1·098	1·026	0·961	0·901	0·846	0·795	0·748
18	1·611	1·499	1·397	1·304	1·219	1·141	1·069	1·004	0·944	0·888
19	1·895	1·763	1·642	1·533	1·433	1·342	1·258	1·181	1·110	1·004
20	2·210	2·056	1·916	1·788	1·672	1·565	1·467	1·377	1·295	1·219
21	2·558	2·380	2·218	2·070	1·935	1·812	1·698	1·594	1·499	1·410
22	2·941	2·736	2·550	2·380	2·225	2·083	1·953	1·833	1·723	1·622
23	3·361	3·127	2·914	2·719	2·542	2·380	2·231	2·095	1·969	1·853
24	3·819	3·553	3·310	3·090	2·888	2·704	2·535	2·380	2·237	2·106
25	4·316	4·015	3·742	3·492	3·265	3·056	2·865	2·690	2·529	2·380
26	4·855	4·517	4·209	3·928	3·671	3·438	3·223	3·026	2·844	2·677
27	5·437	5·058	4·713	4·106	4·113	3·850	3·610	3·389	3·185	2·998
28	6·064	5·641	5·257	4·906	4·586	4·294	4·026	3·779	3·553	3·344
29	6·737	6·267	5·840	5·451	5·096	4·771	4·472	4·199	3·947	3·715
30	7·459	6·938	6·466	6·035	5·641	5·281	4·951	4·648	4·369	4·113
31	8·230	7·656	7·134	6·658	6·224	5·827	5·463	5·129	4·821	4·538
32	9·052	8·421	7·847	7·324	6·846	6·430	6·009	5·641	5·303	4·991
33	9·927	9·235	8·606	8·032	7·508	7·029	6·590	6·187	5·816	5·474
34	10·858	10·100	9·412	8·785	8·212	7·688	7·208	6·766	6·361	5·986
35	11·844	11·018	10·267	9·583	8·858	8·386	7·862	7·381	6·938	6·530
36	12·889	11·989	11·172	10·428	9·748	9·126	8·564	8·032	7·550	7·106

It will at once appear that the arrangement of Table II. is precisely the same as that of Table I., but the circumstances of strain in the two cases are very different. In Table I. the numbers indicate the load in tons which the beam will bear at the middle of its length, when strained to the full extent of its elastic power, the deflexion in that state being such as is due to the ultimate load. The numbers in Table II. denote the load in tons which the beam will bear at the middle of its length, when the central deflexion is limited to one inch, and from this we can readily determine the load that will produce any deflexion at pleasure within the limits of elasticity. The manner of using the Table is the same as that which we have already exemplified, with this exception, that the load as found by the Table must always be multiplied by the given deflexion, in order to obtain the load by which that deflexion is produced; but the following examples will elucidate the subject better than pages of verbal description.

EXAMPLE 18.—A cast iron beam of the complete rectangular section, is 40 feet in length between the points of support, 4 inches in breadth, and 30 inches in depth; how much will it support at the middle of its length, under circumstances that will not permit of more than $\frac{1}{4}$th of an inch of central deflexion?

The load which a beam of these dimensions will bear within the limit of elasticity has already been shown in the first example, and by the inspection of Table I. it was found to be 34·1516 tons, including the effect produced by its own weight, or 30·723 tons exclusive of that effect. But in this case, the central deflexion would be 1·067 inches very nearly; for, by Rule 16, we have

$$\text{central deflexion} = \frac{\cdot 02 \times 40 \times 40}{30} = 1\cdot 0\dot{6}\dot{6}.$$

In Table II., under the given length of 40 feet, at the top of the page, and opposite 30 inches in the left-hand column, we find 8·032 tons for the load that will produce a deflexion of 1 inch, at the middle of a beam of the same length and depth, and 1 inch in thickness or breadth; consequently, the whole load for the beam in question is $8\cdot 032 \times 4 = 32\cdot 128$ tons, including the effect produced by its own weight. Now, the weight of the beam as calculated in the first example is 6·8572 tons, and this weight acts uniformly throughout the length; but we have stated, under the fifteenth example, that a uniform load produces the same deflexion as would be produced by five-eighths of that load applied at the middle point; we must therefore deduct $\frac{5}{8}$ths of the weight of the beam to obtain the extraneous load corresponding to a deflexion of 1 inch; hence we have $32\cdot 128 - 6\cdot 8572 \times \frac{5}{8} = 27\cdot 842$ tons very nearly. This is the extraneous load that will produce a central deflexion of 1 inch; but, by the question, the deflexion is to be only $\frac{1}{4}$th of an inch, and the deflexions are proportional to the loads that produce them; hence it is 1 : 0·25 : : 27·842 : 6·9605 tons, the load required.

The same thing, however, may also be found from Table I.; for the strength of a beam 1 inch in breadth is 8·5379 tons, as appears by the first example, or the ultimate strength of the beam within the limits of elasticity is 34·1516 tons, the corresponding deflexion being $40 \times 40 \times \cdot 01993 \div 30 = 1 \cdot 0624$ inches; and the deflexions are directly as the weights or forces by which they are produced; hence, by proportion, we get 1·0624 : 1 : : 34·1516 : 32·145 tons, being very nearly the same as we obtained by inspection from the second Table, the difference being caused by taking the last place of decimals to the nearest unit. Hence it appears, that in so far as the mere determination of the load to produce a given deflexion is concerned, Table II. may be altogether dispensed with, since the same thing can be found by the application of Table I. with the greatest facility. But when it is required to determine the dimensions of a beam that shall be competent to sustain a given load with a given deflexion, the importance of the second Table becomes manifest. We shall close the discussion of this subject with the resolution of the following numerical example.

EXAMPLE 19.—A cast iron beam of the complete I or double-flanged section, is 40 feet in length between the points of support, and 4 inches in breadth, having all the parts of the section in the proportions specified in the formation of equation (H); what must be the whole depth of the section and the distance between the flanges, in order that the beam may support 24 tons at the middle of its length, without being deflected more than $\frac{5}{8}$ths of an inch?

The solution of this and similar questions involves some very nice considerations, and, without the greatest attention on the part of the operators, very erroneous results may be obtained; we shall, therefore, be the more explicit in stating the mode of procedure in this instance, since it must serve as a guide for calculating all the other forms of section.

In the first place, then, since the tabular numbers are calculated to a breadth of 1 inch only, we must find the load that can be borne by a beam of the given length and 1 inch in breadth, and this requires that the whole given load be divided by the entire breadth, which gives a quotient of 6 tons for the central load on a beam 40 feet long and 1 inch broad. Now this load produces 1 inch of deflexion, and the corresponding depth is between 27 and 28 inches; but, by the question, the deflexion is only to be $\frac{5}{8}$ths of an inch, which, with the same load, will obviously require a greater depth to resist that deflexion, and by the arrangement of the Table a greater depth will correspond to a greater load, which is found thus; $\frac{5}{8} : 1 :: 6 : 9{\cdot}6$ tons, which is the load corresponding to the depth for a rectangular section, being very nearly 32 inches. Now, the strength of the complete I section has already been shown to be to the strength of its circumscribing rectangle, as 0·7856 to 1; hence we have

$$0{\cdot}7856 : 1 :: 9{\cdot}6 : 12{\cdot}219 \text{ tons},$$

the tabular load corresponding to the required depth.

Therefore, in the Table, under 40 feet, the given length of bearing, at the top of the page, we find 11·692 tons for the next less number to 12·219, which corresponds to a depth of 34 inches, and the next greater tabular number is 12·755 tons, which corresponds to a depth of 35 inches; hence we have the following operation:

12·755	35	12·219
11·692	34	11·692
1·063 :	1 ::	0·527 : 0·496 of an inch,

the correction for the depth to be applied additively; consequently, the required depth is $34 + 0{\cdot}496 = 34{\cdot}496$ inches very nearly, the distance between the flanges being $34{\cdot}496 \times 0{\cdot}7 = 24{\cdot}1472$ inches, and the depth of the flange $34{\cdot}496 \times 0{\cdot}15 = 5{\cdot}1744$ inches, so that the parts of the section are as under:

Whole depth		34·496 inches.
Distance between the flanges	$34{\cdot}496 \times 0{\cdot}7 =$	24·1472
Depth of flanges	$34{\cdot}496 \times 0{\cdot}3 =$	10·3488
Depth of upper flange	$10{\cdot}3488 \div 2 =$	5·1744
Depth of lower flange	$10{\cdot}3488 \div 2 =$	5·1744
Whole breadth		4
Breadth of flanges	$4 \times {\cdot}625 =$	2·5
Breadth of the middle part	$4 \times {\cdot}375 =$	1·5

And in a similar manner must the operation be conducted for all the other forms of section; but the process may be somewhat facilitated by multiplying altogether the given breadth, the given deflexion, and the constant number peculiar to the form in question; then the given load being divided by the product, will give the tabular number answering to the required depth. Thus, in the preceding example, it is

$$24 \div 4 \times 0{\cdot}625 \times 0{\cdot}7856 = 24 \div 1{\cdot}964 = 12{\cdot}219 \text{ tons},$$

the tabular number corresponding to the required depth, the same as before.

In the foregoing pages we have considered the strength and deflexion of cast iron beams when placed in a horizontal position, and exposed to a transverse strain by a force acting in the direction of gravity, or at right angles to the length. This is a very important inquiry in the practice of *Architecture*, and in the various departments of *Civil and Military Engineering*, inasmuch as horizontal supports are of more frequent occurrence than any other; and when the bearers are inclined to the plane of the horizon in an angle of which the magnitude is known, the strength, as determined for the horizontal position, can easily be modified for the given obliquity, seeing that the strain varies inversely as the secant of the angle of elevation. Consequently, when the elevation is 90°, that is, when the beam is perpendicular to the horizon, the resistance to a force acting in the direction of gravity is indefinitely great; or, in other words, the effect of the force in straining the beam transversely vanishes altogether. But when the beam is placed at right angles to the horizon and strained in the direction of its length, the law of resistance changes, and the transverse strength is no longer available in leading us to the required result.

A simple and accurate rule for calculating the strength of upright supports has long been sought after by mathematicians; but it does not appear that any thing satisfactory has hitherto been obtained; indeed, the law of resistance to strains of this sort is too imperfectly understood to admit of a ready and rigorous application, and the paucity of experiments on a large scale, as referred to the resistance of pillars and columns, leaves us but little to hope from the investigations of the analyst as applied to data arising from experimental results.

In the case of cylindrical columns, if the load could always be so adjusted as to bring the direction of pressure into a perfect coincidence with the axis, a very near approximation to the strength might be arrived at from laws which are already sufficiently established; but, in consequence of settlements and other causes, it would be imprudent in practice to calculate for such a nice adjustment; for in this case, whatever error may arise from the supposition of a perfect coincidence, will always tend to increase the danger.

Mr. Tredgold, on whose authority we can rely with the greatest confidence, considers that in all practical calculations on this subject we ought to conceive the direction of pressure as coinciding with the surface of the column, this being the weakest position in which a column can be employed in practical constructions. By this means he proposes to circumscribe the danger; for whatever deviation may take place from the assumed direction, will bring it nearer and nearer to a coincidence with the axis of the pillar, in consequence of which the danger will be continually lessening, or the results of calculation will lean more and more to the side of safety.

Some experimentalists have lately been endeavouring to throw discredit on the principles of Mr. Tredgold; but we cannot perceive, from an examination of their results, that they have done any thing that will have a tendency to supersede his theory, which is likely, after all, to constitute the most approved standard for guiding us to safe results in all our inquiries respecting the application of cast iron to the mechanical arts.

The formula which he employs for calculating the strength of a cylindrical column, when the direction of pressure coincides with the surface, is

$$\text{weight} = \frac{2390 \cdot 5 \times \text{diam.}^4}{\text{diam.}^2 + 0 \cdot 045 \times \text{length}^2}.*$$

In this equation, when the diameter of the column is given in inches and the length in feet, the operation for the load within the limits of safety is very easy, and can be performed with the greatest facility. The rule in words at length is as below:

RULE.—*Multiply the constant coefficient* 2390·5 *by the fourth power of the diameter in inches, and reserve the product for a dividend.*

To the square of the diameter in inches, add the constant fraction 0·045 *drawn into the square of the length in feet for a divisor.*

Then, divide the dividend by the divisor for the weight which the column can sustain in pounds, and again by 2240 *for the weight in tons.*

EXAMPLE.—The length of a cast iron cylindrical column is 18 feet, and its diameter 8 inches; what weight may it safely be loaded with, on the supposition that it is solid, and the direction of pressure coincident with the surface, or at the distance of half the diameter from the axis?

Here by the rule we have, $2390 \cdot 5 \times \text{diam.}^4 = 2390 \cdot 5 \times 8^4 = 9791488$, the dividend; and furthermore, it is $\text{diam.}^2 + 0 \cdot 045 \times \text{length}^2 = 8^2 + 0 \cdot 045 \times 18^2 = 64 + 14 \cdot 58 = 78 \cdot 58$, the divisor; hence by division we get,

$$\text{weight} = \frac{9791488}{78 \cdot 58} = 124605 \cdot 35 \text{ lbs., or } 55 \cdot 63 \text{ tons;}$$

and precisely according to this rule have the numbers in Table III. been computed.

* The investigation of this formula is too intricate for admission according to the plan which we have adopted in drawing up this Essay; but those who wish to trace the *rationale* of the rule will have their curiosity amply gratified by turning to the section on this subject in Tredgold's "Essay on the Strength of Cast Iron and other Metals."

TABLE III.—*The numbers in Table III. exhibit the load in tons that can be supported by Cast Ir*
Enter with the length in feet at the top, and the diameter in inches on the left han

Diameter in inches.	Length of the column or pillar in feet.—Form											
	6	7	8	9	10	11	12	13	14	15	16	17
	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons
1	0·41	0·33	0·27	0·23	0·19	0·17	0·14	0·12	0·11	0·10	0·09	0·0
1½	1·40	1·21	1·05	0·92	0·80	0·70	0·62	0·55	0·49	0·44	0·39	0·3
2	3·04	2·75	2·48	2·23	2·01	1·81	1·63	1·47	1·33	1·21	1·10	1·0
2½	5·30	4·93	4·57	4·21	3·88	3·57	3·27	3·01	2·77	2·55	2·35	2·1
3	8·14	7·72	7·28	6·84	6·40	5·85	5·58	5·21	4·85	4·52	4·21	3·9
3½	11·55	11·08	10·58	10·08	9·56	9·05	8·55	8·07	7·60	7·16	6·74	6·3
4	15·50	15·01	14·47	13·91	13·33	12·74	12·15	11·57	11·01	10·46	9·93	9·4
4½	20·01	19·49	18·92	18·31	17·68	17·03	16·37	15·71	15·05	14·41	13·77	13·1
5	25·05	24·52	23·92	23·28	22·61	21·91	21·19	20·46	19·72	18·99	18·26	17·5
5½	30·64	30·09	29·48	28·81	28·10	27·36	26·59	25·80	24·99	24·19	23·38	22·5
6	36·76	36·20	35·57	34·89	34·15	33·37	32·56	31·72	30·86	29·98	29·11	28·2
6½	43·42	42·85	42·21	41·51	40·75	39·94	39·09	38·21	37·30	36·37	35·43	34·4
7	50·62	50·04	49·39	48·67	47·89	47·06	46·18	45·27	44·32	43·34	42·34	41·3
7½	58·35	57·76	57·10	56·38	55·58	54·73	53·83	52·88	51·89	50·87	49·83	48·7
8	66·61	66·03	65·36	64·62	63·81	62·94	62·02	61·05	60·03	58·97	57·88	56·7
8½	75·41	74·82	74·15	73·40	72·58	71·70	70·76	69·76	68·72	67·63	66·50	65·3
9	84·75	84·15	83·47	82·72	81·89	81·00	80·04	79·02	77·95	76·84	75·68	74·4
9½	94·61	94·02	93·34	92·57	91·74	90·83	89·86	88·83	87·74	86·60	85·41	84·1
10	105·02	104·42	103·73	102·97	102·12	101·21	100·12	99·18	98·07	96·91	95·69	94·4
10½	115·95	115·35	114·66	113·89	113·04	112·12	111·13	110·06	108·94	107·76	106·53	105·2
11	127·42	126·82	126·13	125·35	124·50	123·57	122·57	121·49	120·36	119·16	117·90	116·6
11½	139·43	138·82	138·13	137·35	136·49	135·55	134·54	133·46	132·31	131·10	129·83	128·5
12	151·97	151·37	150·66	149·88	149·02	148·08	147·06	145·97	144·81	143·58	142·29	140·9
12½	165·04	164·43	163·73	162·95	162·08	161·13	160·11	159·01	157·84	156·60	155·29	153·9
13	178·64	178·03	177·33	176·55	175·68	174·73	173·69	172·59	171·41	170·16	168·84	167·4
13½	192·78	192·17	191·47	190·68	189·81	188·85	187·82	186·70	185·52	184·26	182·93	181·5
14	207·45	206·84	206·14	205·35	204·47	203·51	202·47	201·36	200·16	198·89	197·56	196·1
14½	222·66	222·05	221·34	220·55	219·67	218·71	217·67	216·54	215·34	214·07	212·72	211·3
15	238·40	237·79	237·08	236·29	235·41	234·44	233·40	232·27	231·06	229·78	228·42	227·0
15½	254·65	254·06	253·35	252·56	251·68	250·71	249·65	248·52	247·31	246·02	244·66	243·2
16	271·48	270·87	270·16	269·36	268·36	267·51	266·46	265·32	264·10	262·81	261·44	259·9
16½	288·82	288·21	287·50	286·70	285·82	284·84	283·79	282·65	281·42	280·12	278·75	277·3
17	306·70	306·08	305·37	304·57	303·69	302·71	301·65	300·51	299·28	297·98	296·59	295·1
17½	325·11	324·49	323·78	322·98	322·09	321·12	320·05	318·91	317·68	316·37	314·98	313·5
18	344·04	343·43	342·72	341·92	341·03	340·05	338·99	337·84	336·60	335·29	333·90	332·4
18½	363·52	362·91	362·20	361·40	360·50	359·52	358·46	357·31	356·07	354·75	353·35	351·8
19	383·53	382·92	382·21	381·40	380·42	379·53	378·46	377·31	376·07	374·74	373·34	371·8
19½	404·08	403·46	402·75	401·94	401·05	400·07	399·00	397·84	396·60	395·27	393·87	392·3
20	425·15	424·53	423·82	423·02	422·13	421·14	420·07	418·91	417·67	416·34	414·93	413·4
20½	446·76	446·14	445·43	444·63	443·73	442·75	441·68	440·51	439·27	437·93	436·52	435·0
21	468·91	468·29	467·58	466·77	465·88	464·89	463·81	462·65	461·40	460·07	458·65	457·1
21½	491·58	490·96	490·25	489·45	488·55	487·56	486·49	485·32	484·07	482·73	481·31	479·8
22	514·80	514·18	513·46	512·66	511·76	510·77	509·69	508·53	507·27	505·93	504·51	503·0
22½	538·54	537·92	537·21	536·40	535·50	534·51	533·44	532·27	531·01	529·67	528·24	526·7
23	562·82	562·20	561·48	560·68	559·78	558·79	557·71	556·54	555·28	553·94	552·51	551·0
23½	587·63	587·01	586·30	585·49	584·59	583·60	582·52	581·35	580·09	578·74	577·31	575·7
24	612·97	612·36	611·64	610·83	609·93	608·94	607·86	606·69	605·43	604·08	602·65	601·1

drical Pillars, on the supposition that the direction of the force coincides with the surface.— it the angle of meeting, in the body of the page, is the load required in tons.

:ulation, load $= \dfrac{2390{\cdot}5 \times \text{diameter}^4}{2240\ (\text{diam.}^2 + 0{\cdot}045 \times \text{length})}$.

	19	20	21	22	23	24	25	26	27	28	29	30
.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.	tons.
7	0·06	0·06	0·05	0·05	0·04	0·04	0·04	0·03	0·03	0·03	0·03	0·03
2	0·29	0·27	0·24	0·22	0·21	0·19	0·18	0·17	0·15	0·14	0·13	0·13
2	0·84	0·78	0·72	0·66	0·61	0·57	0·53	0·50	0·46	0·43	0·41	0·38
1	1·85	1·72	1·60	1·49	1·39	1·30	1·21	1·14	1·07	1·00	0·94	0·89
7	3·42	3·20	3·00	2·81	2·61	2·48	2·33	2·19	2·07	1·95	1·85	1·75
7	5·62	5·29	4·99	4·71	4·44	4·20	3·97	3·75	3·55	3·37	3·20	3·04
3	8·47	8·04	7·62	7·23	6·86	6·52	6·19	5·89	5·60	5·33	5·07	4·84
6	11·99	11·44	10·91	10·41	9·93	9·48	9·05	8·64	8·25	7·88	7·53	7·20
5	16·17	15·51	14·87	14·26	13·67	13·10	12·56	12·03	11·54	11·07	10·84	10·18
3	21·00	20·24	19·49	18·77	18·07	17·39	16·73	16·10	15·49	14·90	14·34	13·80
4	26·47	25·61	24·77	23·94	23·13	22·34	21·57	20·82	20·10	19·40	18·73	18·08
2	32·57	31·62	30·68	29·75	28·84	27·94	27·07	26·21	25·38	24·57	23·78	23·02
0	39·27	38·24	37·22	36·20	35·19	34·20	33·22	32·26	31·32	30·40	29·50	28·63
7	46·58	45·48	44·37	43·27	42·18	41·09	40·02	38·96	37·92	36·89	35·89	34·90
3	54·47	53·31	52·14	50·96	49·78	48·61	47·45	46·30	45·15	44·03	42·92	41·83
5	62·95	61·73	60·49	59·24	57·99	56·75	55·50	54·26	53·03	51·81	50·60	49·41
5	71·01	70·73	69·43	68·12	66·81	65·49	64·16	62·84	61·52	60·23	58·92	57·63
2	81·62	80·30	78·95	77·59	76·21	74·82	73·43	72·03	70·64	69·24	67·86	66·48
4	91·81	90·44	89·05	87·63	86·20	84·75	83·29	81·83	80·36	78·89	77·42	75·95
1	102·55	101·14	91·71	98·25	96·76	95·26	93·74	92·21	90·68	89·13	87·59	86·05
4	113·84	112·41	110·94	109·43	107·90	106·35	104·78	103·19	101·59	99·98	98·35	96·75
2	125·70	124·23	122·72	121·18	119·61	118·01	116·38	114·74	113·09	111·41	109·73	108·05
5	138·10	136·60	135·06	133·49	131·87	130·23	128·56	126·87	125·14	123·43	121·69	119·94
2	151·04	149·52	147·96	146·35	144·70	143·02	141·31	139·57	137·81	136·03	134·24	132·42
3	164·54	162·99	161·40	159·76	158·09	156·37	154·62	152·84	151·04	149·21	147·36	145·49
)	178·58	177·01	175·40	173·73	172·03	170·28	168·49	166·66	164·83	162·95	161·05	159·13
)	193·16	191·57	189·94	188·25	186·52	184·74	182·92	181·07	179·18	177·26	175·32	173·35
3	208·28	206·68	205·02	203·31	201·56	199·75	197·90	196·02	194·09	192·14	190·15	188·13
5	223·95	222·33	220·66	218·92	217·14	215·31	213·44	211·52	209·56	207·57	205·54	203·54
2	240·15	238·52	236·83	235·08	233·28	231·42	229·52	227·58	225·59	223·56	221·50	219·41
3	256·90	255·25	253·55	251·78	249·96	248·08	246·16	244·18	242·17	240·11	238·01	235·88
7	274·18	272·52	270·80	269·02	267·18	265·28	263·34	261·34	259·30	257·21	255·08	252·97
)•	292·00	290·33	288·60	287·00	284·95	283·03	281·06	279·04	276·98	274·86	272·71	270·51
7	310·36	308·68	306·94	305·13	303·25	301·32	299·34	297·30	295·20	293·06	290·88	288·65
3	329·26	327·57	325·81	324·00	322·10	320·16	318·15	316·09	313·98	311·81	309·60	307·35
2	348·69	346·99	345·23	343·39	341·49	339·53	337·51	335·43	333·30	331·11	328·88	326·60
)	368·67	366·96	365·18	363·33	361·42	359·45	357·41	355·31	353·16	350·96	348·70	346·39
1	389·17	387·46	385·67	383·81	381·89	379·90	377·85	375·65	373·57	371·34	369·07	366·74
3	410·22	408·49	406·70	404·83	402·90	400·90	398·83	396·70	394·52	392·28	389·98	387·63
5	431·79	430·07	428·26	426·39	424·44	422·43	420·35	418·21	416·01	413·75	411·43	409·06
7	453·91	452·17	450·36	448·48	446·53	444·50	442·41	440·26	438·04	435·77	433·43	431·04
2	476·56	474·82	473·00	471·11	469·15	467·12	465·01	462·85	460·62	458·33	455·98	453·57
1	499·75	498·00	496·17	494·28	492·31	490·26	488·15	485·97	483·73	481·43	479·06	476·63
1	523·47	521·71	519·88	517·86	516·00	513·95	511·83	509·64	507·39	505·07	502·69	500·24
)	547·72	545·97	544·13	542·22	540·23	538·17	536·04	533·84	531·58	529·24	526·85	524·39
)	572·51	570·75	568·91	566·99	565·00	562·93	560·79	558·59	556·31	553·96	551·56	549·09
2	597·84	596·07	594·23	592·30	590·30	588·23	586·08	583·86	581·58	579·22	576·80	574·32

The arrangement of the preceding Table will be readily understood, but since it admits of various applications, the manner of using it will be best elucidated by the resolution of a series of examples adapted to the several cases.

EXAMPLE *a*.—The length of a cylindrical column of cast iron is 11 feet, and its diameter 11 inches; what load will it bear with safety, on the supposition that it is solid, and the direction of pressure coincident with the surface, or distant from the axis by half the diameter of the column?

Entering the Table with 11 feet at the top of the page, and 11 inches in the left-hand margin, under the one and opposite the other in the body of the page, we find 123·57 tons for the required load.

Hence it appears that in a case of actual practice, if we are certain that the load is so adjusted as to throw the direction of pressure into a position between the surface and the axis, there will be no danger of failure, even although the column should be strained with a greater load than that determined above; but since there is no possibility of assigning the true direction of the straining force, it is not advisable to load the column with more than what the Table indicates. If it is necessary that a greater load than this should be supported, the diameter of the column must be increased accordingly, and this brings us to another case of the problem, as expressed in the following example:

EXAMPLE *b*.—Suppose the length of a cast iron cylindrical column to be 11 feet; what ought its diameter to be, so that it may be able to support 174¾ tons, under the conditions specified in the preceding example?

In order to answer this question, we must enter the Table with the given length at the top of the page, and run down the corresponding column of numbers, till we find a load that agrees either exactly or nearly with the load proposed; then in the left-hand margin, opposite to the load thus found, will be exhibited the required diameter. In the present example the diameter corresponding to the given length and load is 13 inches, so that by comparing the several circumstances of these two examples, we find that by increasing the diameter of the column by a quantity equivalent to 2 inches, the strength is increased 51·18 tons, for $174{\cdot}75 - 123{\cdot}57 = 51{\cdot}18$. From this we infer, that a cylindrical tube or hollow column of cast iron whose outer and inner diameters are 13 and 11 inches respectively, will bear a load of 51·18 tons, admitting the direction of pressure to coincide with its surface; whereas, the same quantity of metal in the solid state, and under the same conditions, would bear only about 47 tons, for in that case the diameter would be very nearly 7 inches, which, with a length of 11 feet, corresponds to 47·06 tons. This result points to the propriety of casting the columns hollow, for we not only gain a greater strength with the same quantity of material, but the stability is also increased in a higher degree.

Example c.—The length of a hollow cylindrical column of cast iron is 11 feet, the exterior diameter 11 inches, and the thickness of metal $\frac{3}{4}$ of an inch; how much ought it to be loaded with, admitting the direction of the strain to coincide with the surface?

The solution of this example has been anticipated in that of the preceding, but since it is a case which has actually been executed, we have thought proper to state it as a distinct question.

The exterior diameter being 11 inches, and the thickness of metal $\frac{3}{4}$ of an inch; it follows that the interior diameter is $9\frac{1}{2}$ inches, for $11 - \frac{3}{4} \times 2 = 9\frac{1}{2}$. Therefore it is as follows:

Under 11 feet at top and opposite 11 inches in the margin, we have				123·57 tons.
„	11	„	$9\frac{1}{2}$ „	90·83
Therefore, the load with which the column ought to be charged should not exceed				32·74 tons.

When considering the strength of beams exposed to a transverse strain in the preceding part of this Paper, we adopted a law which had been established by Dr. Young, for reducing the portions of the metal that were to be abstracted, in order to obtain the true strength of the portions that remained to form the section. In the case of columns, however, we have no precedent of such a law being adopted, but we can see no satisfactory reason why it should not, especially when the material is cast iron or other granular metal; for it is manifest that the arrangement of the particles must be the same, whether we consider the mass longitudinally or laterally: this, certainly, is not the case with regard to timber, but it is cast iron that we are contemplating, and if the law is applicable and correct for one kind of resistance, we cannot reconcile ourselves to the exclusion of its effects in another kind, while the material remains the same.

To apply the law of tension in the present case, we have $11 : 9\frac{1}{2} :: 90·83 : 78·444$ tons; consequently the load, as thus corrected, becomes $123·57 - 78·444 = 45·126$ tons, being an increase on the former result of 12·386 tons; but, with respect to the adoption of the law from which the difference arises, we leave our readers to form their own opinion; ours is decidedly in its favour, and we would therefore apply it in all cases where it is practicable; but, in the following examples, the conditions of the parts are so related that the effect of tension cannot be estimated but by trial or the rule of position.

EXAMPLE *d.*—The length of a hollow cylindrical column of cast iron is 11 feet, and its exterior diameter 11 inches; what must be the thickness of metal, that it may be competent to sustain a load of $60\frac{2}{3}$ tons, admitting the direction of pressure to coincide with the surface of the column, and taking the effect of tension into the account?

In the Table, under 11 feet at the top and opposite 11 inches in the margin, we find 123·57 tons for the strength of a solid column 11 inches in diameter; from which subtract the load which the fistular column is required to support, and the remainder will be the strength of a solid column corresponding to the inner diameter: thus we have $123{\cdot}57 - 60\frac{2}{3} = 62{\cdot}91$ tons; then in the column of numbers under the given length at the top of the page, the nearest number to 62·91 is 62·94, which corresponds to a diameter of 8 inches; the difference of the diameters is therefore $11 - 8 = 3$ inches, and the thickness of metal $1\frac{1}{2}$ inches. It is, however, obvious that a less thickness of metal will answer the purpose, if we can estimate the effects of tension.

Now one thing we know, that the reduced quantity, or that which is to be taken away to give the strength of the tube or fistular column, is 62·91; consequently the quantity from which it is reduced must exceed this, and of course it belongs to a greater diameter. Suppose the diameter to be $8\frac{1}{2}$ inches, the corresponding strength is 71·7 tons; then by the law of tension it is 11 : 8·5 : : 71·7 : 55·40 tons, but it ought to be 62·91; hence the error is 7·51 too little.

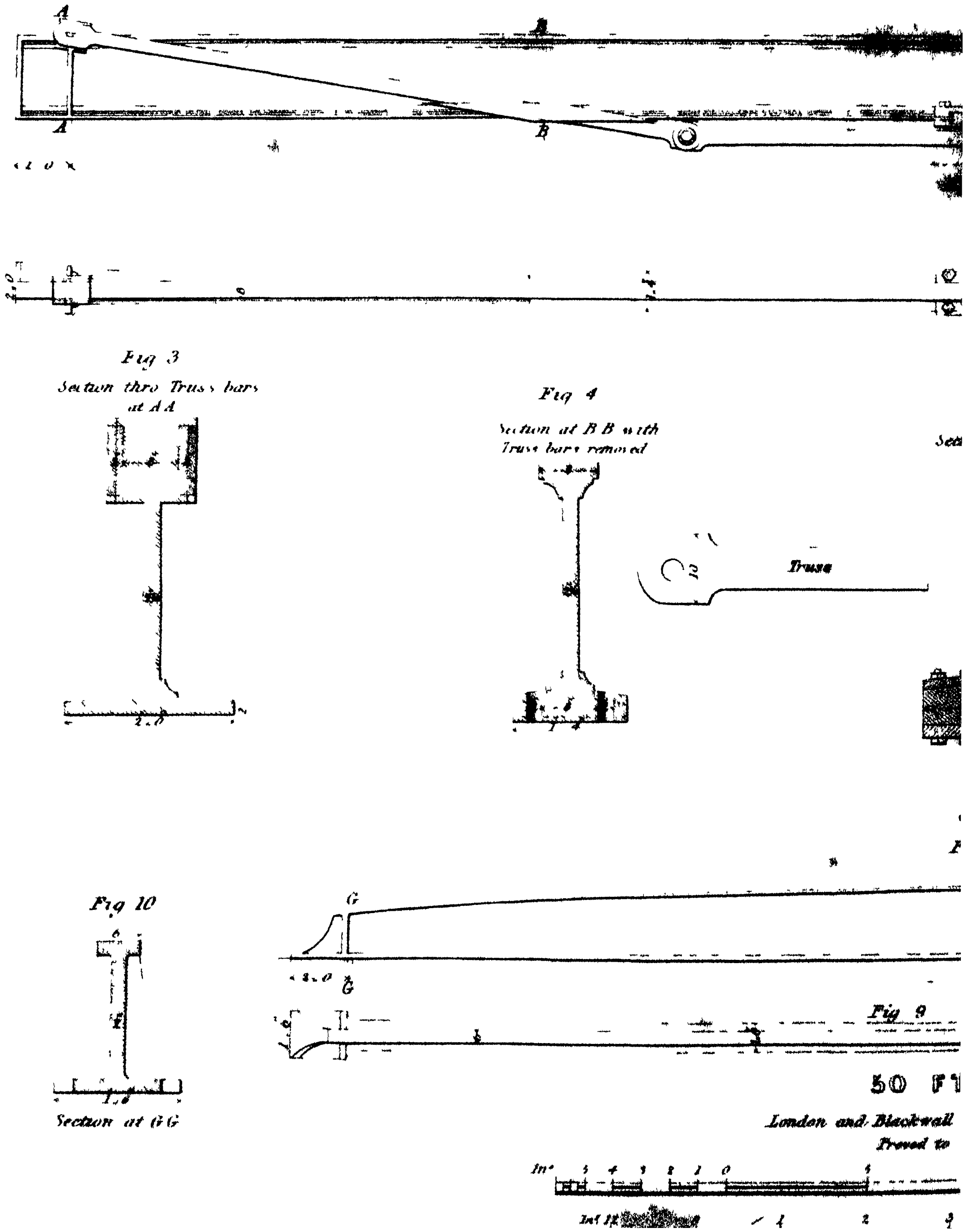
Again, suppose the diameter to be 9 inches, the corresponding tabular strength is 81 tons; therefore by the law of tension it is 11 : 9 : : 81 : 66·27 tons, but it ought to be 62·91; hence the error is 3·36 too much; consequently, by the rule of position, we have

$8{\cdot}5 \times 3{\cdot}36 = 28{\cdot}56$ first product,
$9{\cdot}0 \times 7{\cdot}51 = 67{\cdot}59$ second product,

10·87) 96·15 (8·85 inches,

70 FT. TR

Northern and Eastern



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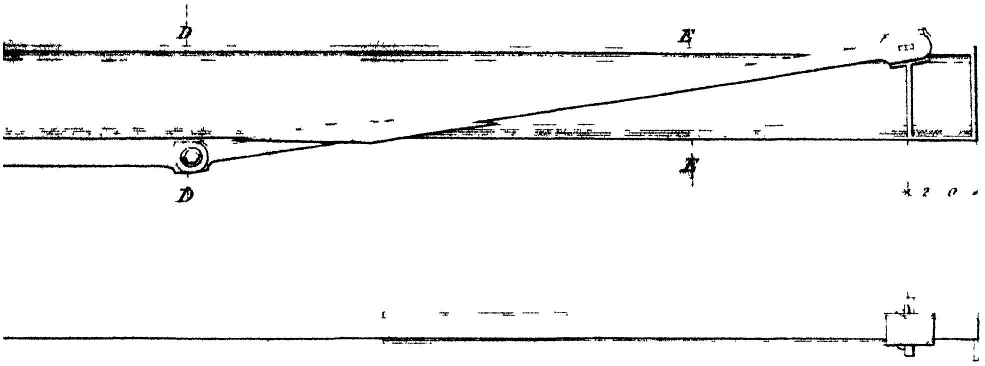


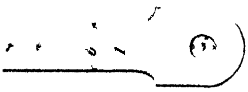


Fig 6

Section at DD

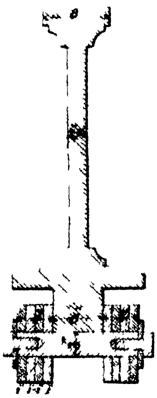
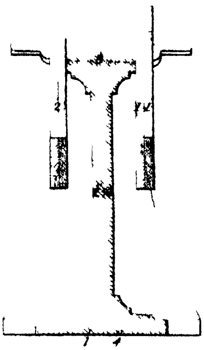


Fig 7

Section at EE



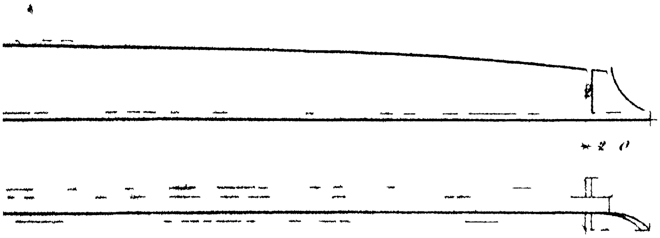
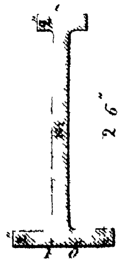
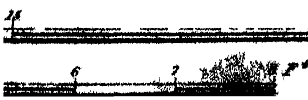


Fig 11



Section at HH

1 Dr Road



the approximate diameter, and therefore the thickness of metal is $(11-8{\cdot}85) \times {\cdot}5 = 1{\cdot}075$ inches, instead of $1\frac{1}{2}$ inches, as determined above.

EXAMPLE *e.*—Let the length remain as in the foregoing examples, and let the inner diameter be 9 inches; what must be the exterior diameter, that the column may be competent to sustain a load of 80 tons, the effect of tension not being considered?

Under 11 feet, the given length, and opposite 9 inches, the given diameter, we find 81 tons for the strength of a solid column whose diameter is 9 inches; to this add 80 tons, the given load, and we have $81+80=161$ tons for the strength of a solid column whose diameter is sought. Then, in the column of numbers under 11 feet at the top of the page, the nearest to 161 is 161·13, which corresponds to a diameter of $12\frac{1}{2}$ inches; so that the thickness of metal is $(12{\cdot}5-9) \times {\cdot}5 = 1\frac{3}{4}$ inches. And in this manner may the Table be applied to the solution of any case that can be proposed.

As connected with the foregoing Paper on the Strength of Iron Girders and Columns, I annex drawings (Plate XVI.) of two girders of large dimensions, actually executed; one, figs. 1 to 7, being a trussed girder cast in two parts, having a clear bearing of 66 feet; the other, a single casting, having a bearing of 46 feet: this latter was proved to 28 tons at the centre. The drawings are so clear as to require no explanation.

HYDRAULIC PRESS FOR PROVING GIRDERS.

Girders, when cast, must be proved in order to ascertain their capacity to sustain the required weight or load. I give here the drawings and description of a light portable hydraulic press which has been used for this purpose.

The press shown on the Plates consists of two principal parts, viz., the pump by which water is forced through a pipe of small diameter, and the press, properly so called, or apparatus by which the water is made effective in pressing with any required force against the girders. Plates XVII. and XVIII.

The pump (F) comprises a pail for holding the water, with a barrel dipping into it, and a plunger fitted thereto. The pump is worked with a handle, and the intended pressure is indicated by the rising of a valve that acts against the under side of a graduated lever, which lever has been previously weighted according to the amount of the intended test.

The press consists of a strong cast iron cylinder with a solid piston or plug working within and through one end of it; at the other end the cylinder is bored only with a small aperture, with which the pipe from the pump communicates. In use, the open end of the cylinder is placed against the middle of the girders to be tested, and the piston is forced against them by the pressure of the water through the small pipe at the other end of the cylinder.

REFERENCES TO DRAWINGS OF PORTABLE HYDRAULIC PRESS FOR PROVING CAST IRON GIRDERS, &c.

A A. Girders, supported on wooden blocks (*a a*), and kept apart at the ends by cast iron plugs (*b b*).

B. Solid cast iron cylinder, turned on the outside, and bored within for

C. Solid cast iron piston called the "ram," accurately turned to fit the open end of the cylinder.

D D. Strong iron bracing bars, made of the best metal, with mortise holes punched in them for the tenons on the iron head (*h*). The lower bracing bar has a similar head formed at the front end of it, which also has a tenon for securing it to the top bar: the front head has a circular hole formed in it, as shown on the Plate, for clearing the nut that attaches the pipe to the cylinder. The bars and heads are held together by split keys (*c c*).

E. A light cast iron carriage supporting the cylinder, which rests in two half hoops (*d d*), that are attached to the handles (*e e*).

F. The pump forcing the water into the cylinder through the pipe (*j*), which has a boss joint at *k*.

n. Pump pail, made of cast iron.

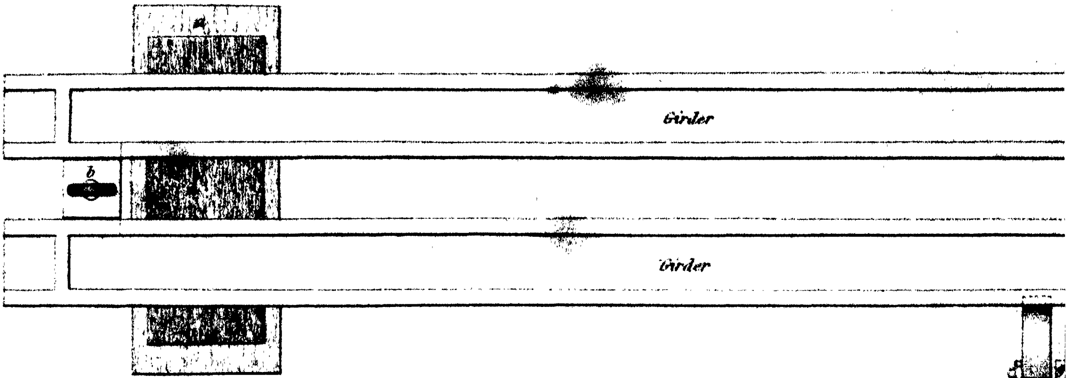
m m. Cast iron frame or standard, screwed to the lid of the pail; the sides of this frame have slots, as shown at *u*, in which

o—the handle is worked. At *t*, are two holes which are fitted with a pin that passes also through the pump-handle, and thus forms its fulcrum. The handle is attached at the outer of these holes while the pump is first worked, so as to lengthen the lift, and thus save time, but is shifted afterwards when the pressure increases.

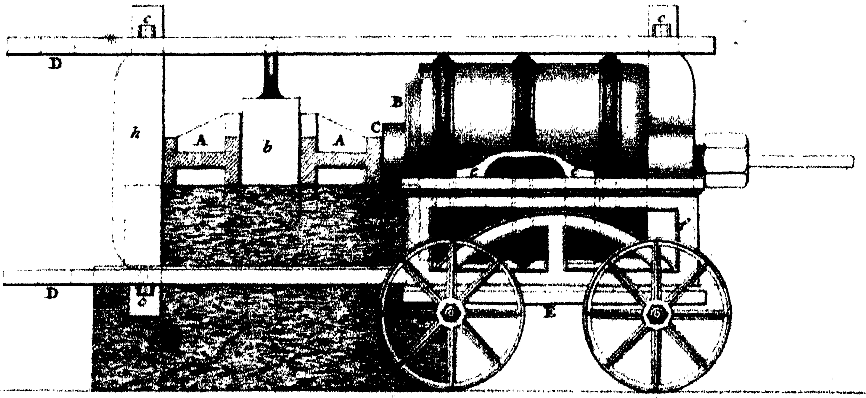
x—is the piston rod, which is made with a slot at *s*, in which a link that is also pinned to the pump-handle works.

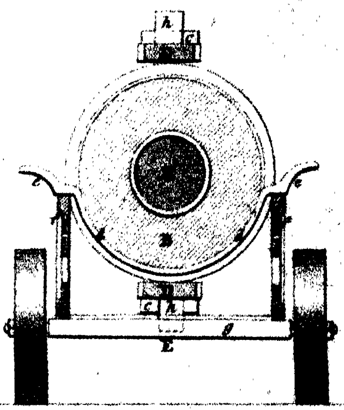
p—is a lever connected with a valve that is raised by the pressure of the water: this lever is graduated, and by loading it with the weight (*q*), suspended at either of these points of division, a pressure is obtained of the amount indicated at that point.

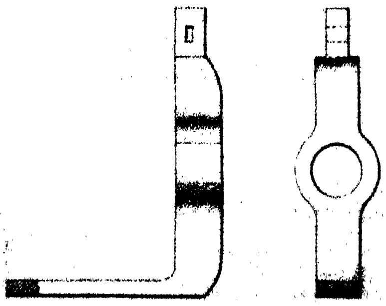
PORTABLE HYDRAULIC PRES



Side View of Cylinder Carriage & Section of Girders.

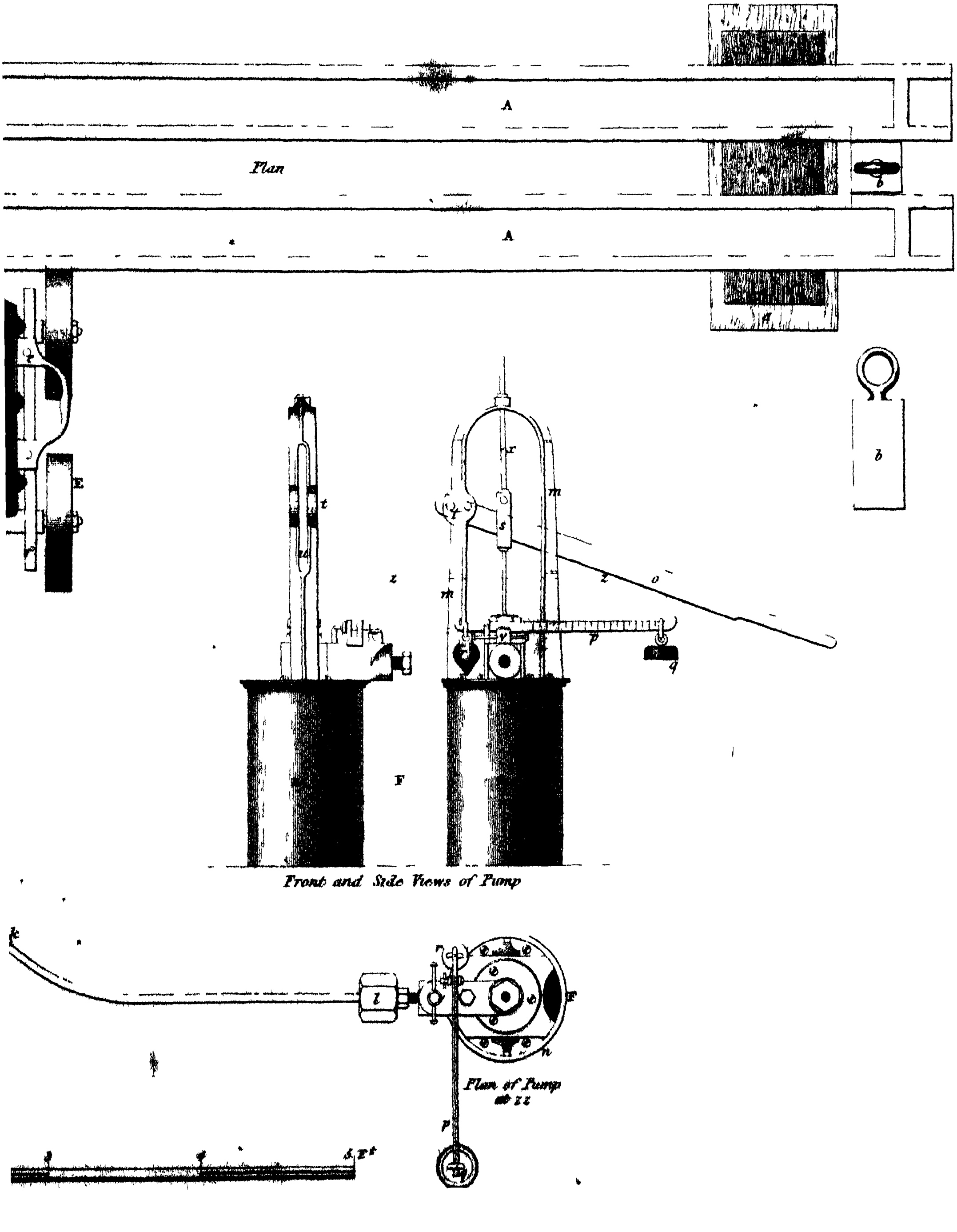






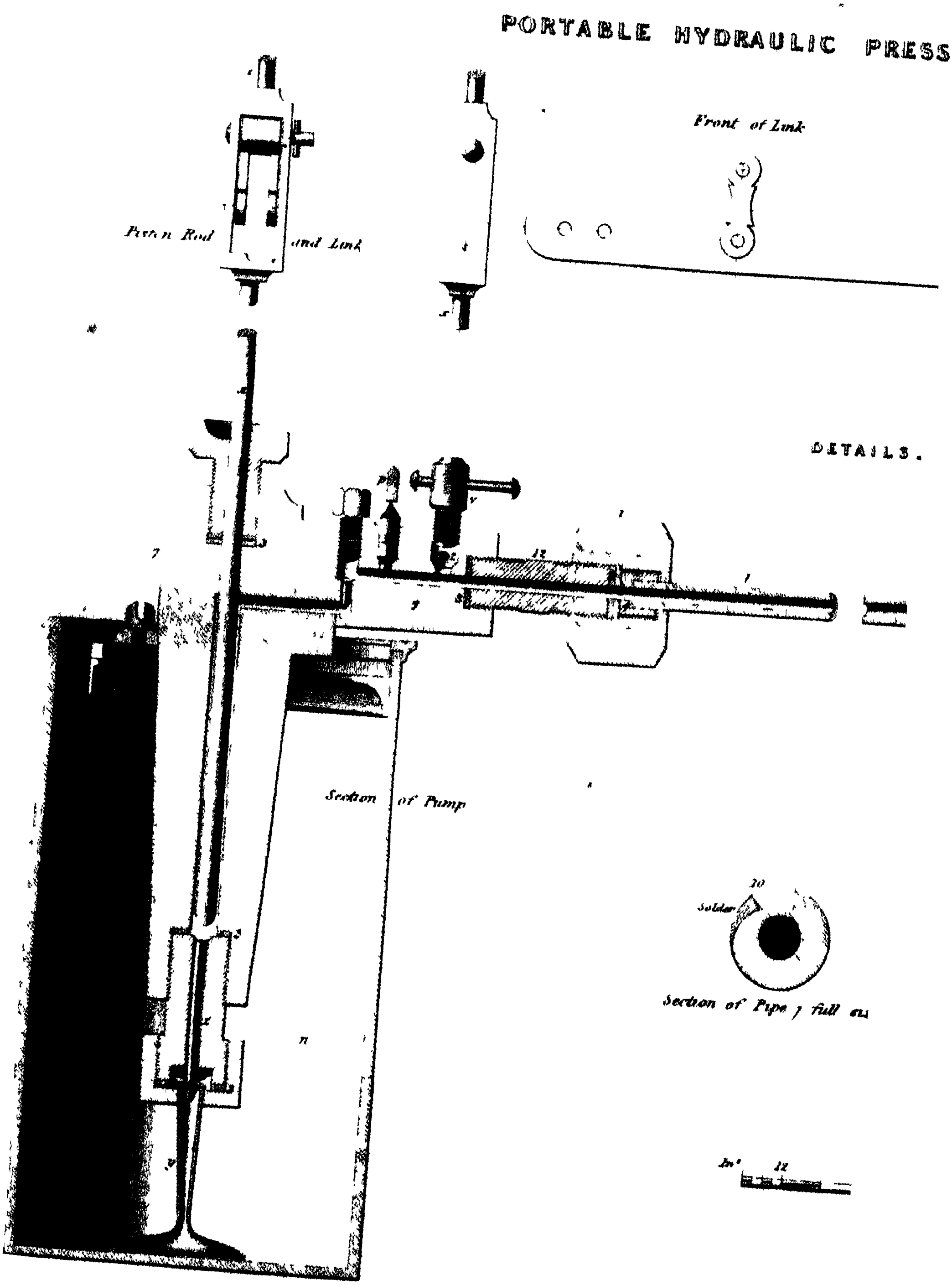
Front end of lower Bracing bar.

OVING CAST IRON GIRDERS, &c.



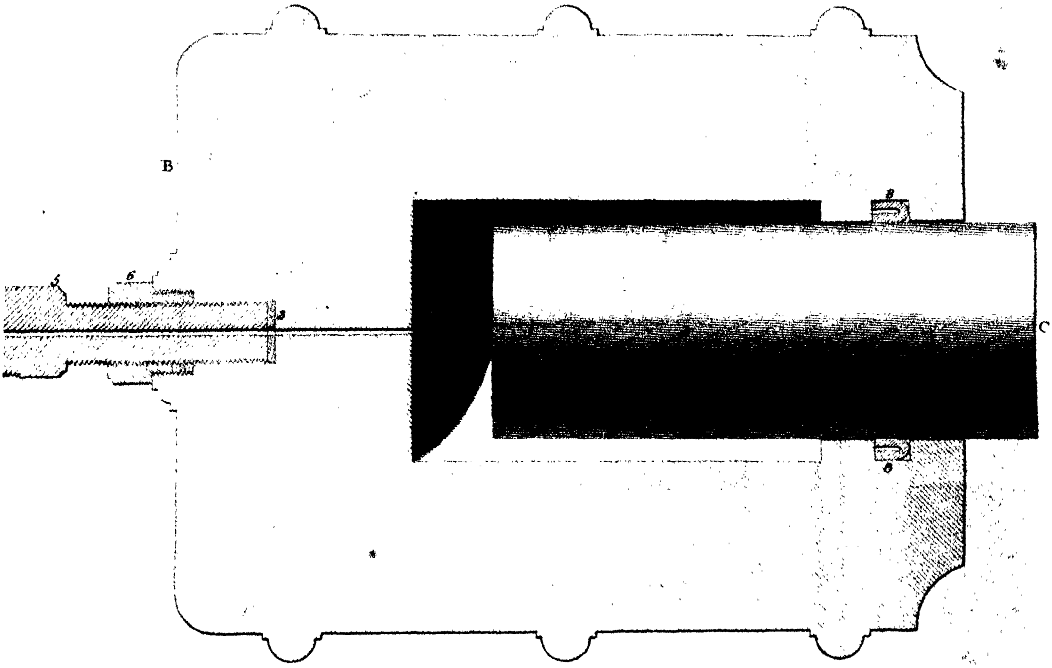
Front and Side Views of Pump

Plan of Pump at z z


PORTABLE HYDRAULIC PRESS
Front of Link
Piston Rod and Link
DETAILS.
Section of Pump
Solder
Section of Pipe 7 full size

ING CAST IRON GIRDERS, &c.

ndle



Section of Cylinder.

Scale.

r—is a weight to counterbalance that of the lever itself.
w—is an opening in the lid of the pail, through which it is filled with water.

Referring to the details, a section is shown through the centre of the pump and the cylinder. Plate XVIII.

7—is the barrel of the pump, made solid, but bored out for the piston rod (*x*) and the pipe (*j*), with their connexions.

y—is a funnel-shaped feeder, through holes in which the water is admitted beneath the plug (*z*). By the rising of this plug from its seating the water acts beneath the piston, and passes into the channel shown in the section, and then through the pipe (*j j*) into the cylinder.

1—is the valve already referred to, shown as acting against the lower surface of the lever (*p*).

v—is a screw with cylindrical head and sliding handle; this screw, while the pump is in use, is screwed down so as to cover the small hole 2; when it is desired to relieve the pressure, this screw is worked up, and the water escapes through the hole 2.

12—is a boss screwed into the trunk of the pump, and at the other end into the large nut (*i*).

5—is a similar boss screwed into the end of the cylinder through the socket 6, and screwed at the other end into the large nut (*l*).

4 4—are small bosses into which the ends of the pipe are securely brazed.

3 3 3—are leather washers.

The passage of the ram (C) within the cylinder is kept water-tight by the leather washer at 8, which is formed from one leather and fixed in a groove turned within the head of the cylinder. A metal spring is sometimes adapted to lie within this washer, and keep it distended.

The pipe (*j j*) is made of a strip of plate copper, one edge of which is beat thin to form the interior of the tube at 9. When the tube is formed, the shoulder formed by the outer edge of the plate at 10, serves to bed the solder for the joint.

The method of using the press is as follows: the girders being supported on blocks of wood, are laid with their sides downwards, and their under faces opposite to each other, at such a distance apart that the plugs (*b b*) fill the space at the ends, and are equally in contact with the opposing faces of both girders. These plugs are also carefully placed so that their inner edges correspond with the front edges of that part at the end of each girder intended to rest on the wall or other bearing-place when the girders are fixed. Care is taken that the girders bed fairly on the wooden blocks (*a a*); and if the flanges are of unequal width, wedges are put under the smaller flanges so as to keep the body of the girders in a truly horizontal position, and ensure that the pressure of the ram exerted in that direction shall be transmitted through both the girders in the same line in which the strain will be borne by them when in use.

The cylinder-carriage is wheeled to the side of the girders, and placed so that the head of the ram occupies the middle of the length of them; the lower bracing-bar is pushed into its place from the hinder end of the carriage, the head (*h*) dropped into that mortise hole in the lower bar which is close or the nearest to the girder, and the top bracing-bar secured by keys through the tenons of the head (*h*) and the front of the lower bar. When the depths of the girders are such that a space is unavoidably left between them and the head (*h*), this space must be quite filled with wedges or pieces of iron, of which a quantity is always at hand for this purpose.

The girders being thus properly kept apart at the ends and embraced with the cylinders by the bars, the copper pipe (*j*) is screwed, with a suitable wrench, into the end of the cylinder, and at the other end similarly connected to the pump (F). Of the whole of the apparatus, this pipe is the most liable to injury, and the bosses 4 4, into which the ends of it are brazed, require great attention to avoid their being strained off or loosened, for in such case the press is instantly rendered inoperative,—the water, driven forward with great force, oozes through the nuts (*i l*), and, of course, no pressure is produced against the ram. The best way of adjusting the pump so as to preserve this pipe, is to connect it with the cylinder first, letting an assistant support, without directing it: the screwed nut thus fixes the pipe without strain, and the pump must afterwards be moved to suit the other end of the pipe exactly, before they are connected. This being done, and the pail supplied with water, the orifice 2 closed with the screw (*v*), and the weight (*q*) placed on that point of the lever (*p*) which the scale for working the pump directs to produce the required pressure, the press is ready for use.

The pump is first worked until the plugs (*b b*) and packings between the girders and (*h*), if any, are found to be perfectly tight and immoveable; the pressure is now withdrawn by raising the screw (*v*), and suffering the water to escape, and the distance between the two girders at the point where the ram is situated is exactly measured. The press is then worked until the lever (*p*) is raised, taking care that as the pressure against, and the deflexion of, the girders increase, the pump must be worked with more care and less speed, because the girders are, by their deflexion from the right line, becoming constantly weaker; and therefore a hasty and violent action against them may occasion fracture, although they are fully equal to the maximum test allotted to them. As soon as the lever (*p*) is raised by the pressure of the water, the proof is complete, and the diminished distance between the girders is to be measured at the same point as before: half the difference between these two dimensions is, of course, due to each girder, and represents its deflexion under the prèssure. The screw (*v*) must now be slowly and carefully raised, and the girders will gradually resume their original form.

If it be desired to determine the deflexion of each girder independently, it is easily done by striking a chalked line along the upper surface, say the projecting flange of each girder, before proving, and by relaying the line to correspond at the ends with its first points: when the pressure is against the girders, the difference between its first and present positions at the centre shows its individual deflexion. By this expedient, also, two girders of different strength, but similar length, may be tested together, and the due deflexion assigned to each, or a small girder may be tested against a larger one with equal correctness of result.

VII.—*Description of the Saw Mills and Machinery for Raising Timber in Chatham Dock-yard. By* Mr. Dempsey.

The saw mills and hoisting machinery erected in Her Majesty's Dock-yard at Chatham in the year 1814, were designed and erected by Mr. Brunel, the engineer of the Tunnel under the River Thames. The river frontage of the dock-yard being occupied by slips for ship-building, it was necessary that the sawing machinery should be placed in the interior and higher part of the yard. Hence the timber arriving at the river front would require to be conveyed a considerable distance, and also raised to the saw mill. For these demands Mr. Brunel provided by floating the timber through a tunnel partly subterranean, and thence raising it within a brick shaft by the descent of a counterpoise of water. Further, he designed that the steam engine which should work the saws, besides pumping water into the contiguous barracks, &c., should also be made to raise the timber to a still higher level than that of the yard, and, by means of a crane travelling on an inclined plate railway, deposit it for stacking in any part of a range of 800 feet adjoining the railway on either side.

These arrangements, with the entire machinery erected, are represented on Plates XIX. to XXVIII.

Plates XIX. and XX. exhibit generally the tunnel, the brick shaft, the railway with a curved slip constructed of cast iron, on which timber to be sawn is made to descend to the immediate front of the sawing-shop. They also show the relative positions of the counterpoise water tank, with gearing above, and the drag with chains on which the log is placed in order to raise it.

Plate XXI. represents elevation and details of the travelling crane, and shows the construction of the railway on which it runs.

Plate XXII. contains the remaining details of the crane, and exhibits the large drum, &c., on which the crane chain is wound.

Plate XXIII. represents completely the counterpoise tank, with machinery for lowering it, and the drag on which the timber is raised.

Plates XXIV., XXV., XXVI., XXVII., and XXVIII., represent elevations, sections, &c., of one of the saw mills, and exhibit distinctly the modified apparatus used, whether for sawing large logs and whole timbers, or sawing deals into square and weathered boards.

In Plates XIX. and XX. the same letters refer to the same parts.

Fig. 1. General elevation of hoisting machinery, sectional through the brick shaft.

Fig. 2. Side elevation of ditto; also sectional through shaft and through the well into which the tank is lowered.

Fig. 3. General plan of shaft, railway, and slip.

Fig. 4. Side elevation of slip.

A, iron standards cast in lengths and bolted together. B, brick shaft, into which the water of the River Medway is admitted through (C), the tunnel, opening into the side of the shaft. Along one side of the tunnel, and also around the interior of the shaft, is the towing-path or pavement (D), being formed of stone landings, bedded on brickwork. E, a platform of wood supported on an iron frame attached to the standards (A): the front of this platform is curbed, and flush with the front of the standards, so as to give room for the attendant, without interfering with the ascent and descent of the drag (F), on which the log to be raised is placed. For this purpose the drag is lowered under water until its upper surface is below the bottom of the log, which is then hooked over it while the tank is lowered. G, chain attaching the drag to the drums at J, which are keyed on the same shaft with other drums having chains attached to the counterpoise tank (K).—H, cast iron open girders, made in semi-arches joined by flanches and bolts. The middle girder, with the standards (A), support four cross girders (the two on A are shown in dots) on the same level, and which carry the tank machinery. The arch girders also support cross girders above, on which are fixed the stone landings (I), on the same level with the yard. K is the tank, made of boiler plate iron, riveted and strengthened internally by diagonal and cross stay-rods. J, the machinery for lowering the tank. L, longitudinal timbers, on which the iron plate rails (M) are bolted down with countersunk screw bolts. These rails are cast in 6-feet lengths, jointed obliquely, and have an external rim or guard for the wheels of the crane. The railway inclines 22 inches vertically for every 100 feet of horizontal length. N is a cast iron stop or guard bolted to the timber to prevent the crane over-running at that end. O, cast iron columns, on which the railway timbers are supported. These columns stand on cylindrical stone blocks, and are connected laterally by open girders (P), on which are the bearings for iron sheaves or pulleys (Q) that turn freely on their centres, and support the chain by which the crane is drawn up. R is the frame of the travelling crane, which is mounted on wheels adapted to the plate railway, and descends it by its own gravity, being brought up by a chain wound on a drum that is turned by the steam engine. S are stone steps built in the shaft for descending it. T, girders bolted to the standards (A).—U, counterfort of brickwork, and capped with stone. V, impost or springing stones for the girders (H).—W, well in which the tank is received. This well was originally designed to keep the condensed water from the engine, with which the tank is charged, separate from the river water admitted through the tunnel, and a 7-inch syphon with 22-feet lift was provided to return the condensed water; but this provision has been found practically needless, as the supply is superabundant. X, section of brickwork of shaft. Y (fig. 3) are bearings for levers, by which motion is transmitted from the engine to a toothed rack (see I, Plate XXI.) that works the crane. Z are the stone blocks of columns already described.

In discharging logs of timber from the slings of the travelling crane which it has hoisted from the shaft or brought up the railway from the stacks, and which are intended for the saw mills, the logs are not at once unslung and sent down the slip, but are stopped against the catches (*a*); these catches are keyed upon the same shaft (*b*) with a curved arm (*c*), the other end of which is kept down by the spring (*d*). When the log has been detached from the crane slings, the spring (*d*) is drawn back, and the log thus allowed to press down the catches (*a*), and descend the slip. The three cast iron parallel frames (*e*), forming the slip, are supported on iron columns similar to those supporting the railway, and terminate in lines parallel with the ground, bedded in masonry (*f*): this gives facility for placing wooden rollers beneath the log, on which it is drawn into the sawing-shop.

In Plates XXI. and XXII. the same letters refer to the same parts in the following figures:

Fig. 5. Elevation of travelling crane, sectional through the roof.

Fig. 6. Cross section of ditto, showing gearing, clutches, &c., omitting the roof and upper pulleys.

Fig. 7. Front elevation of ditto, showing wheels for turning it round, omitting roof, &c.

Figs. 8, 9. Front and side views of chain enlarged.

Fig. 10. End view of a log in the slings.

Fig. 11. Self-acting grip enlarged.

Fig. 12. Partial plan of crane, showing the rack and tooth by which the hoisting machinery of the crane receives motion from the steam engine.

Fig. 13. Plan of gearing, &c., attached to the central column of the crane.

Fig. 14. Side elevation of the clutch, &c.

Fig. 15. Underneath plan of roof, and upper framing of crane; half below upper pulleys, and half below lower pulleys.

A, front and hind wheels, of different diameters to allow for the inclination of the railway and keep the frame of the crane horizontal. B, centre wheels. These six wheels are of cast iron; they support the frame of the crane, and have broad flat rims adapted for the rails.

The chain by which the crane is drawn up the railway is attached by a contrivance that may be called a grip, and is thus constructed:

C is a long lever of unequal arms. D, the chain, one end of which is wound on a drum of 12 feet diameter that receives motion from the engine. E, a pin or stud formed at the end of the shorter arm of the lever (C), on which stud the extreme link of the chain (D) is placed. F, an iron stop-piece fixed on the timber (L). G, stock, against which the pin (E) presses when the chain is on it. The weight of the lever (C), and the downward tension of the chain, are sufficient to retain it firmly on the stud (E). But in case of the crane being overdrawn at the upper end of the railway, it will be seen that the lever (C) will itself detach the chain by running up the stop (F), and dropping the stud (E).

The power from the steam engine is transmitted through a series of levers, of which H are two, to a toothed rack (I), which, being jointed to H, receives an alternating motion. The machinery of the crane by which this alternating movement of the rack (I) is made to raise the chain slings bearing the logs of timber, is the following: J is a pin or tooth fixed at the ends of two side bars (K), lowered or raised by a handle jointed to them, and thus connecting the crane machinery with the steam engine, or disconnecting it. The side bars (K) are jointed to the projecting arm (M) of a toothed arc (N), that has bearings on the framing of the crane, and works a pinion (O).—On the other end of the shaft (P) of this pinion is a mitre wheel (Q), working with a mitre pinion (R) on a vertical shaft that also bears a spur wheel (S), which gives motion to two pinions (T).—Each of these pinions has a worm (U) in its shaft, working a worm wheel (V). The worm wheel (V) is attached to the two drums (W), extending on both sides of it, and on each of these drums a chain (X) is wound. These four chains pass over pulleys (Y and Z), revolving in bearings fixed to the upper frame-work of the crane carriage, and terminate in sling chains (*q q*), in which a log is suspended on each side of the crane.

Between the worms (U) and the pinions (T) are two clutches (*a*), which slide on keys on the shaft (*b*). Each of these shafts is embraced by a forked lever (*l*, fig. 14), which has a counterweight (*m*), and is at the other end jointed to the vertical rod (*k*). The rods (*k*) are attached above to handles (*j*), by which the attendant alternately lowers and raises them, so as in the one case to close the clutch (*a*), while the forward movement of the rack (I) winds the chain on the drum (W), and in the other to raise and thus disengage the clutch, while the reverse motion of (I) would unwind it.

When the crane has been loaded with one log raised from the drag (F, Plate XIX.), it becomes necessary to turn the crane round, in order either to discharge the log down the slip, or to load the crane with another, and ultimately convey the two logs down the railway for stacking in the yard. The apparatus for doing this is as follows: The upper circular framing of the crane has eight smaller rollers 2 (fig. 6), which run on a ring within the lower circular framing; it also has a horizontal ring 1, toothed on its under surface. This circular rack, with the whole of the framing and machinery above, is made to revolve by the toothed pinion (*z*), which works into this toothed ring. On the shaft of this pinion is a wheel (*y*) which, by an intermediate pinion (*x*) and the pinion (*w*), is turned by a handle fixed in the shaft of *w*. These wheels and bearings are attached to the lower and fixed framing of the crane.

In order to deposit the timber on the head of the slip, it has to be lowered through a short distance: this is effected by a hand wheel (*d*), which has on its shaft a mitre pinion (*e*), working another mitre pinion (*f*), keyed on the same vertical shaft (*i*) with the lower pinions (T) already described: *h*, handle of friction band of the wheel (*d*).

To prevent the crane descending the railway while in use over the shaft, a lever (*r*), which turns independently on the axis of the centre wheel (B), has a projection at *u*, which is screwed down into a notched plate on the upper surface of the timber (L) by the screw (*t*), worked by the handle (*s*).

g—is the main column, firmly attached to the upper circular framing, and, in conjunction with the four small columns (3 3), supporting the annular frame (4), the pulleys, slings, &c., and the roof (5), which is made of thin sheet iron plates, riveted together.

In figs. 8 and 9, *a b* are the projecting links which work in grooves on the drums (W).

In Plate XXII. the same letters refer to the same parts in the following figures:

Fig. 16. Elevation of drum for receiving the crane chain.

Fig. 17. Half side elevation and half cross section of ditto.

Fig. 18. Frame and small drum for supporting and guiding the chain.

A—cast iron frame supporting the front gudgeon of the drum; the other works in a plummer block (B), occupying a recess in the wall (Q). C are the arms of the drum, of which there are twelve; the rim of the drum is made in six pieces, each sextant being cast with two arms and a similar portion of a nave ring. D, a pinion connected with the main shaft of the steam engine, and which works the drum by means of the teeth formed on the face of the rim of it. E, wooden battens 5 inches wide, screwed on the periphery of the drum to receive the chain; these battens are strengthened by an internal ring of wrought iron (F), and the drum is stayed laterally by the diagonal and cross stay rods (G and H), connected at I with the nave and at J with the arms of the drum. K are the snugs or eyes for bolting the sections of the rim together. L is a sheave or pulley on which the chain is conducted; the channel in which the chain passes has projecting teeth, which are caught by the links, and thus ensure the rotation of the pulley. In order to wind the chain evenly across the width of the drum, this pulley (L) is placed on a screwed shaft (N), the screw being pitched so that L moves 2 inches laterally on its shaft, for each revolution of the large drum. One end of the shaft has bearing in the frame (M), suspended from the rafter above, and the other works in a block (O) in a recess in the wall (Q).

In Plate XXIII. the same letters refer to the same parts in the following figures:

Fig. 19. Side elevation of machinery for lowering the tank.

Fig. 20. Front elevation of ditto.

Fig. 21. Plan of tank.

Fig. 22. Front elevation of drag on which the timber is raised.

Fig. 23. Side view of ditto.

Fig. 24. Section of well, showing water governor.

Figs. 25 and 26. Side and back views of standard, showing the rack, &c., for working the valves above.

A—tank constructed of boiler plate iron, riveted, strengthened by internal cross and diagonal stay rods, and having eyes by which it is attached to the four chains (B) that are wound upon the four grooved drums (C). On the same shaft with these are two larger grooved drums (D), and on these are wound the chains (E) which pass over pulleys on the top of the standards (*q*) (marked A in Plates XIX. and XX.), and are attached to the drag. In fig. 20, two of the drums (C), and one (D), are shown in section. To stop the descent of the tank when necessary, a friction wheel and band (F) are fixed in the drum shaft, and brought into action by a lever (G) connected by the sling (H) with the lever (I).—J is the fulcrum of this lever, and at the other end of it is jointed a long handle (K), which is within the reach of the attendant who occupies the platform (E, in figs. 1 and 2, Plate XIX.).

To fill the tank: L is the water pipe which delivers the condensed water from a tank supplied from the steam engine into the chamber (M).—N, sluice for closing the water way. P, the lower part of the chamber (M), fitted internally with a valve, of which Q is the rod, connected by a cross pin below with the vertical rods (R), which are braced above, and connected by a link (S) with the lever (T). This lever turns on a fulcrum at U, and is jointed to a rod (V), terminating below in a rack (W), in connexion with a pinion (X), turned by the handle (Y). By turning this handle the attendant is thus enabled to charge the tank, and also to shut off the supply of water as soon as the weight of the tank and its contents overbalances that of the timber to be raised.

To moderate the velocity of the descent of the tank, which would ensue instantly it were fully charged, a water governor has been applied, which acts thus: *a* is a bevel wheel, keyed on the drum shaft, and working a bevel pinion (*b*), turning in bearings on a frame (*c*), connected with the girders (*d*). The shaft (*g*) of this pinion is extended through the wall, and carries a bevel pinion (*h*, fig. 24); *h* gives motion to another bevel pinion (*i*), keyed on the vertical shaft (*j*). With this shaft, two metal discs (*k*), 8 inches in diameter, are connected in the manner of an ordinary steam engine governor. The shaft terminates below in a pivot, which turns freely in the shoe (*l*). The well (*m*), in which this governor works, is supplied with water by the pipe (*n*), the orifice of which is fitted with a leather flap or valve (*o*); *p* is the water pipe whence the syphon (*n*) is supplied. The action of the governor is obvious: a rapid descent of the tank, causing the drum shaft to revolve with increased velocity, this is communicated by the shaft (*g*) to the governor, the discs of which, extending with the speed, meet a greater resistance from the fluid in which they move, which, in proportion, overcomes their impetus, and thus reduces the velocity of the drum shaft and tank.

The log having been raised, and the tank occupying its lowest position, it becomes necessary to discharge the water from it, so that it may ascend rapidly, and suffer the drag to descend for another load. This discharge is effected by opening two valves fitted in the bottom of the tank, and shown in elevation in fig. 20, (where the tank is, for this purpose, exhibited partly in section,) and in plan at fig. 21: *r r* are the two valves, the rods of which are connected with the lever (*s*); this lever is weighted at one end, and at the other jointed to the rod (*t*). A crank (*u*) connects *t* with a cross rod (*v*), to which a long lever (*w*) is keyed; *x* is a cord tied to the outer end of this lever. By the adoption of two valves in this manner, which act reversely, the one being opened downwards and the other upwards, the discharge of the contents of the tank is an easy matter. The valves are nearly of equal areas, and hence the weight of the column of water standing on the upward-opening valve is counterbalanced by that of the similar column on the downward-opening valve. The actual weight to be raised is thus reduced nearly to *o*, and through the two orifices the emptying takes place very rapidly. By means of the cord (*x*), the attendant (occupying the platform E, figs. 1 and 2) can operate on these valves when the tank is at any elevation.

The drag represented in figs. 22 and 23 is guided at each end by three metal rollers, 9 inches in diameter, adapted to run on the surfaces of the standards (*q*): the timber rests on two iron brackets, projecting forward. It was originally designed that the weight of the timber should be made to act by the wooden springs (G) on the palls (1) that should strike into the racked edge of the standards (*q*), but this has been found unnecessary, and been therefore abandoned.

THE SAWING MACHINERY

exhibited in Plates XXIV., XXV., XXVI., XXVII., and XXVIII., is erected in a large building which contains eight saw mills of similar construction, distinct from each other, but all turned by the same main engine shaft. They occupy a basement story, and extend upwards into a ground story, in which are the saw frames, &c. One of these mills has an apparatus connected with it that adapts it especially for cutting deals; the others are adapted for cutting large logs and whole timbers into every variety of scantling. Circular saws are also fitted up within the same building for cutting lathing, fillets, &c. The sawing-shop is flanked at one end by the engine-house, and at the other by the millwrights' shop, wherein is fixed the large drum for the crane chain.

The Plates represent the deal-sawing mill complete, but it will be understood that the same details are common to all the mills, excepting the *feeding* apparatus, as it is called, by which the progress of the timber is adjusted. The feeding apparatus, both for deal cutting and log cutting, are exhibited enlarged in Plates XXVII. and XXVIII.

Plate XXIV. Fig. 27. Side elevation of saw mill.
Fig. 28. Side elevation of the apparatus above saw mill, for lifting the timber.
Fig. 29. Partial plan of ditto.
Plate XXV. Fig. 30. Front elevation of saw mill.
Fig. 31. Side elevation of standard, showing small drum, &c., for slackening the band that drives the crank shaft.
Plate XXVI. Fig. 32. Section of saw mill.
Fig. 33. Plan of drag.
Fig. 34. End elevation of ditto.
Plate XXVII. Figs. 35 to 39 are details of saw mill, showing the mode of tightening the saws and the guides that keep the saw frames in a vertical direction, &c.
Figs. 40 to 43 are details of the feeding apparatus for deal cutting.

In all the figures in Plates XXIV., XXV., and XXVI., excepting figs. 28 and 29, the same letters refer to the same parts.

qq—main standards, fixed in stone blocks (*rr*). A, saw frame, which receives an alternating vertical motion by the connecting rod (B) and crank (C) from the crank shaft (D), made to revolve by means of the drum (E) and strap (F). This strap is turned by the drum (G) on the main shaft (H); H receiving the first motion from the engine. This band is kept adequately tightened by a small rigger or drum (A 5), the centre of which swings in a frame (A 7), jointed at

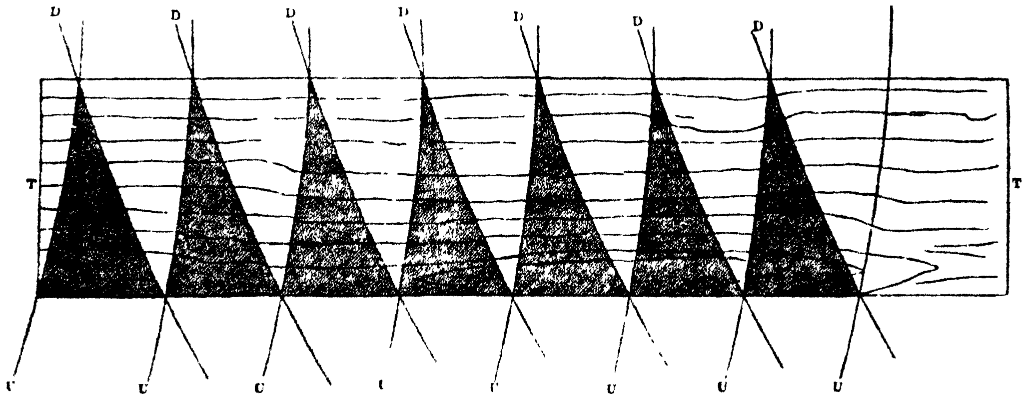
A 6 to a bracket that is bolted to the main standards (*q q*). This frame has a curved arm (A 4), to which a cord (A 8) is tied, and wound on a drum attached to the upper standard (see fig. 31), and having a ratchet wheel and pall (A 9) worked by a handle (A 10). The man attending the saws has thus the means of instantly disengaging the driving strap (F), and thus stopping the saw frame, and also of tightening the strap to any required degree.

J is the drag, 36 feet in length, on which the timber to be sawn is fixed. A progressive motion is given to it simultaneously with the movement of the saws in this way: under the side frames of the drag, which are of wood, a toothed rack of iron (K) is bolted; this rack is moved by two pinions (L), keyed on the same shaft with a ratchet wheel (M) and also a chain wheel (N). This ratchet wheel is pushed round by two palls (O and P), linked together: the other end of O is connected by a hand pin (Q), and with a perforated arm or crank (R) keyed on a shaft (S). On this shaft a crank (T) is fixed, and receives motion from the lower end of the saw frame by means of the rods U and V (keyed on a shaft W), and X and Y. The speed with which the drag (J) is allowed to travel, determined of course by the comparative hardness of the wood to be sawn, is regulated by the perforated crank (R) and pin: as the hole in R, to which the pall (O) is pinned, is further from the shaft (S), the speed of the drag (J) is increased, and *vice versâ*. Whenever it is necessary to stop the drag in its advancing course, the palls (O P) are raised by a cord (*s*), which passes over two pulleys (*t u*), and has a handle (*v*, fig. 31) that may be hooked on the pin (*w*), and thus retain the drag in a stationary condition. *x x*, fig. 33, is the frame in which the deals (*w w*) are kept steady on the drag by the claws (C C) that are screwed up against them by the screw (A A) and handle (B B). This frame is supported on a cross frame of wood (*y y*), and bolted through the cross iron frame (*z z*), provided with a roller (D D) that runs on an iron plate, level with the floor. The under sides of the timbers of the drag are plated with iron, and run on rollers (*v v*) which are placed at intervals throughout the drag courses.

When the cut is completed, the return of the drag for another deal or log is effected by releasing the handle (*q*) from the spring (*v v*), and pressing it down so as to raise the crank (*p*) and rod (*o*). This rod is jointed at its other end to one arm of a crank (*n*), the other arm being attached to a rod (*m*); *m* is jointed to the lower end of a swinging frame (*t t*), which turns on a centre at *u u*. By raising the rod (*o*), the toothed wheel (*c*), which is constantly in gear with *b*, is put into gear with *d*, and thus by the wheels (*f* and *g*) receives motion from the main shaft (H). In the same axis with *b* is a drum (*a*), which, by means of the endless chain (Z Z) passing over pulleys (*h h*), and thence around the wheel (N), gives an accelerated backward movement to the rack of the drag (J). The chain (Z Z) is kept in proper tension by a weight (*l*) attached to a rope (*k*) passing over two pulleys (*j j*), and connected by the rod (*i*) with one of the chain pulleys (*h h*).

The saw frame is guided in its vertical movement by bright metal guides (*x*), which press against faces of gun-metal that are screwed to the three outer surfaces of each side of the saw frame. The saws (*y*) are hung by hooks (*z*) to the upper part (Y Y) of the frame (A); the lower ends of the saws are hooked at *a a* to a ledge formed on the lower cross bar of the frame.

An experiment was made with the saws here described to give them a peculiar obliquely-curved motion, similar to that of a hand-worked pit saw, but the means tried were not found practically available. The utility of such a modification may be roughly illustrated thus:



Supposing T T a piece of timber to be sawn, and the curved lines to represent the motions of a pit saw as worked by two sawyers; those marked D to indicate the *downward* strokes, and U the *upward* strokes: the angular tinted parts will then show the operation of the down cuts, and the white parts will show the space passed through in the upward cuts. It will be seen that the saws thus work only at intervals through the entire depth of the timber, and are ordinarily cutting only angular sections. The consequence is, that much less force is required to impel them than would be necessary if they moved always vertically; and, bearing in mind the unavoidable rigidity of all self-acting machinery, and consequent enormous strain on the saws in their frames, it would seem highly desirable to effect a similar movement to that of the pit saw.

To provide against the tendency of the saws to swerve from the vertical position, especially when cutting large and hard timber, the means of tightening them to any required degree is afforded in the following manner:

The saw frame (A) is stopped when in its highest position (see fig. 38, Plate XXVII.), that is, when the crank (C) stands vertically over the crank shaft (D). The upper hooks (*z z*) terminate upward in a forked bar (*b b*), which embraces the cross frame (Y Y), and has grooves or key places cut in it on both sides for keys and cotters (*c c*), and also other key places above these: a link (*z z z*), which also has a key groove in it, and may be slid along to any part of the cross frame (*d d*), is now brought within the forked bar (*b b*): in this position their grooves correspond, and the key (*y y y*) is driven through them together. The frame (*d d*) has a short range of vertical motion by slots working on pins at *e e*, and is forcibly kept in its highest position, being connected by the rods (*f f*) with the counter-weighted lever (*i i*), to which they are jointed at *h h*. The attendant, standing on a step-board put in the grooves of the brackets (*p p*), places his foot in the stirrup (*u u*), presses it down, and thus by the rods (*k k*) and (*j j*) raises the weighted bar (*i i*), and consequently depresses the frame (*d d*) just described. This gives more key-room for *y y y*, which is then driven further in, and by successive depressions of the frame (*d d*) any required degree of tightness is obtained.

The feeding apparatus shown in detail in Plate XXVII., figs. 41, 42, and 43, by which the deals are conducted through the saw frames, consists of rollers (X X), on which the front ends of the deals (*w w*) are placed, being firmly fixed at the other end in the frame (*x x*, fig. 33) already described. E E is the framing of the feeding apparatus. The inner sides of the deals are pressed against by T T, bright metal face plates of the guide frames (S S). These guide frames have two eyes, and are attached to the column (R R) by a pin passing through them, and also through the projecting arms of the column. The columns (R R) turn on centres above in the frame (E E), and below in a shoe plate, and are turned either way, so as to press the guide frames against the deals, or withdraw them by the handles (V V) of the screws (W W), which move the levers (Q Q) of the columns. The outer sides of the deals are pressed closely by bright metal rollers (I I), turning vertically in arms projecting from the columns (H H).

These columns are similarly centered to the columns (RR), and have levers (KK) keyed on them; the other ends of KK are connected by cords (LL) passing over pulleys (MM) with the heavy weights (NN), and thus the due pressure of the rollers (HH) against the deals is obtained. In figure 43, on Plate XXVII., one of the stops (*o o*) is shown, turned against one of these levers (KK), so as to throw back the roller (II) when it is required to remove the deal.

Feather-edged or weathered boards are cut by tilting the deal against a conical roller, as shown at JJ (figs. 42 and 43); the face plates (TT) of the guides (SS) being blocked out to the same angle, so that the deal still moves between parallel surfaces. In this way three saws cut two square and two feather-edged boards simultaneously from a deal, while two other saws cut another deal into three square boards. The saws are kept apart at the required distances at top and bottom by wooden blocks which are kept ready for use, of all sizes, the end blocks being pressed closely by a metal arm and screw (FF). (See Plates XXV. and XXVII.)

Plate XXVIII. exhibits the feeding apparatus used for cutting whole timbers.

Fig. 44 is a side elevation, and

Fig. 45 a plan.

A represents the log to be sawn, supported on a block (B) that rests upon the drag (C), which is similar to the drag (J), already described in the other Plates. The timber is also supported on a roller (D), and is held fast at the hind end by two strong iron claws (II), screwed up by screws (MM), worked by the handles (KK). To provide means of regulating these claws when bent timber is to be sawn, the shaft (J) to which they are jointed is cut by an internal screw that works on Q; the other end of Q, at R, is fitted with a handle, by turning which any required adjustment is immediately obtained. The sharp edges of the guide wheel (F) are made to press into the upper surface of the timber by a weighted lever (E), which may be raised when required by the cord (P) that passes over a pulley above. The frame (O) turns on centres at G, attached to the main standards (*g g*), before described.

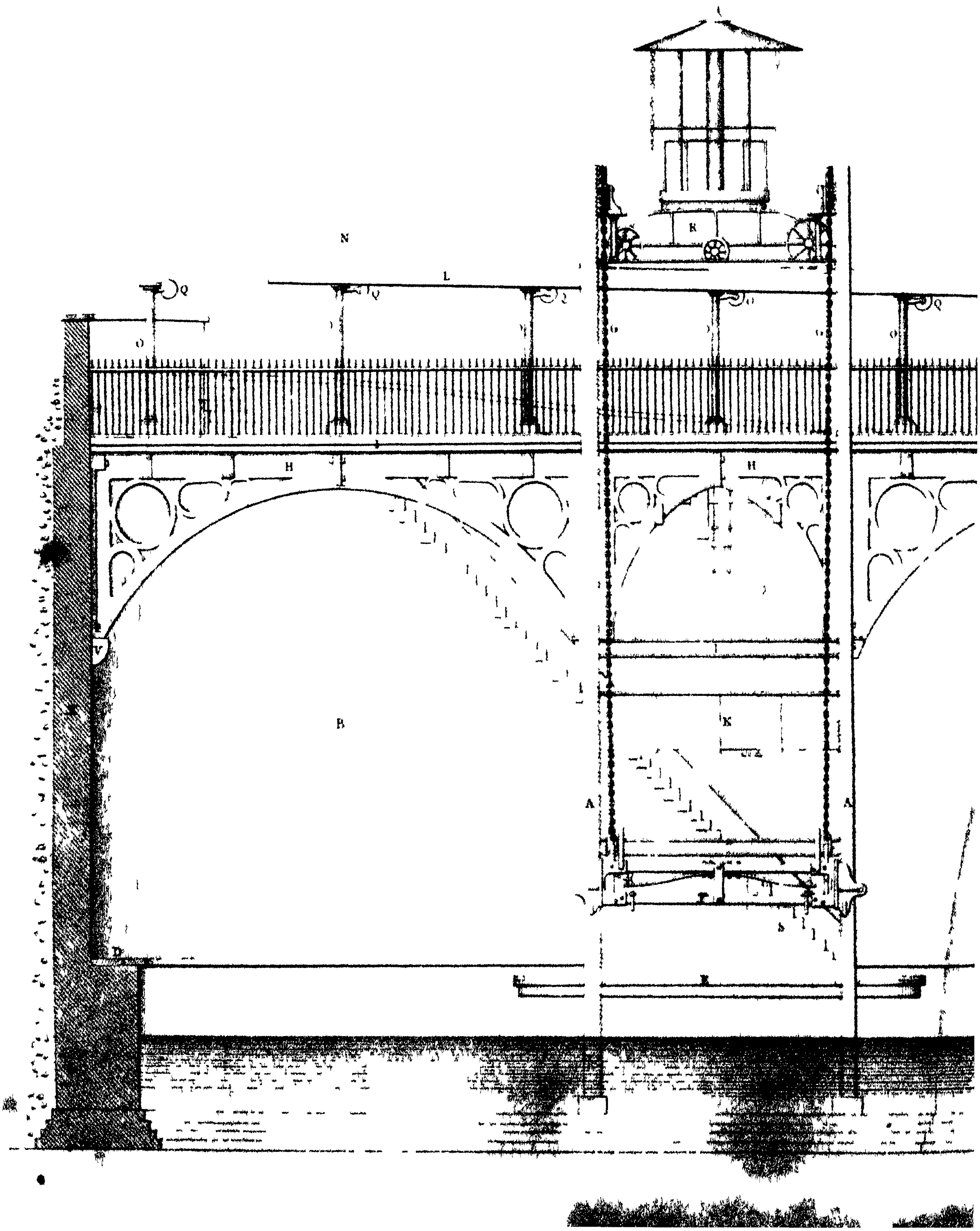
The steam engine is made to complete its work by drawing the timber from the foot of the cast iron slip (Plate XX.) already described, or from the other side of the sawing-room, up to the front of the saws, and further, lifting it to be put on the drag (J). A description of the apparatus for these operations will conclude this sketch.

The timber to be drawn in is made fast to a rope that passes over one of

General Elevation of Hoisting Machinery

(Sectional thro Shaft)

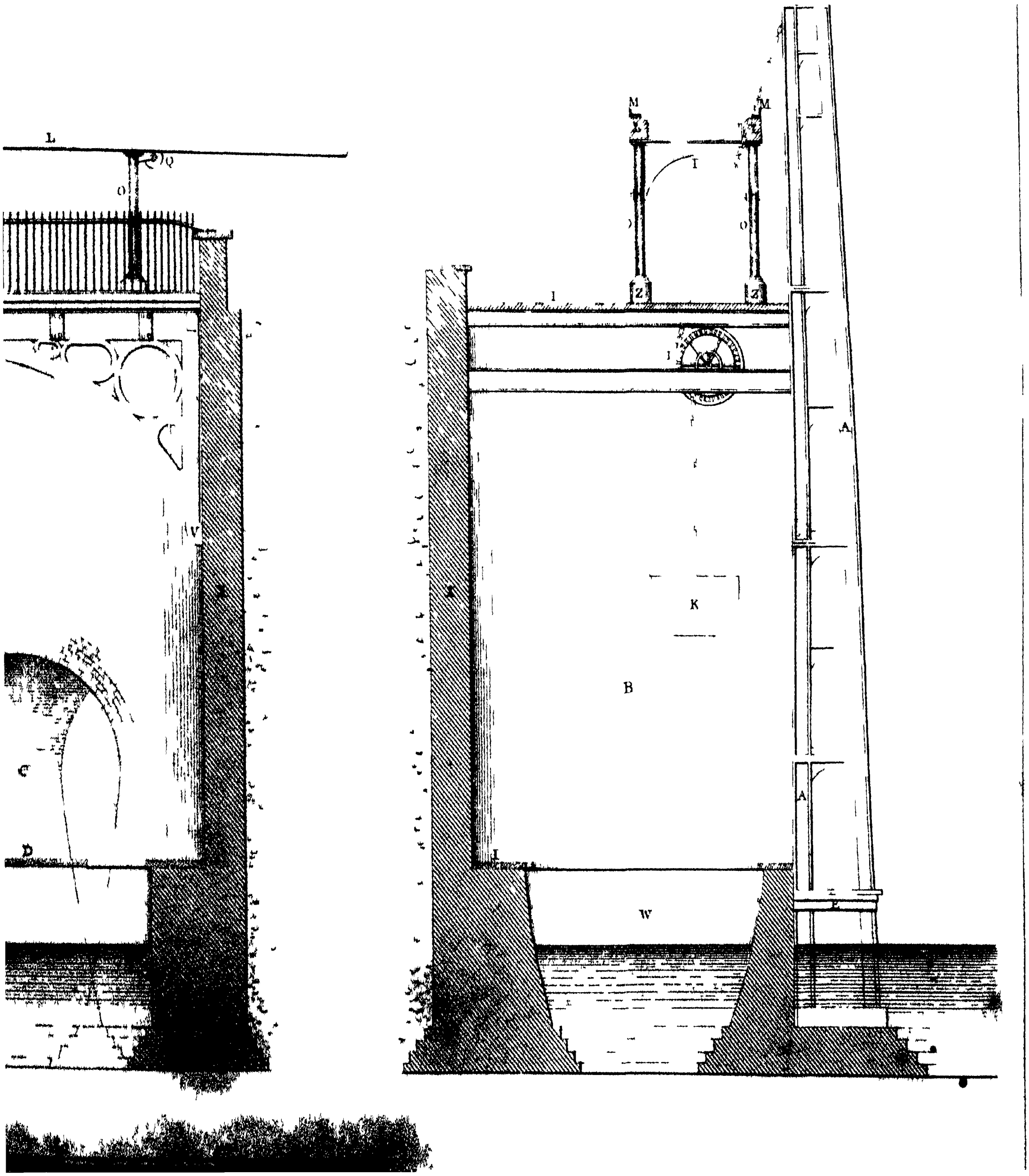
Fig 1



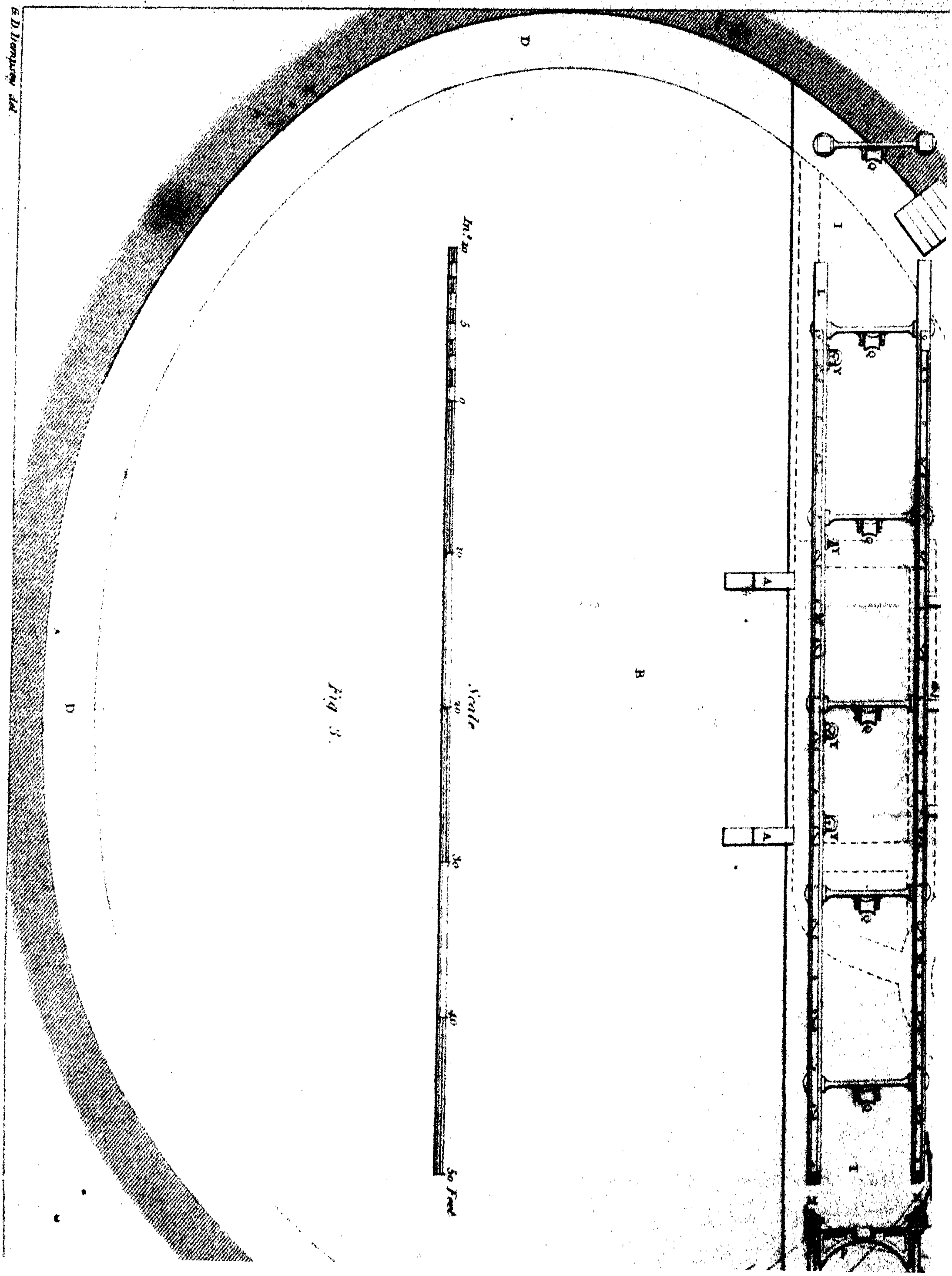
Side Elevation

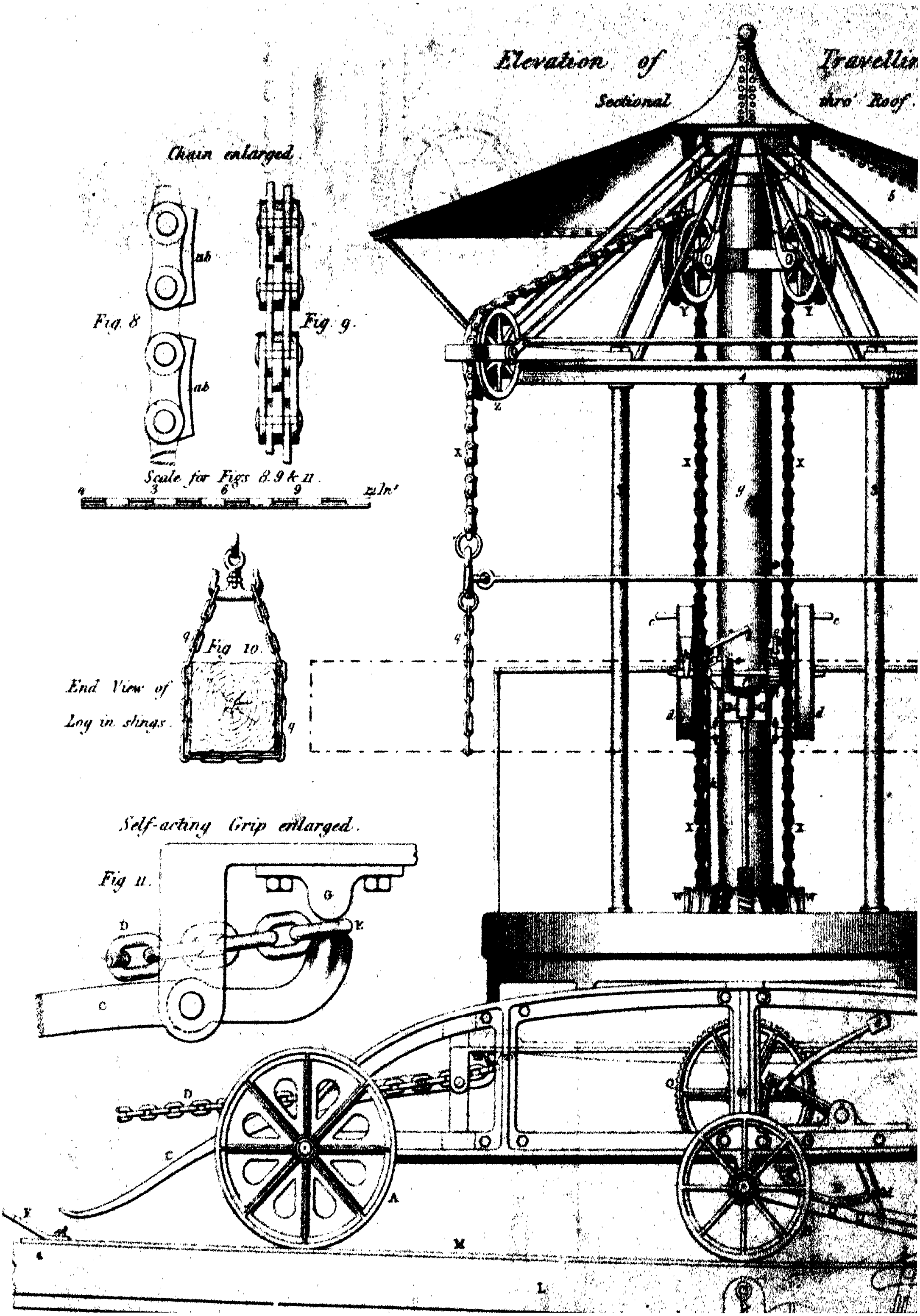
(Sectional thro Shaft and Well)

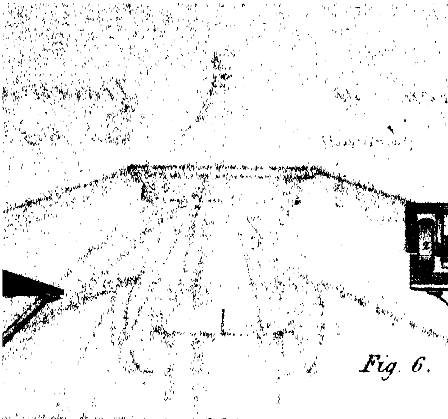
Fig 2



MACHINERY CONNECTED WITH THE




Elevation of
Sectional
thro' Roof.
Chain enlarged.
Fig. 8
Fig. 9.
Scale for Figs 8. 9 & 11.
Fig. 10.
End View of
Log in slings.
Self-acting Grip enlarged.
Fig. 11.



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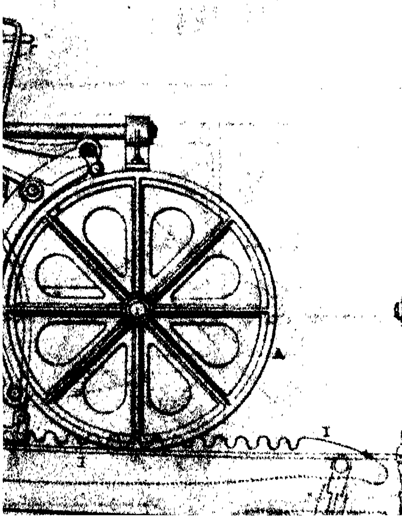


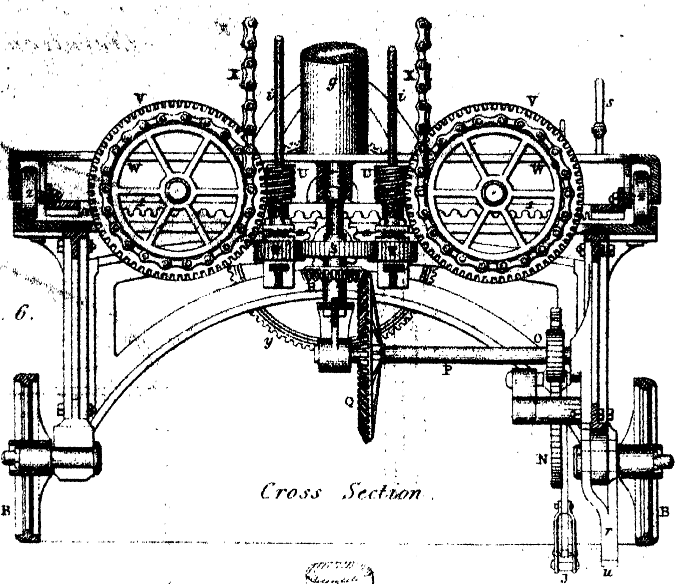


Fig. 6.

Cross Section.

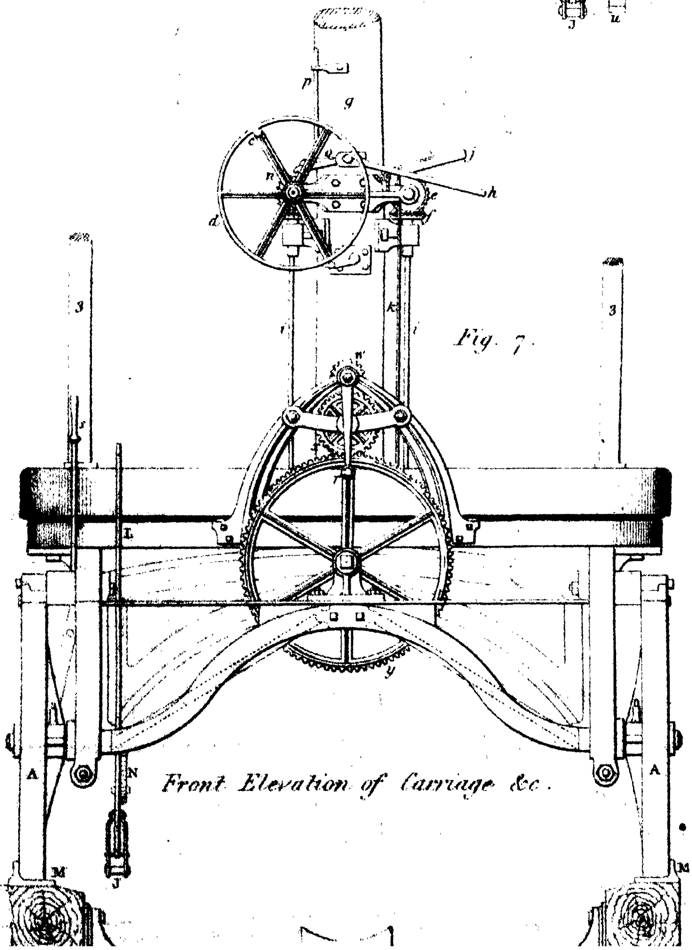
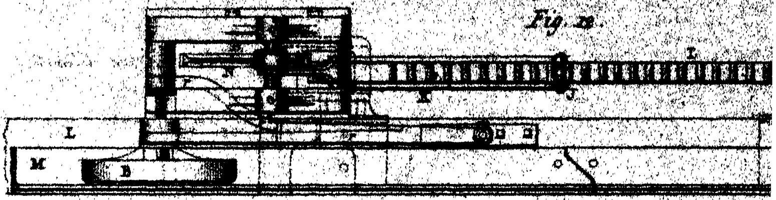


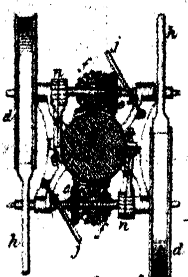
Fig. 7.

Front Elevation of Carriage &c.

Partial Plan of Travelling Crane.

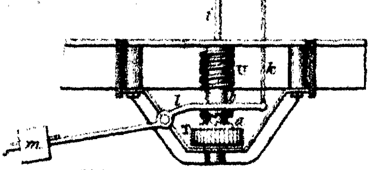
Fig. 12.



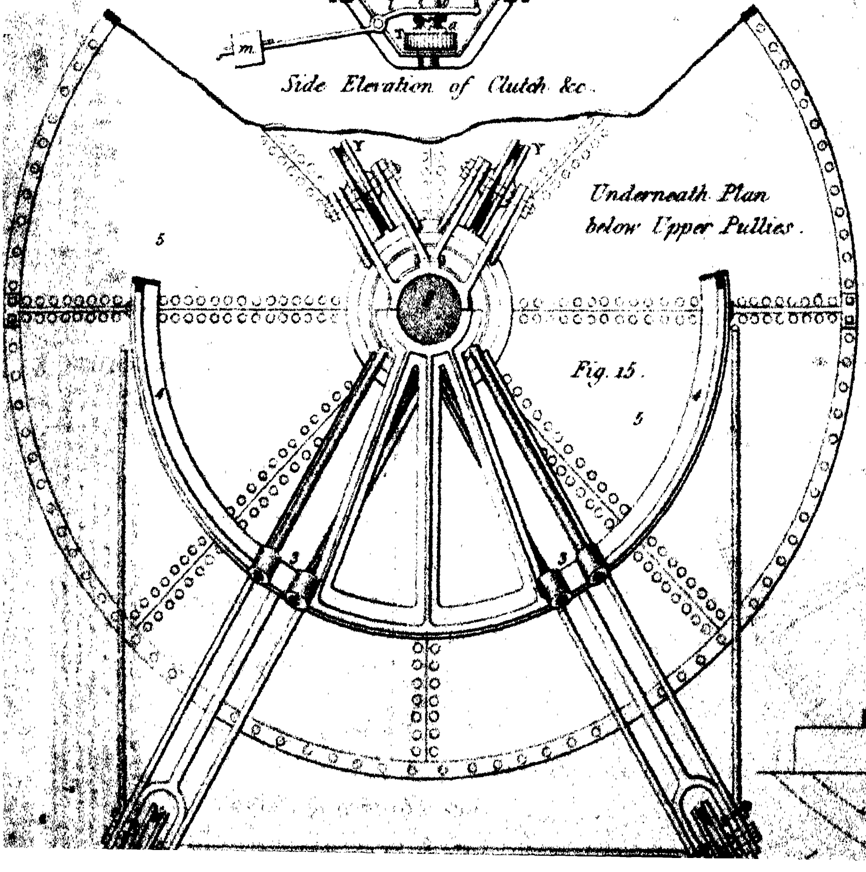


Plan of Gearing &c. attached to Column.

Fig. 13.

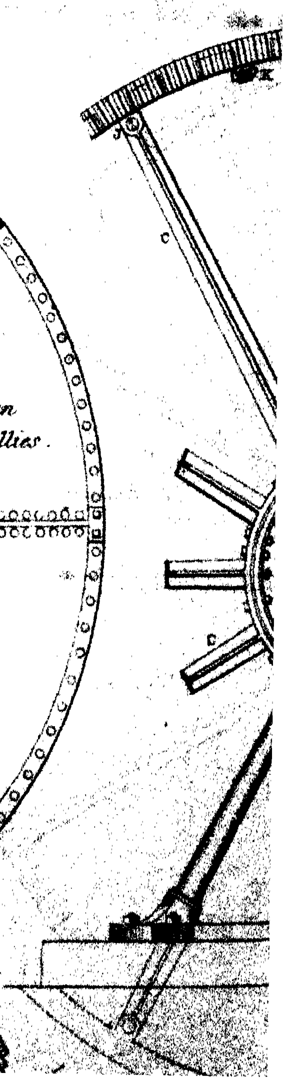


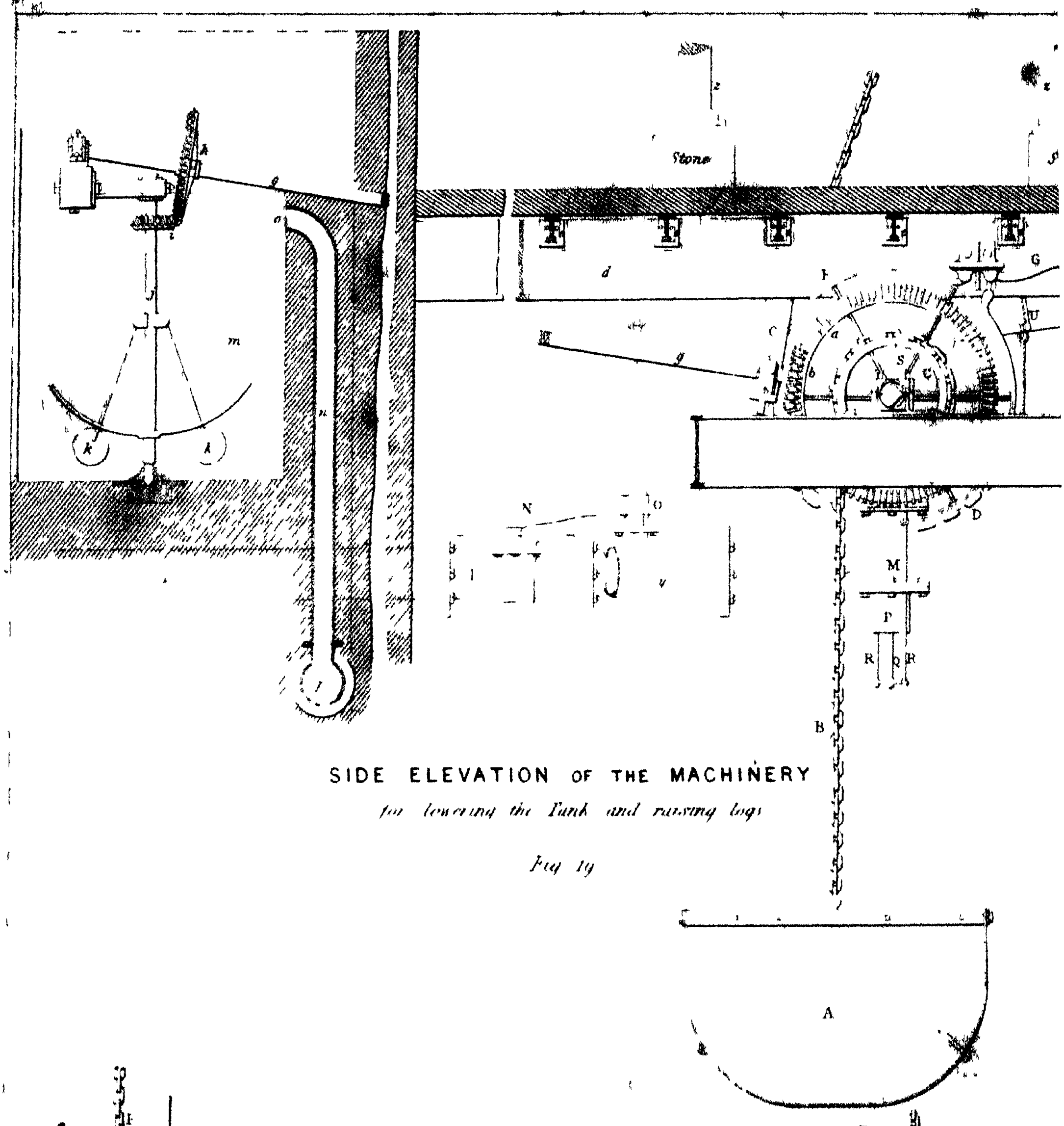
Side Elevation of Clutch &c.



Underneath Plan below Upper Pullies.

Fig. 15.

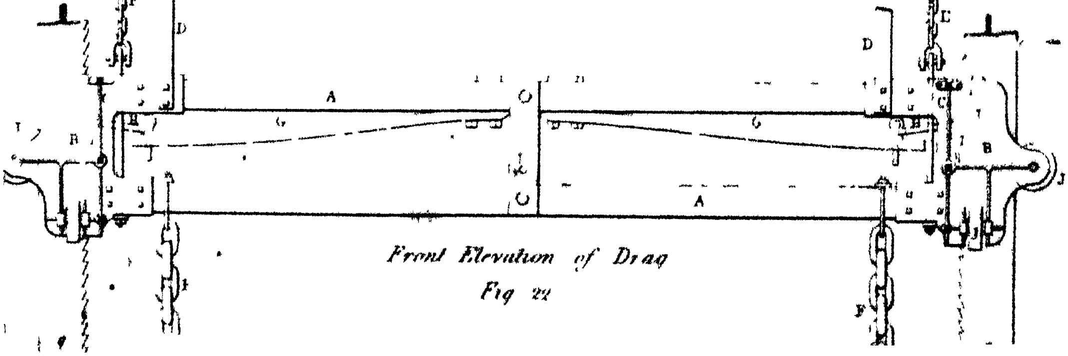




SIDE ELEVATION OF THE MACHINERY

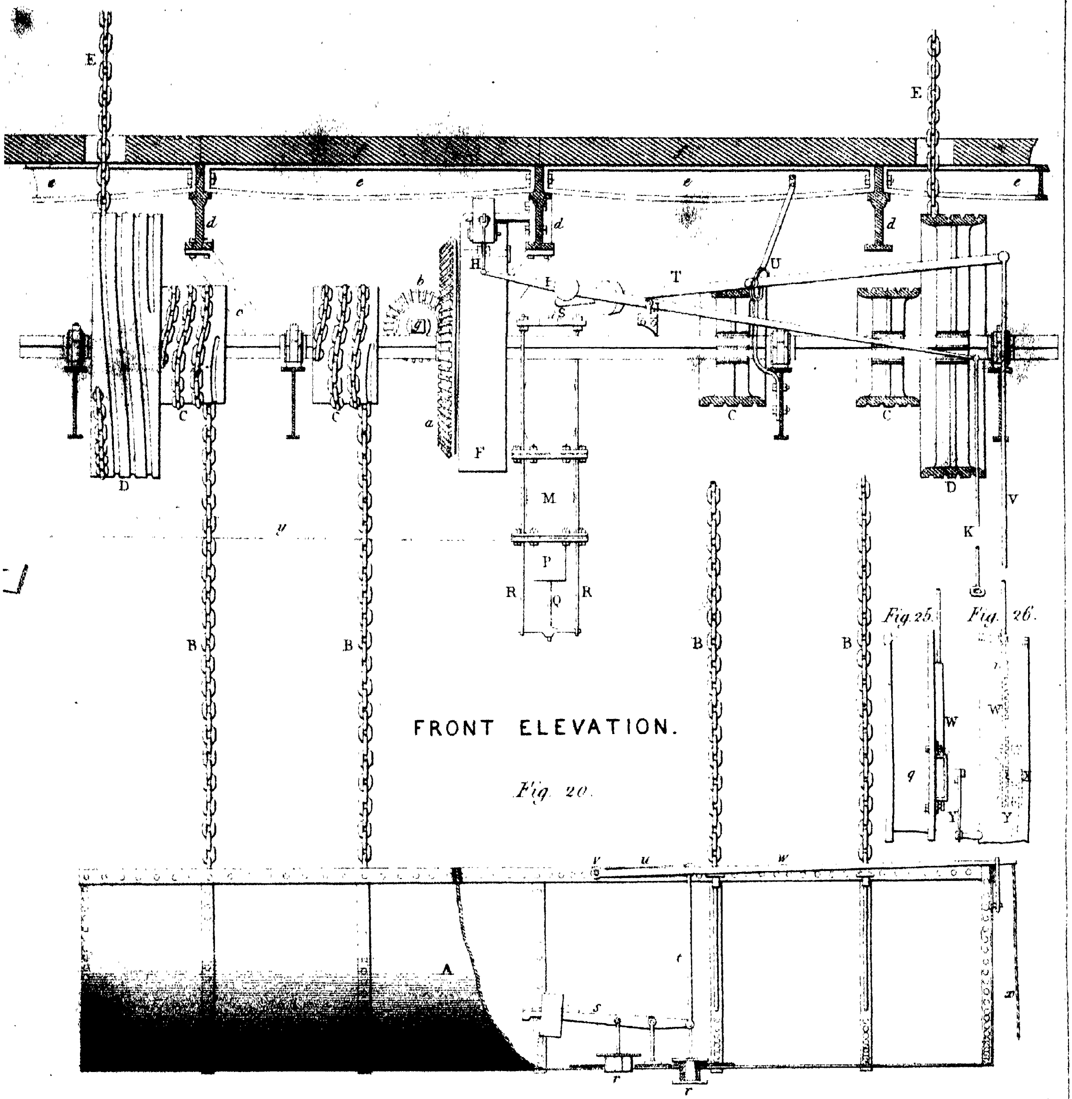
for lowering the Tank and raising logs

Fig 19



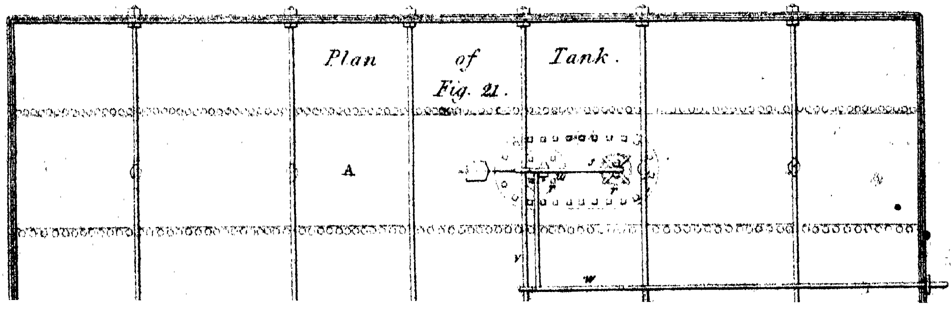
Front Elevation of Drag

Fig 22



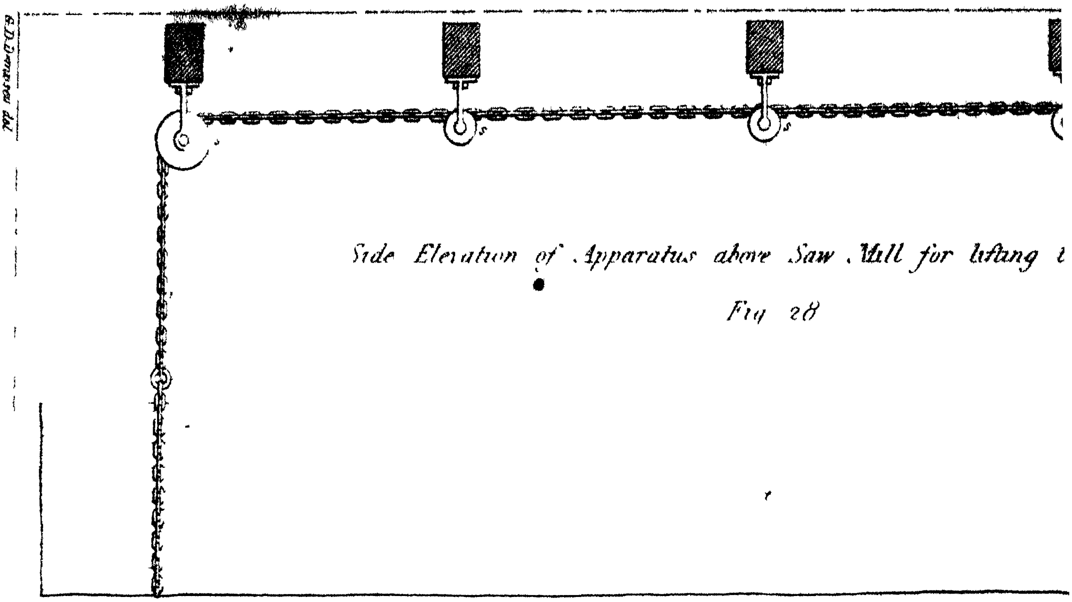
FRONT ELEVATION.

Fig. 20.



Plan of Tank.

Fig. 21.



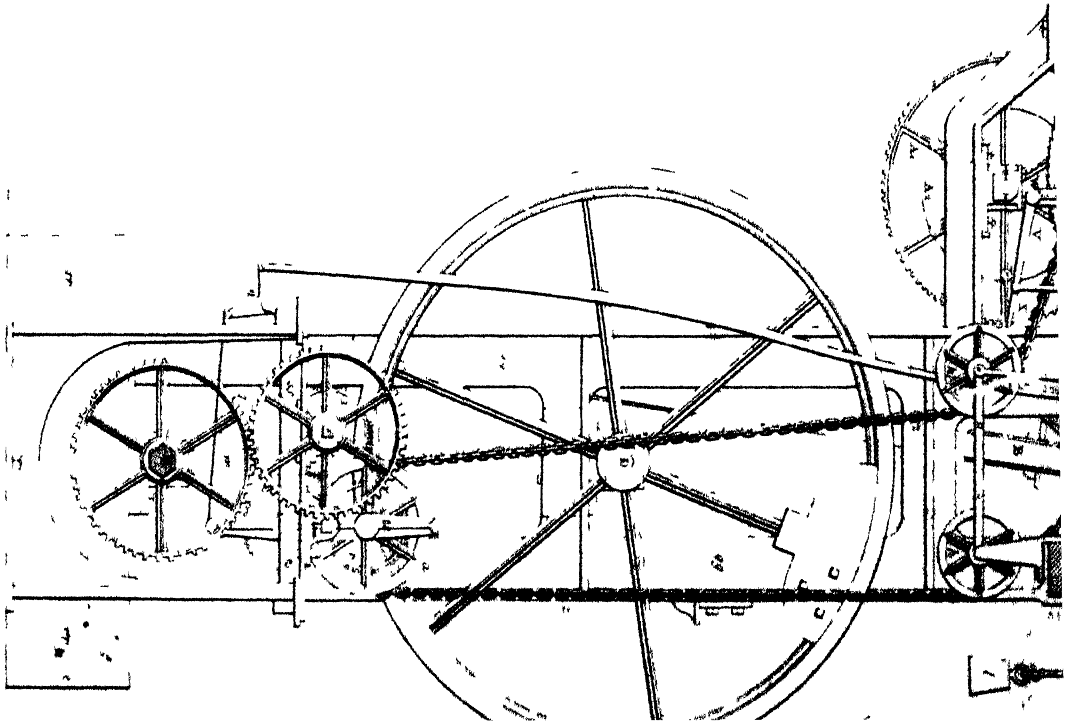
Side Elevation of Apparatus above Saw Mill for lifting t

Fig 28

G.D. Dempsey del

Scale

In. 12 0 1 2 3 4 5 6 7 8 9 10 Feet



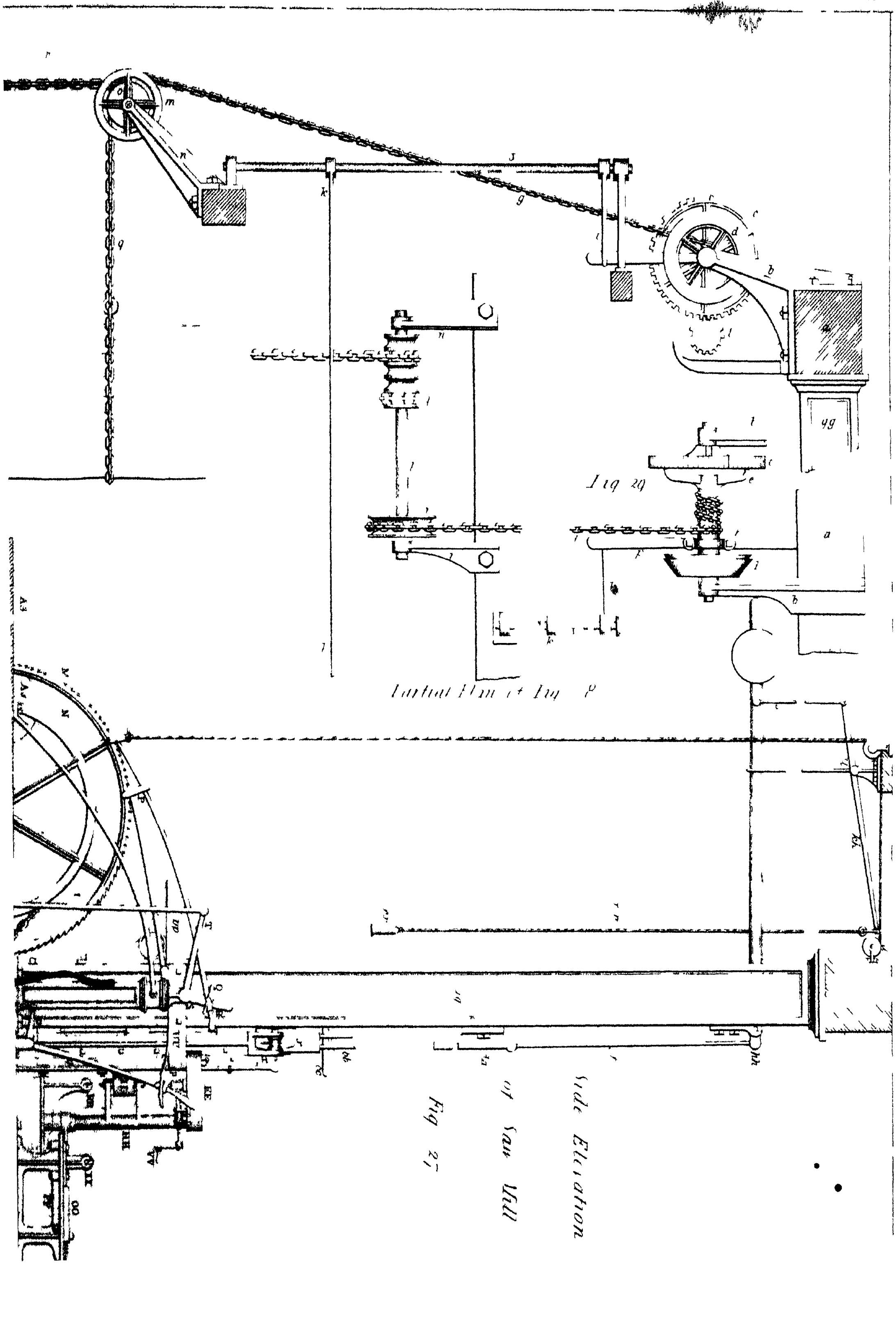


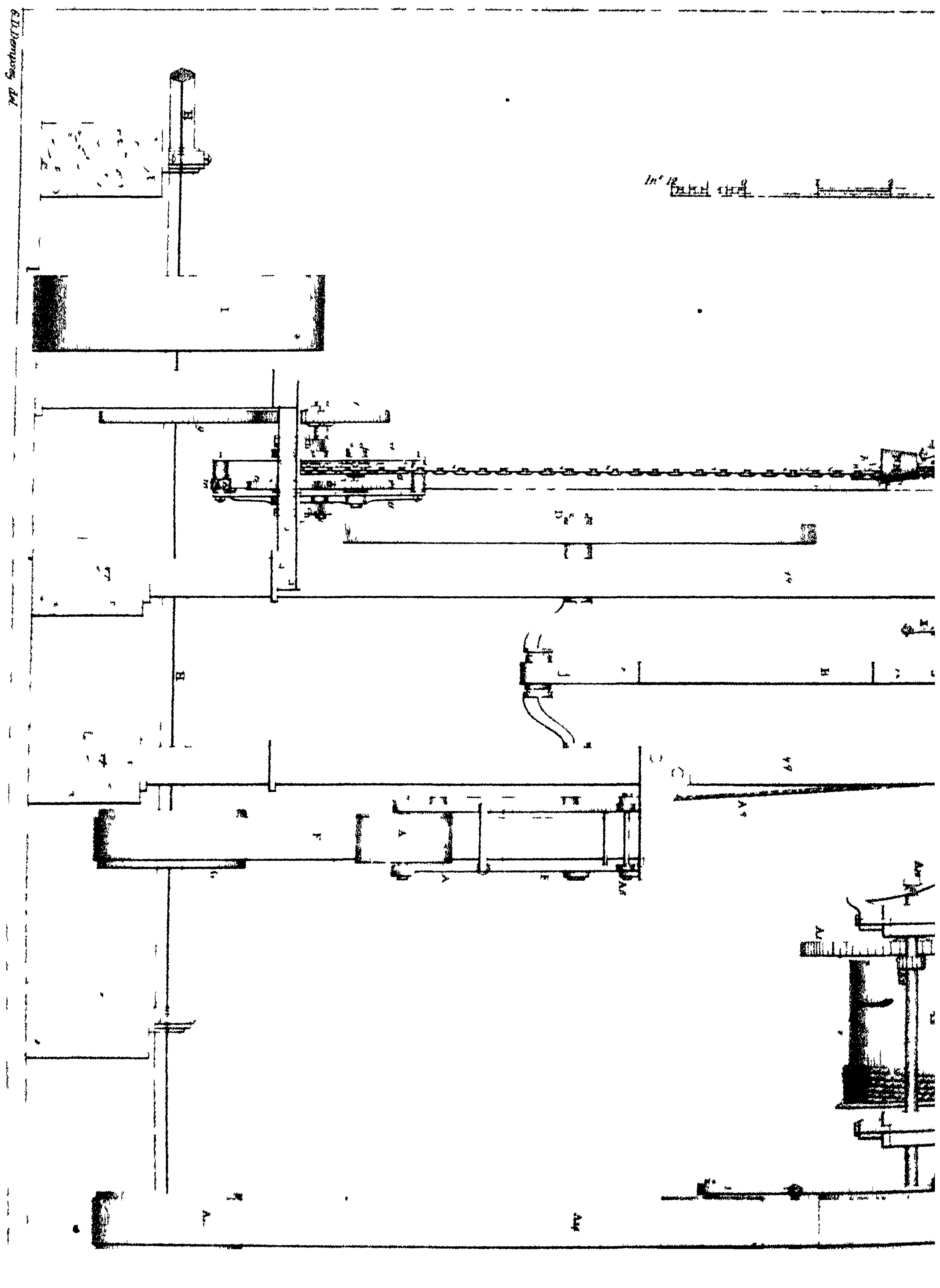
Fig 29

Partial Plan of Fig 28

Side Elevation of Saw Mill

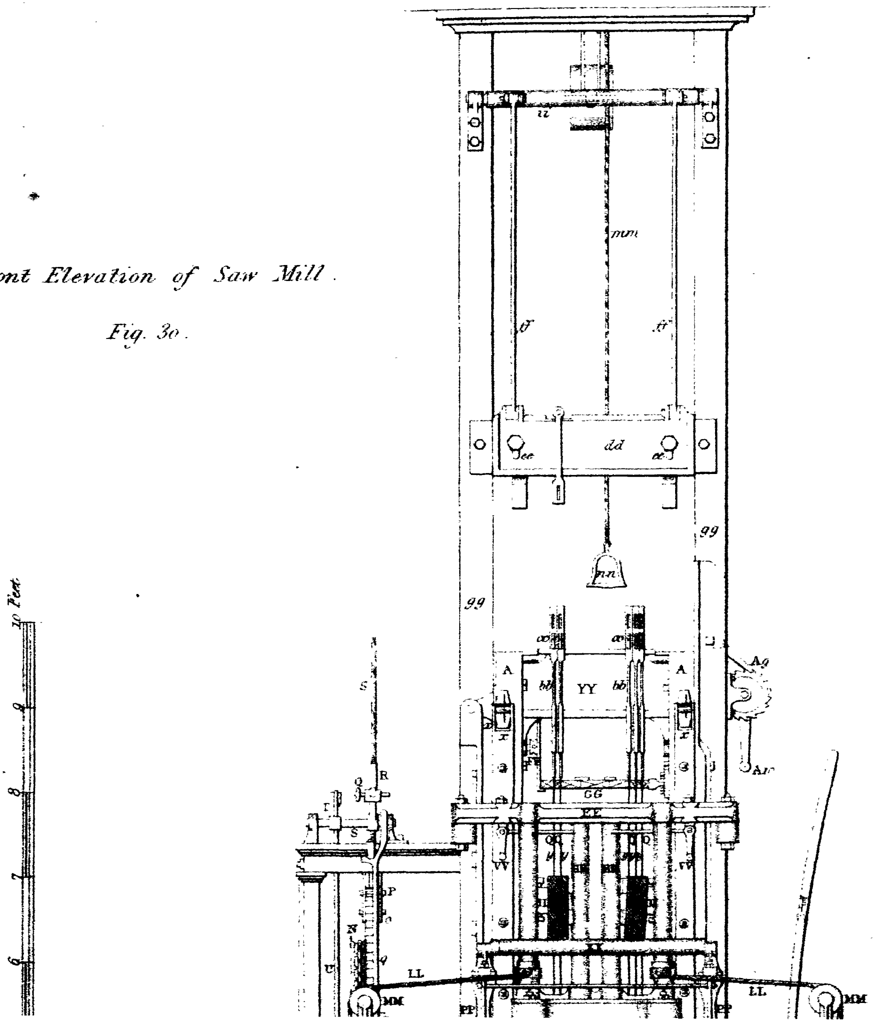
Fig 27

MACHINERY CONNECTED WITH TH



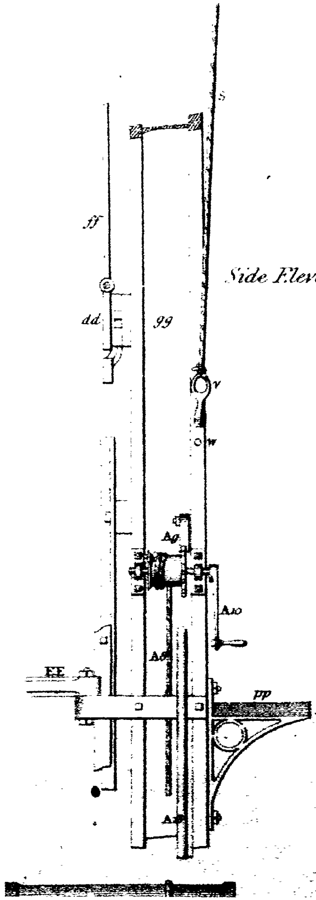
Front Elevation of Saw Mill.

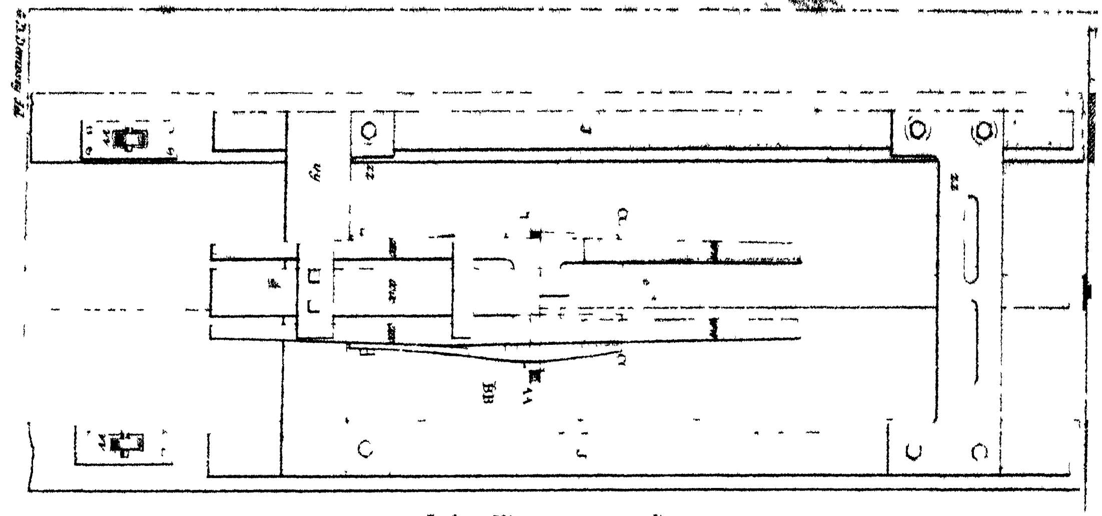
Fig. 30.



Side Elevation of S.

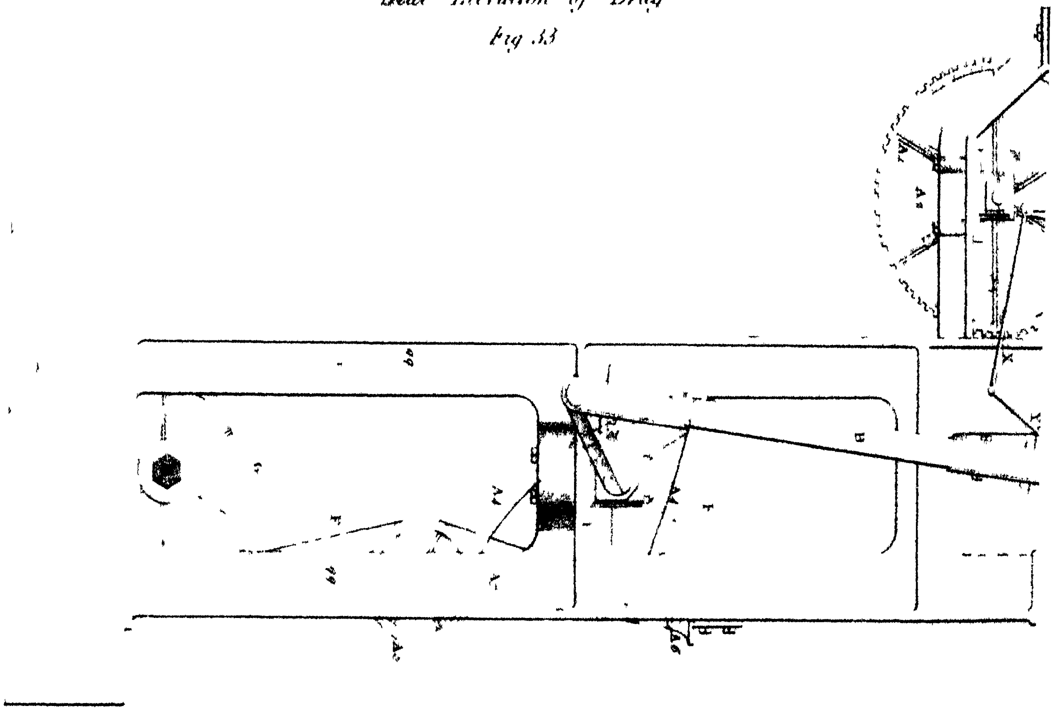
Fig. 31.

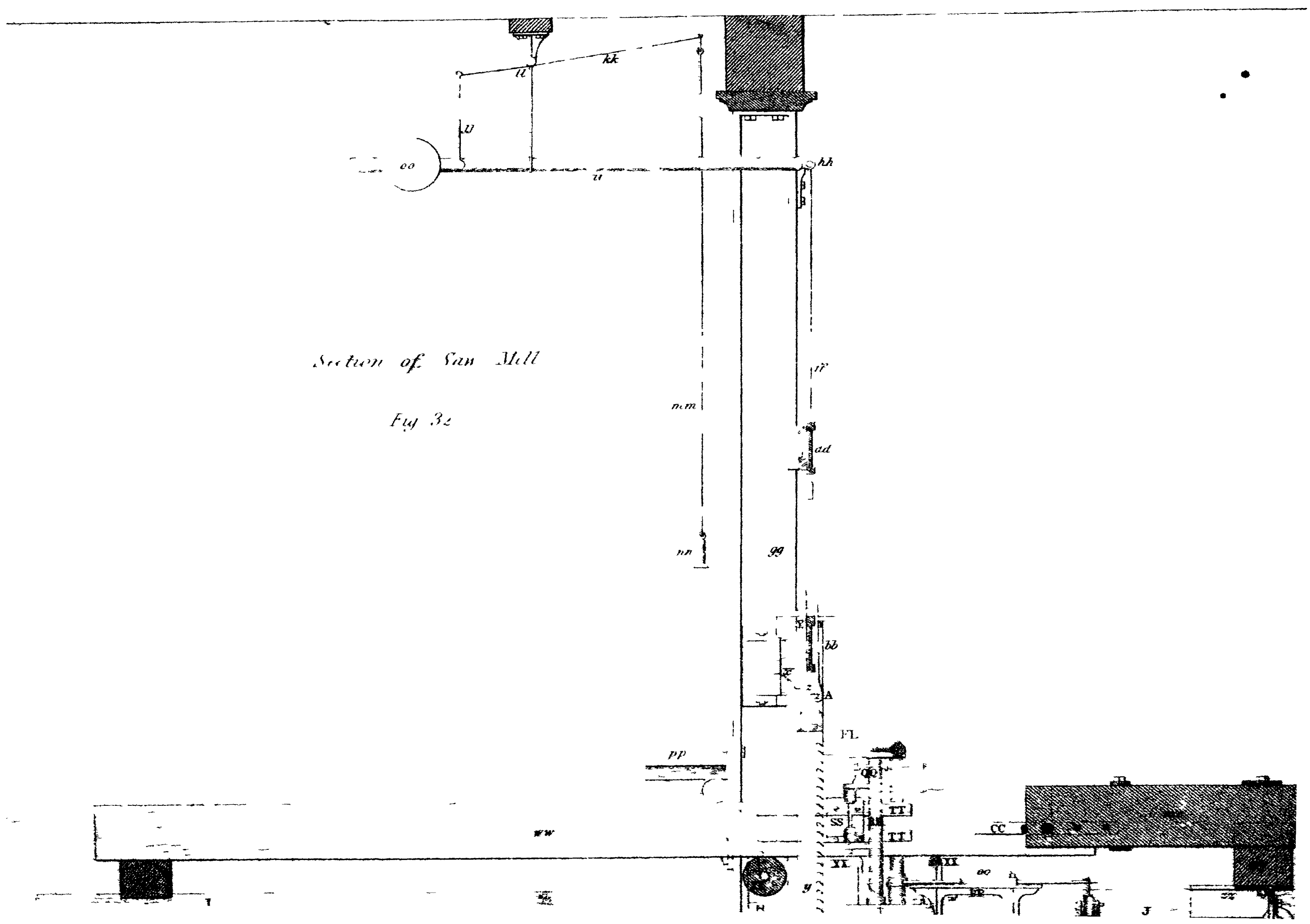




Side Elevation of Drag

Fig 33





Section of Saw Mill

Fig 32

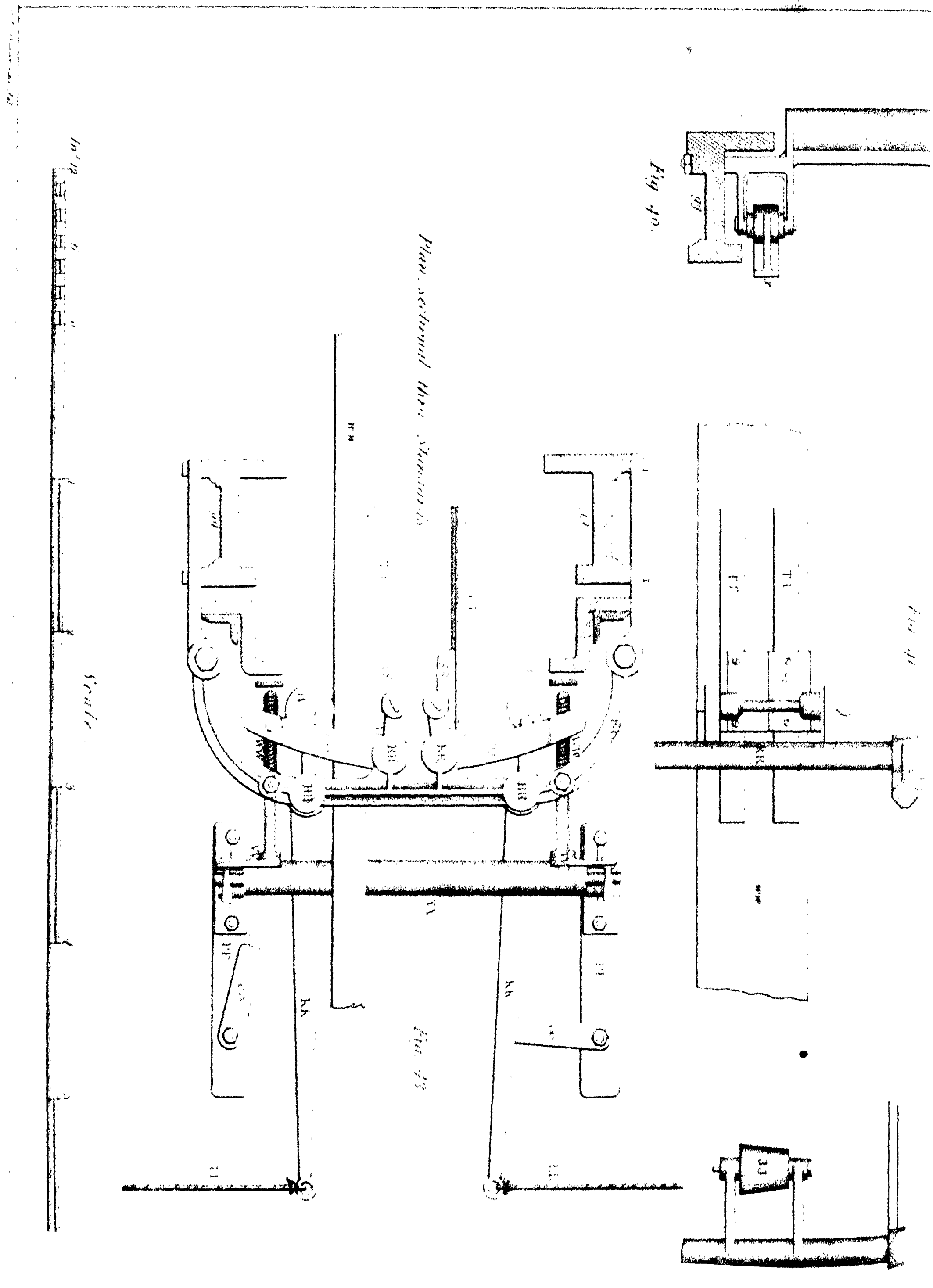


Fig 40
Plan, sectional thro' Stanchions
Fig 41
Fig 43
Scale

Details of Saw Mill.

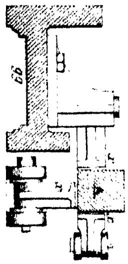


Fig. 39.

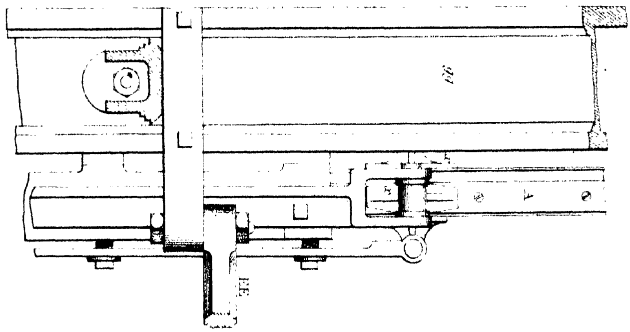


Fig. 35.

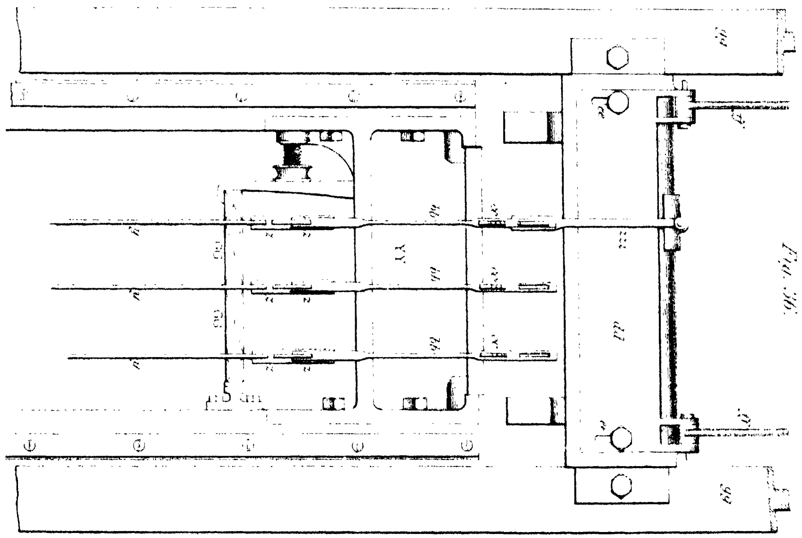


Fig. 36.

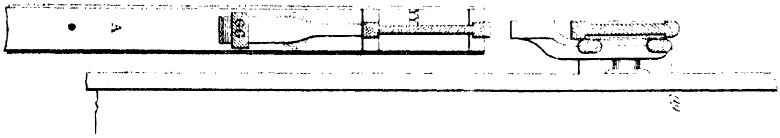


Fig. 37.

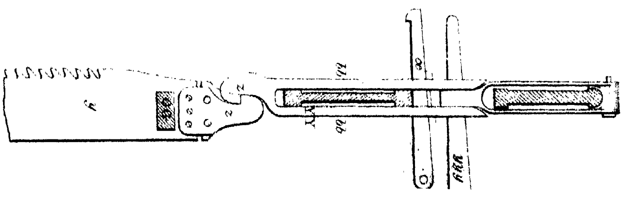
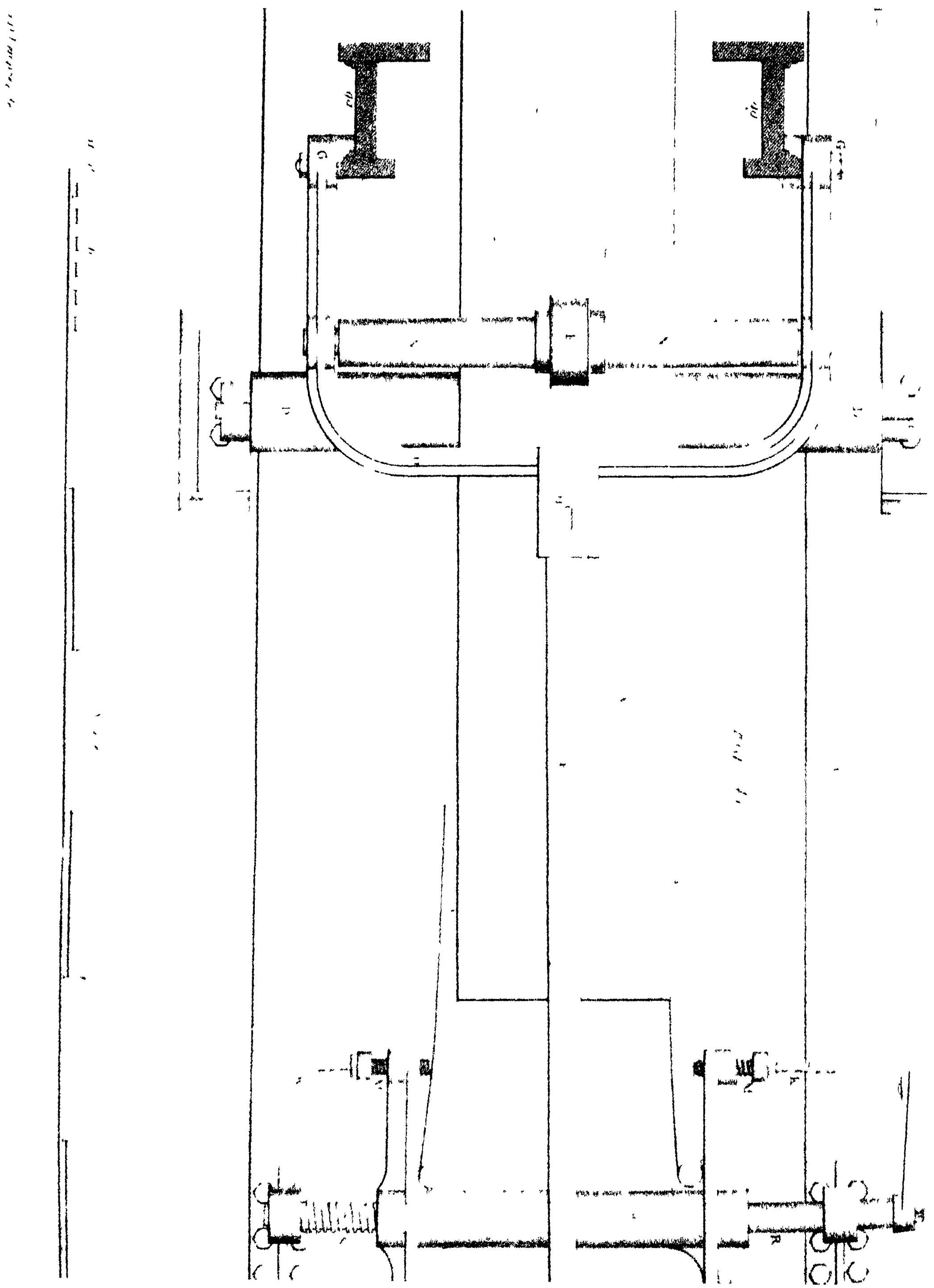
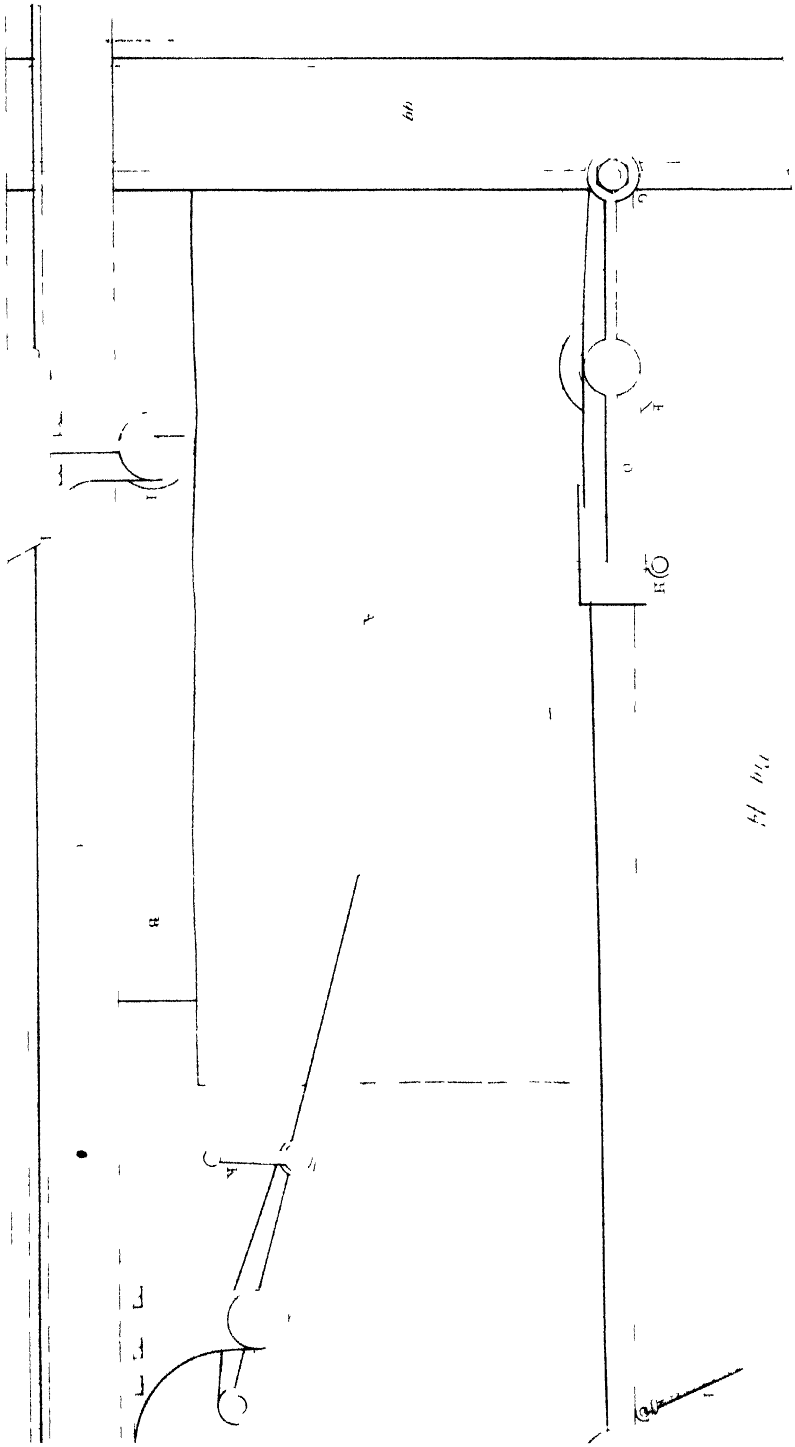


Fig. 38.

MACHINERY CONNECTED WITH THE





Details of Feeding Apparatus as for cutting Logs

Fig. 54

the two drums (A 3), and is received on the drum (A 2). To this drum motion is given from the engine shaft by a band and rigger (A 14 and A 15), which turn the shaft of the pinion (A 11) that is put into gear with the toothed wheel (A 1) on the shaft of the drum (A 2) by the handle (A 13), which is forked over the pinion shaft at A 12.

The apparatus for lifting the timber is shown in figs. 28 and 29, Plate XXIV. *g g* show the upper part of the main standard of saw mill, supporting a strong wooden beam (*a*).—*b*, iron standards bolted to *a*, and carrying a shaft with *c*, a toothed wheel; this wheel is driven by a pinion (*l*) from the engine. *d*, a conical clutch, and *f*, a grooved barrel or drum for the chain (*g*), with *e*, a forked clutch, are fixed on a hollow shaft that turns on the former one *p* is a collar, turning on a centre at *h*, and which, by means of the rod and shaft (*j*), and handle (*k*), may be moved either way; if towards *c*, the forked clutch (*e*) engages the wheel (*c*), opens the conical clutch (*d*), and thus the chain (*g*) is wound upon the drum (*f*); if towards *d*, that clutch is engaged, the engine pinion disengaged, and the chain (*g*) remains stationary. The chain (*g*) is made to raise two slings simultaneously, by being attached to a sheave (*m*), having on its shaft a grooved roller (*o*), to which are fixed the two sling chains (*q* and *r*), the one passing directly downwards, and the other, supported on pulleys (*s*), extending to a considerable distance outward, so that the two slings embrace the two ends of a log (*t*).

The whole of the machinery was constructed by the late Mr. Henry Maudslay, and erected under the personal superintendence of Mr. Bacon who has ever since retained the charge of it.

As a contrast to this complete machinery for sawing timber, I annex, in Plate XXIX., a sketch of a simple saw mill used in America. The power here is supplied by a fall of water, which is easily obtained upon the numerous streams with which the country is intersected. The principle of the machinery is exactly the same as that before described, so that the following references to the Plates will make the whole construction perfectly clear.

A—the dam, formed very commonly of squared logs resting against a standard strutted from the rear, provision being of course made to carry off the surplus water. B is the sluice, which, when it is wanted to work the saw, is raised, and admits the water into the trough (C) to the wheel (D), which is generally made of small diameter, in order that the velocity of the water may give it as many revolutions as possible consistent with the necessary power, and thus enable the saws to make as many strokes as the wheel makes revolutions. E, crank, on the wheel shaft, to which is fixed the connecting rod (F), which is fixed to the bottom of the saw frame (G) which runs up and down between the standards, having an alternating motion communicated to it to the extent of the double length of the crank arm (E).—K is the log to be cut; it is mounted on the frame (L), which has a rack fixed upon its under surface, and which is supported by the rollers (*a a*). The pinion (*b*) on the axis of the wheel (M) works in the rack, and, according as the wheel moves forward and backward, works the frame towards or away from the saws Motion is communicated to the wheel by the pall (*c*), the other end of which is pinned into one of the holes in the arm of the bent lever (*d*). This lever is moved backwards and forwards by the rod (E), which is jointed to the bent rod (*f*), fastened at one end to the frame of the building, and at the other to the frame carrying the saws. When it is wanted to reverse the motion after the log is cut, the pall (*c*) is lifted clear of the teeth of the ratchet wheel (M), and this wheel is turned in an opposite direction by hand. In these simple saw mills, where the frame is fixed at once to the shaft of the water wheel, there are seldom more than two saws at work at once, but the principle, of course, can be extended at pleasure.

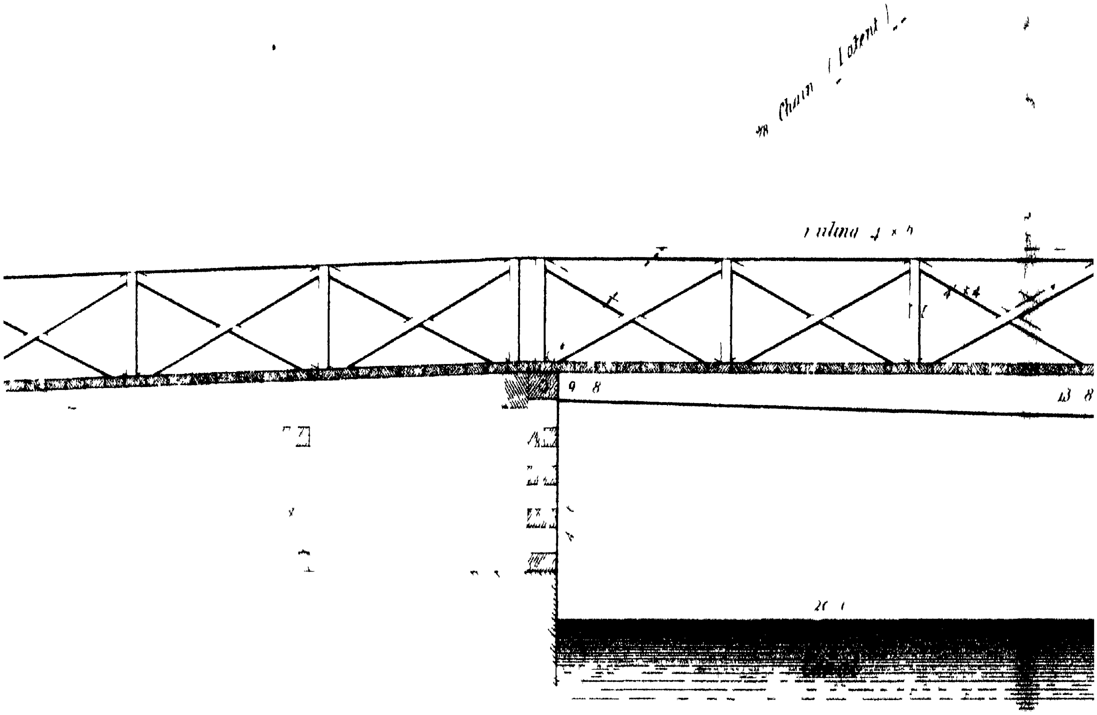
I have inserted this sketch and description because I believe that in many of our colonies it might be desirable to encourage labour and to take advantage of the powers that nature offers to us, and which are too often neglected from a want of the means of applying the power to some simple machine, and thus rendering it available. In the saw mill shown above, I do not think there is a single part which might not be made on the spot by a common carpenter. All the parts which in the sketch are shown as of iron may be easily made of hard wood, and indeed in practice are often so made.

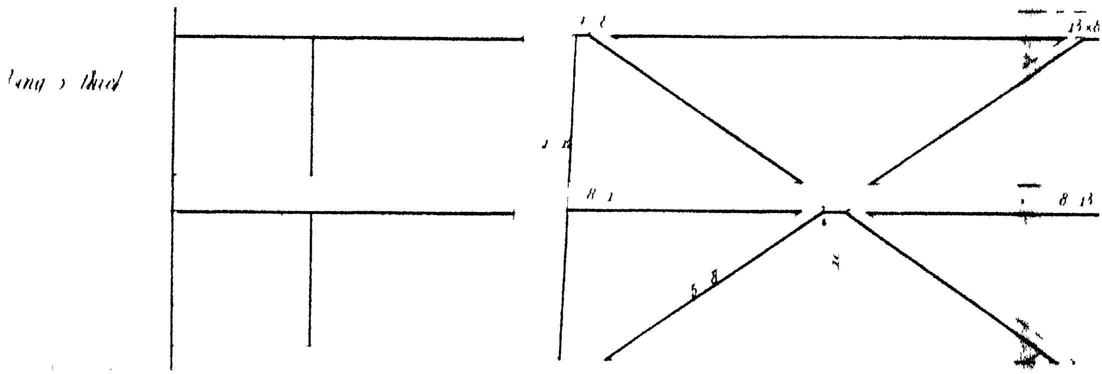
W. D.

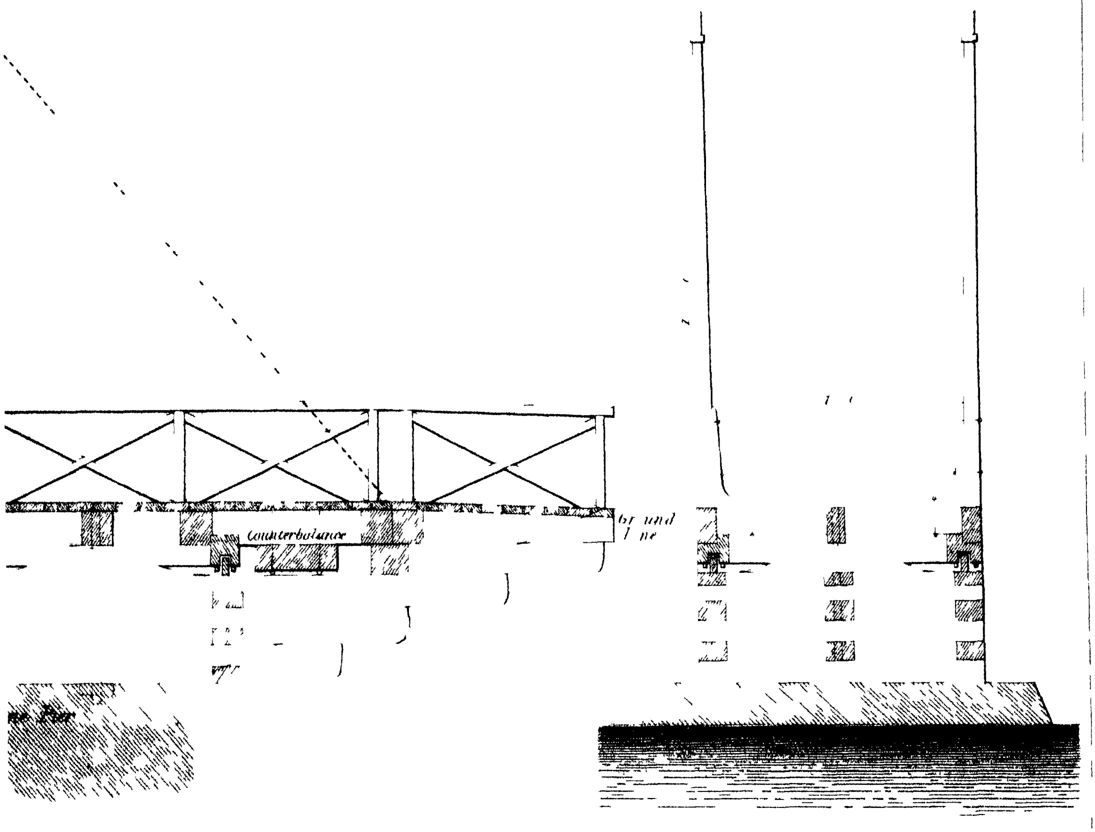
The logs to be not less than 1 foot square, with fair outside face, and to be filled with stones. The string pieces of the bridge to be of oak, 13″ × 8″ at the king post, and tapered to 9″ × 8″ at the swinging end of the bridge. The circle for the trucks to be of oak, in two thicknesses, bolted together. The swinging plate to be of oak, and also the hollow cap, and to be worked correctly to the shape shown in the elevation and section. The king posts to be of oak, 16″ × 5″ at bottom, 12″ × $3\frac{1}{2}$″ at top. The rails of the bridge to be of red pine, of the several dimensions shown. The planking to be 3″ thick. The posts for the railing to be 5″ × 5″. The rail 4″ × 5″, and braces 4″ × 4″. The counterbalance to be of oak framing, bolted to the bridge, and loaded with stones. The king posts to have knees bolted to them, and bolted to the rail of the bridge. The bridge to work eight cast iron trucks, of the pattern and dimensions shown on the plan, running on a wrought iron racer $2\frac{1}{2}$″ × $\frac{1}{2}$″, studded to the bed plate. The position of the bridge to be secured by the swinging plate and hollow cap, and to be kept steady by a wrought iron bolt passing through the rail of the bridge, and fastened under the framing of the abutment by a nut and iron plate. The truss chains to be [illegible]″ patent chain, with wrought iron hoop for the king post, and secured to the strings of the bridge by eye bolts and tightening links. The opening and shutting chains to be $\frac{1}{2}$″ common chain, secured by eye bolts, and to the piers by rings let into the stone, and to be of sufficient length to lie on the bottom of the canal without offering any obstruction to the navigation. The railing to be painted, three coats in oil, and all the other woodwork to be tarred, two coats. The whole of the materials to be of the best description, and the work to be performed in a sound, substantial, and workmanlike manner, subject to the inspection, direction, rejection, or approval of the Royal Engineer officer in charge, or such person as he may appoint to superintend the work.

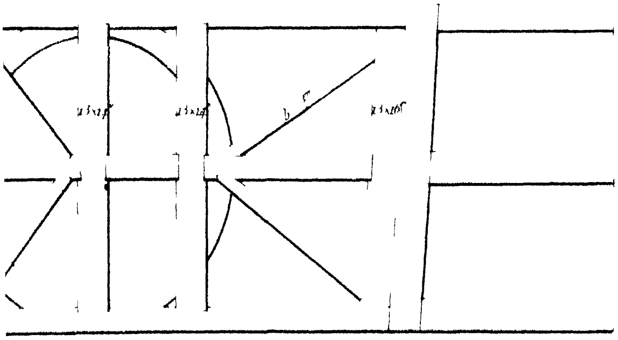
PLAN, ELEVATION AND SECTION OF THE SWING BRIDGES

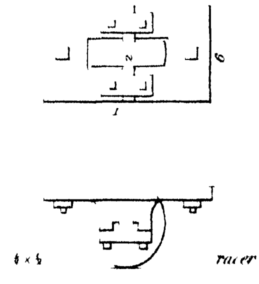
ON THE LINE OF THE GRENVILLE CANAL











Plan and Elevation of the trucks on a larger Scale 1 inch to a Foot

IX.—*On the System of combining Mechanical Ventilation with Warming by Steam Heat, as adapted to Public Buildings.* By Mr. Spencer.

Section I.—*Ventilation.*

Art. 1. The subject stated.
2. The vitiating causes.
3. Respiration.
4. Perspiration.
5. Combustion of fires and lights.
6. The quantity of air to be changed per minute for each person.
7. Constitution of atmosphere.
8. Modes of ventilation.
9. By a rarefied column of air.
10. Counteracting causes.
11. Objections to.
12. Mechanical ventilation.
13. Mr. Oldham employed it in 1823 and 1837.
14. Messrs. Easton and Amos ventilate Post Office, 1840.
15. ,, ,, Reform Club House, 1840.
16. Recommended by an anonymous writer in 1825.
17. Is healthful.
18. Will perfectly expel the vitiated air.
19. Where the air should be admitted.
20. The floor the proper place for the admission of the air.
21. The ventilating fan.
22. The principle of the fan.
23. To calculate the power of.

Section II.—*Steam Warming.*

24. Air must not be in contact with a surface heated to more than 212°.
25. Steam heat economical, example—Reform Club House.
26. Mr. Oldham, inventor of steam heaters.

SECTION I.—*Ventilation.*

Art. 1. Although the great importance of an efficient and economical system of ventilating and warming public buildings has long been generally admitted, it is singular that the subject of *mechanically ventilating* buildings has occupied so little of the attention of writers on this subject; especially when we consider the effective means which it furnishes of diffusing any required amount of heat equally over the whole building; and that without requiring the aid of any apparatus or pipes higher than the basement.

In the present Paper we propose giving—

1st. A condensed view of the subject of ventilation, especially with reference to the above system.

2dly. A method of applying steam heat in combination with mechanical ventilation.

3dly. Illustrations of the proposed system as in present use, with references to the drawings.

2. *Vitiating Causes.*—The principal vitiating causes which render ventilation necessary are, *respiration*, *perspiration*, and the *combustion of fires* and *lights*. In estimating the extent of the vitiation of the air from these causes, nothing more than a mere approximation should be expected.

3. *Respiration.*—Upon this subject Mr. Tredgold says, that upon a fair

average,[1] 800 cubic inches of air passes through the lungs of a man in a minute, 32 inches of which is changed during respiration from oxygen to carbonic acid gas, or about 4 per cent. of the bulk. Professor Brande[2] thinks 4 per cent. to be a fair average, and states that he has found that after emptying the lungs by a violent expiration, that the expired air will generally extinguish a candle. These gentlemen agree that for this cause alone 800 cubic inches should be changed per minute for each person; this has been thought too much by others,[3] while Messrs. Easton and Amos always allow more.

4. *Perspiration.*—Although this must be considered as a cause of vitiation, very little is known respecting its nature, except that air, by remaining in contact with the skin, generates carbonic acid gas. The average quantity of perspirable matter, according to Mr. Tredgold, is about 18 grains per minute from each person; and he thinks the quantity of air changed on this account should be equal to the quantity of air which the moisture would saturate: this he states to be 3 cubic feet per minute. In the above calculation the temperature is supposed to be 60°, but, as the quantity of perspirable matter increases with the temperature, at higher temperatures the amount of ventilation must be increased in proportion.

5. *Combustion of Fires and Lights.*—These causes vitiate the air by consuming its oxygen during combustion, and generating carbonic acid gas: one quarter of a cubic foot of air is generally allowed for these causes to be changed for each person per minute.[4]

6. Assuming these data to be correct, we shall have

For respiration	800	cubic inches.
For perspiration	5184	„ „
For fires and lights . . .	432	„ „
	6416	„ „

[1] Tredgold on Warming and Ventilating, Article 56.

[2] Report of Committee on Ventilation, 1835.

[3] Theory and Practice of Warming and Ventilating, by an Engineer, 1825.

[4] On this subject Professor Brande states to the Committee before mentioned, that "all the common combustibles consist essentially of carbon and hydrogen, and that 1 lb. of carbon in burning consumes 2 and $\frac{6}{10}$ths lbs. of oxygen, which is that contained in about 40 lbs. of atmospheric air. Now, wax, tallow, and oil contain, upon the average, from 77 to 80 per cent. of carbon, and from 11 to 14 per cent. of hydrogen, the remainder being oxygen; and 100 cubical feet of air weigh

or nearly 4 cubic feet of vitiated air to be removed for each person per minute. But in the Reform Club House, and other buildings, Messrs. Easton and Amos have provided 7 cubic feet for each person to be changed per minute.

7. *Constitution of the Atmosphere.*—Atmospheric air, in its pure state, is found to consist of—nitrogen, 7 parts; oxygen, 2 parts; which proportion is found to be invariable at all temperatures, altitudes, and latitudes, over the globe; but with these there is always found in mechanical mixture, *water* in the form of vapour and *carbonic acid gas*, the former varying under $1\frac{1}{2}$ per cent. of the whole weight, the latter, from 3 to 8 parts out of 1000 in weight.[5] Dr. Andrew Combe[6] gives the following as the proportions of the air before and after respiration:

Before—	Nitrogen	·78	After—	Nitrogen	·78
	Oxygen	·21		Oxygen	·13
	Carbonic acid gas	·01		Carbonic acid gas	·09
		100			100

or, 8 per cent. carbonic acid gas generated, the same amount of oxygen being consumed during respiration.

8. *Modes of Ventilation.*—To effect the necessary change of air in buildings, many plans have been proposed, all of which belong to one of the two following classes:

1st. Those which ventilate by a rarefied column of air; 2nd. Those which ventilate by forcing in fresh air to the building by mechanical means.

9. *Ventilation by Rarefaction.*—The common English fire-place and chimney is a familiar example of this class; the heated products of combustion, by rising into the chimney, maintain the air thereof at a higher temperature than that of the rooms; the column of air in the chimney, being thus rendered specifically lighter than the external air, will ascend with a velocity proportional to the difference of temperatures of the chimney and external air, considered with reference to the height of the chimney; for air expands about $\frac{1}{480}$th of its bulk for every degree of the thermometer.

about 112 ounces avoirdupoise, or 7 lbs.; so that from these data the approximate consumption of oxygen by any given quantity of the above combustibles is easily calculated." Coal gas, he assumes, spoils thrice its bulk of oxygen, or fifteen times that of air.

[5] Art. *Atmosphere*, Penny Cyclopædia.

[6] Physiology applied to the Preservation of Health.

If we suppose a case where

The temperature of external air is at	60°	
The temperature of chimney kept at	180°	
Height of chimney	70 feet	or, 280 cubic feet contents.
Area " "	2 feet square	

Now the difference of temperature here is 120°; therefore the air in the chimney is $\frac{120}{480}$ths or $\frac{1}{4}$th lighter than the external air; and if we suppose, first, a column of air of the sectional area and height as above, at the temperature of 60°, and then consider the height this column would reach, if expanded $\frac{120}{480}$ths or $\frac{1}{4}$th its bulk, the sectional area remaining the same; this difference of height will be the distance through which a heavy body would be required to fall, to attain the velocity of the current in the chimney, which in this case is 17·5 feet.

10. This is the theoretical effect, if there were no counteracting causes: but when we consider as elements in the calculation, the friction of the sides of the chimney, the cooling effects of various materials of which the chimney may be built, the resistance to egress owing to the superior density of the burned air, and the want perhaps of due proportion in the chimney, we must not be surprised, in the absence of any accurate experiments, at the total want of congruity in the rules laid down for finding the *practical* effect.

11. Great objection has been raised to the employment of this mode of ventilation, on the score of detriment to health, by Dr. Ure and others,[7] but common experience scarcely justifies the conclusion where sufficient air is allowed to enter; on the score of economy, its *single* employment is, without doubt, extravagant.

12. *Mechanical ventilation* is effected by forcing a supply of pure air into the building to be ventilated, by means of a fan, screw, or air pump, worked by means of steam or other power: this plan is believed to have originated with Dr. Désaguliers, who was employed to ventilate the House of Commons in the year 1736. After ventilation by rarefaction had been tried without success, the Doctor's machine, a diagram of which is given (Plate XXXIV. fig. 1), was continued in use some years with but small success, owing to a mechanical defect in the fan, which will be explained hereafter. Dr. Ure, in his 'Philosophy of Manufactures,' (Knight, 1835,) strongly recommended this mode of ventilation,

[7] Experimental Inquiry: Architectural Magazine, April, 1837.

and explained the proper construction of the fan; since which, it has been used with great benefit to the health of the work-people in many factories in the north.

13. In 1837, the late Mr. Oldham, Engineer to the Bank of England, introduced an air pump which he employed to ventilate the rooms of the engraving and printing departments of that establishment; he had previously, in 1823, introduced it at the Bank of Ireland, where it is still in use.

14. In the year 1840, Messrs. Easton and Amos were employed to ventilate the letter-carrier and inland office department of the New Post Office; a large fan was put up, which gives great satisfaction.

15. In the same year the above engineers were employed to ventilate and warm the Reform Club House in Pall Mall, and the very complete machinery, of which we have given a full description and drawings, was put up by them, and which two years' experience confirms as at once efficient and economical.

16. In 1825, the writer of an anonymous 'Treatise on the Theory and Practice of Warming and Ventilating,' &c., thus recommends this system: "The mode previously suggested would *perhaps* be desirable for an extensive range of buildings, especially if a steam engine were attached to any manufactory adjacent, by which a large supply of air might be obtained at a very slight expense of power." * * * *

"In this way an area of any extent may be ventilated with infinitely greater rapidity and effect than by any arrangement for spontaneous ventilation that could possibly be devised."

17. There can be no doubt also, that the mechanical plan admits of no exception on the score of healthfulness, for the air thrown into the building need undergo no alteration from its original state, unless it be necessary to warm it, which, being performed by steam heat, preserves its original purity and healthfulness.

18. There is also no reason to fear the *perfect* expulsion of the vitiated air, because, that being more rarefied than the cooler fresh air driven in, must occupy the higher parts of the room, and being thus kept under a continual pressure, proportional to the difference of temperatures and the quantity of air forced in, its complete expulsion must take place, if proper exits have been provided in the upper part of the room.

19. There has been some difference of opinion as to what part of the room the air should be admitted, whether at or near the floor, or in or near the

ceiling: some, among whom are Dr. Ure and Mr. Tredgold, say the floor; while others, as Mr. Perkins and Mr. Ainger, say the ceiling is the most natural place for admission of air, " because (say they), with upward ventilation, a *great part* of the vitiated atmosphere of crowded rooms, being specifically heavier than the common air, is liable, by the slightest condensation, to be thrown down, and mixed with the air which is already partly unfitted for the purposes of life." This reasoning appears feasible at first sight, for we know that the weights of equal bulks of air and carbonic acid gas is as 7 to 11 nearly at the same temperature; but it must be remembered, that in perspiration, and in respiration, this gas is held in a condition of minute mixture and mechanical suspension with azotic gas and aqueous vapour, and that the bulk of these greatly preponderates, the carbonic acid gas being only 8 per cent. (after respiration) of the bulk: now the resulting compound at the temperature (98°) at which it is expelled being considerably lighter than the air at any usual temperature, will ascend to the higher parts of the room; Mr. Tredgold says, " with such rapidity that it is entirely removed from us before it becomes diffused in the atmosphere."

But in another point of view, the admission of air at the ceiling seems objectionable: we know that the vitiation of the air does not depend solely on the presence of carbonic acid gas; and as the other mephitic exhalations not possessing its density will rise to the upper strata of air, it follows that these, together with that portion of carbonic acid gas " not condensed," will, in being driven from the floor exits, contravene that great principle of ventilation, " That the same air must never be presented to the lungs twice." [8]

20. From these considerations we must conclude, that the most natural ventilation is that where the air, being admitted at or near the floor, expels the vitiated air from proper exits in or near the ceiling.

21. *The Ventilating Fan.*—In the two diagrams (Plate XXXIV. figs. 1 and 2), the principle of the concentric and of the excentric or spiral fan is shown. Dr. Desaguliers' is stated to have been on the concentric principle, which explains its inefficiency, for a bare inspection of the diagram will show that only two leaves are effective in discharging the air through the exit pipe, while in the spiral-cased fan all the leaves are in continual and uniform action, as will be evident.

[8] Dr. Ure.

22. These fans depend for their action upon the following principles: the rapid revolution of the fan, acting upon the air contained between the blades or leaves, causes it to be thrown out into the case by its acquired centrifugal force, by which action a partial vacuum is formed, into which the external air rushes through the aperture at the shaft centre, and thus a continued current of air is maintained, in proportion to the velocity and size of the fan.

23. The power of the fan is calculated thus: take the area of the concentric ring contained between the top and bottom of the fan blades, then find that circle which will divide this area into two concentric rings of equal area. The velocity of this point will be the velocity of the current which passes through the exit pipe, and this velocity in seconds, multiplied by the area of one of the fan blades, gives the quantity of air discharged through the exit pipe per second. Plate XXXIV. (figs. 3, 4, 5, 6,) shows the Reform Club House fan in elevation and in section; this fan throws 11,000 cubic feet per minute

SECTION II.—*On Warming by Steam Heat.*

24. Mr. Tredgold says,[9] "The principle of not suffering air to be in contact with any substance heated above 212° excludes a multitude of contrivances called stoves, which it would be a waste of time to examine." Experience daily confirms the justice of this remark, and the advantage of employing steam as a vehicle for diffusing heat is becoming much more understood.

25. In conjunction with mechanical ventilation, especially where steam power is required for any other purposes, its employment is found to be very economical as well as efficient: in the Reform Club House, for example, the machinery of which is described in Section III., the greater part of this extensive establishment—namely, the large kitchen *on the basement*, the saloon, coffee room, lower library, house dinner room, *on the ground floor*, the drawing room, upper library, committee room, private drawing room, card room, smoking room, and billiard room, *on the first floor*, are all warmed and ventilated, all the coals required raised, and all the water used in this large establishment pumped, at an expense of fuel of only three shillings per day.

26. The first idea of combining steam warming with mechanical ventilation, it is believed, originated with the late Mr. Oldham, who introduced his steam

[9] Warming and Ventilating, Art. 8.

chest at the Bank of England in 1837, which is the same in principle as the one shown in the drawing as in use at the Reform Club House. It will be seen that the air and steam occupy alternate channels in the chest; the air passing rapidly through these channels, receives the heat contained in the steam, as it becomes condensed, and thus the air, although receiving a great amount of heat, is never in contact with the heaters at a temperature of more than 212°.

27. This must be allowed to be a great improvement on the plan of carrying the steam in pipes over the building, the chances of derangement being diminished, and the action so much more certain, to say nothing of the unsightliness of the pipes.

28. As compared with water circulation its advantages are great, for steam contains in the same bulk six times the quantity of caloric that water at the boiling point does; therefore a vessel to present equal surfaces of heat would require in a hot water warming apparatus 6 feet of surface for 1 of steam.

29. In addition to this, steam gives off its heat in much less time than water, which makes the water a more clumsy vehicle in diffusing warmth than steam.

30. In Plate XXXI. of the Reform Club House machinery, are shown four hot water heaters, which are intended to be warmed by the furnace and boilers shown in the next apartment. These heaters together present a heating surface of over 1000 feet, but could never by any exertion or expenditure of fuel be made to warm the building sufficiently, while the three smaller steam heaters, supplied by the waste steam of the engine, and presenting a surface together of about 468 feet, have been found ample in all cases for heating the building.

31. The steam apparatus possesses a great advantage also in the rapidity with which the amount of heat supplied may be increased or diminished, while the water apparatus requires much more time in preparing, and does not allow of quick alternations of heat.

32. In order to calculate the quantity of surface required for the heaters, Mr. Tredgold's rule, founded on his ingenious experiments on cooling, as detailed in his work (art. 42), is generally followed, as proved by experience to be sufficiently accurate.

Rule.—Multiply the cubic feet, per minute, of air to be heated, to supply the ventilation and loss of heat, by the difference between the temperature the room is to be kept at, and that of the external air in degrees of Fahrenheit's thermometer, and divide the product by 2·1 times the difference between 200 and the temperature of the room; this quotient will give the quantity of surface of cast iron that will be sufficient to maintain the room at the required temperature. For example, suppose it be required to find the surface necessary to raise 1100 cubic feet per minute, from 32°, the supposed temperature of the external air, to 60°, the required temperature of the rooms, the pressure of the steam being $2\frac{1}{2}$ lbs. per inch above the pressure of the atmosphere;

$$\text{Then } \frac{1100 \times \overline{60^\circ - 32^\circ}}{2{\cdot}1 \times \overline{200^\circ - 60^\circ}} = 104{\cdot}7 \text{ feet super. the required surface.}$$

Section III.—*Description of the Reform Club House Ventilating and Warming Apparatus.*

33. Reference to the Plates.

Plate XXXI. Fig. 1 is a general plan of that part of the building containing the apparatus, and shows the relative position of the machinery.

Fig. 2. A sectional elevation through the heat chamber, and air passage or vault.

Fig. 3. A transverse section showing the position of the hot water heaters and circulating pipes.

Fig. 4. A transverse section showing the position of the steam heaters, pipes, and valves.

Fig. 5. A transverse section in the air passage, showing the position of steam pipe and condensed water pipe.

Plate XXXII. is a sectional elevation through boiler house, engine room, and fan room. The boiler is of copper, and is cylindrical: *a*, mercurial gauge; *b*, syphon for emptying boiler: *c*, supply pipe from tank in lifting room; *d*, extra supply pipe; *e*, engine steam pipe; *f*, safety valve; *g*, waste steam pipe connected with the eduction pipe (*h*) of the engine, and then continued to the heaters; *i*, damper for boiler flue.

Engine Room.—*j*, pump for supplying boiler with water, worked by the engine crank; *k k k k*, riggers for driving the fan; that in the lift-house, between the engine and fan, drives a pulley at *l*, for lifting coals: a pinion on the crank shaft drives a cog wheel placed below the pavement, which is keyed on the shaft for working the pumps in well, as shown on the general plan.

Fan House.—*m*, fan, opening into the air chamber or passage; *n*, a rack of coke *intended* for *purifying* the air, which is drawn through it; it is supposed to have an opposite effect,[10] and to diminish the effective power of the fan.

[10] See Dr. Ure's Report: Engineer and Architect's Journal, 1842.

Plate XXXIII. Fig. 1 is an enlarged front elevation of the three cast iron steam heaters shown in position in fig. 4, Plate XXXII.

Fig. 2 is a plan of the same.

Fig. 3 is a side elevation of the same.

Fig. 4 is a section through A B, showing the relative positions of steam passages (*s*), and air passages (*a*).

Fig. 5 is a section through C D, showing the position and mode of fixing the steam jacket or cover (J).

Plate XXXIV. fig. 1. A diagram showing the construction of the concentric fan.

Fig. 2. A diagram showing the construction of the excentric or spiral fan.

Fig. 3. A section of the fan in use at the Reform Club House.

Figs. 4 and 5. Elevations of the same fan.

Fig. 6. Plan of the same.

Figs. 7 and 8. Front and side elevations of the hot water heaters at the same place.

Fig. 9. A section through one of the heaters. These heaters consist of a cast iron dished plate, $\frac{1}{4}$ inch thick, to which is bolted a flat plate made of $\frac{1}{8}$-inch boiler plate; thirteen of these, connected at opposite corners to semicircular pipes through which the water circulates, form a heater, of which there are four.

Fig. 10. One of the registers used to regulate the quantity of air admitted to the rooms. These are placed in the passage over the flues, and act in the manner shown.

In all cases in the Plates, references, and descriptions, similar letters indicate similar parts.

34. *The Ventilating Action.*—The rigger (*k*) on the engine shaft (by means of the intermediate riggers and bands) gives motion to the small rigger on the fan shaft; a rapid motion being thus given to the fan, air is drawn through the circular aperture at the fan shaft (Plate XXXII. fig. 4), and thrown by the motion of the leaves of the fan through the exit pipe into the air passage, and along thence into the heat chamber, from whence it is conveyed through flues in the walls to channels passing round the rooms, placed near the floor, and so formed that the air is directed downwards to the floor, by which means the air is equally diffused through the lower part of the room, and draughts of air avoided: the quantity of air admitted is regulated by the dampers and registers, with which each flue is provided: one of these is shown (Plate XXXIV. fig. 10).

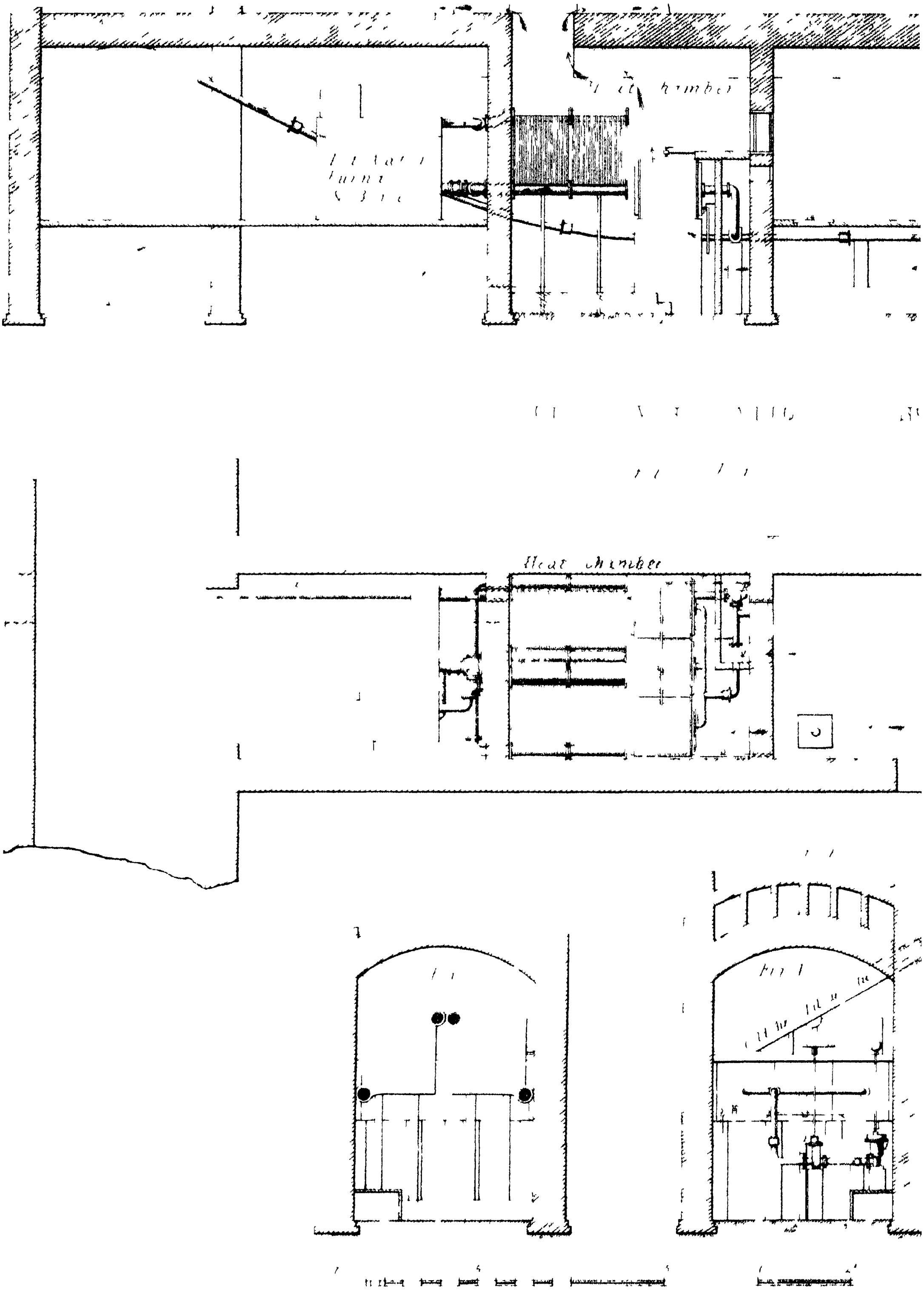
Another set of flues, connected with apertures in the ceilings of the rooms, and all terminating in a large chamber in the attic, carry off the vitiated heated air, by virtue of the pressure of the colder air in the lower part of the rooms.

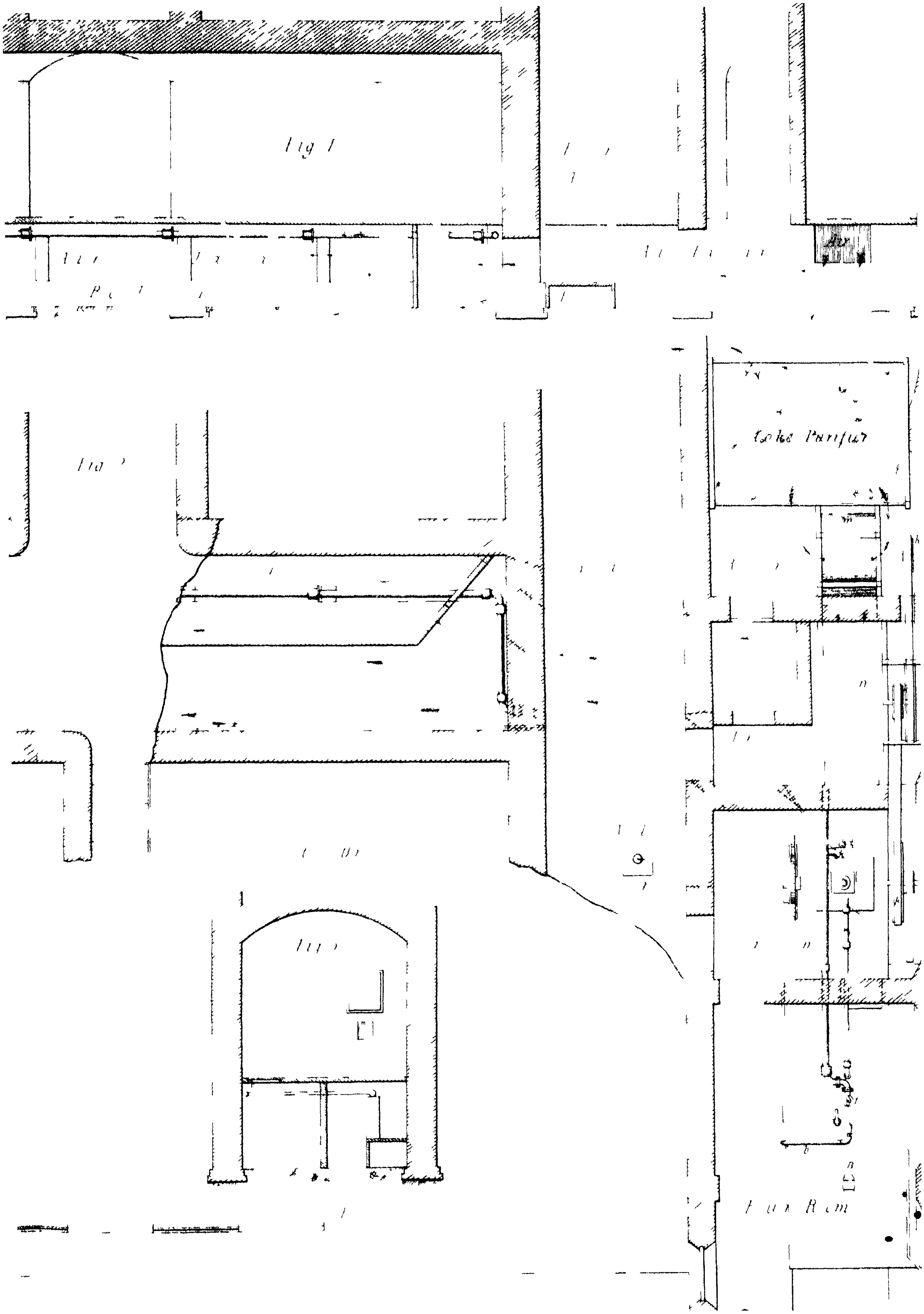
In this chamber a large furnace is placed with the intention of rarefying the air, and thus assisting the ventilation of the rooms below; but with a great consumption of fuel (3 cwt. daily), the effect was found so small that it has been entirely discontinued. It should be observed, however, that the construction of this part of the machinery is most unscientific.

35. *The Warming Action.*—A reference to the plan will show that the air passage is separated into two compartments, having doors at each end; through one of these passages the steam pipe is conducted, resting on brick piers, built on the boiler flue (Plate XXXI. fig. 1). If cold air only be desired, these doors being closed, and the steam turned off from the heaters in the heat chamber, cold air only will be thrown into the rooms. If warm air be desired, the doors at each end of the hot air passage being opened, and the steam turned on to the heaters by the valve (P), and prevented from passing up the waste steam pipe by closing the valve (R), it will give out its heat, by condensation, to the air in passing through the channels (A) in the steam heaters, and will be further warmed in its passage along the hot air vault by the heat given off by the steam pipe: the condensed water from the heaters and steam pipe is carried back to the tank in the lift-house which supplies the boiler, by the small pipe (*s*), which, after passing along the air passage to the well, drops down 16 feet, and then rising to its level, passes into the tank, and discharges; this arrangement being of course to prevent the escape of the steam from the heaters. A small pipe (*t*) is provided on the heaters to blow off the steam when required. The steam is usually kept at a pressure of about 3 lbs. per square inch. The arrangement will be readily understood by tracing the course of the steam pipe from the boiler. B is the escape pipe from safety valve joining the eduction pipe of engine at *u*; then passing through the tank into the hot air passage, to the *valve chamber*, it branches to the left into the heaters, and to the right to the escape pipe[11] into the chimney.

36. The steam is thus made to perform two distinct offices; first, by its elastic force it drives the air into the building by means of the engine, and then being brought into the heaters, it is condensed and gives out heat in any required degree.

[11] An improvement has been suggested by Mr. Amos, by bringing all the flues into a shaft or chimney, and then conducting the escape steam pipe into condensers placed there, by which a great rarefying power will be added, especially in the summer season, when the steam is not required for warming.


Heat chamber


Coke Purifier

It should be remarked that the hot water apparatus and furnace, &c., shown in the plan, together with the furnace at the top of the building, and the coke purifier in the vaults, form no part of Messrs. Easton and Amos's plans, the two former being altogether disused, and the latter being considered an incumbrance to the proper ventilation of the building.[12]

[12] Experience has pointed out a defect in the arrangement of the flues in this building, there being no means provided for varying the temperature of the air thrown in at any one given time to the different rooms: to remedy this defect, it is proposed to furnish two sets of flues; one, as now, passing from the heat chamber to the rooms, another passing from the cold air passage to the rooms; or these two flues might be connected beyond the heat chamber, when one set would suffice beyond that point: by these means air of any temperature, between that of the external air and that in the heat chamber, might be supplied to the various rooms *at the same time*. This suggestion, which will render the system much more perfect, originated with Mr. Webb, the engineer in charge of the machinery at the Reform Club House.

WORKS ON VENTILATION.

1. A Popular Treatise on Warming and Ventilating, by Charles Richardson, Architect. John Weale, 1837.
2. On Warming and Ventilating, &c., by Neil Arnott, M.D. Longman, 1838.
3. Tredgold on Warming and Ventilating. Taylor, 1840.
4. Warming and Ventilation. Encyclopædia Brit.
5. Steam Warming. Art. Steam, Encyclopædia Brit.: J. S. Russell.
6. Ventilation (chapter on): Combe on Health, pp. 224-239. Simpkin and Marshall.
7. Theory and Practice of Warming and Ventilating, by an Engineer. 1825.
8. A Paper on Warming and Ventilating, describing Mr. Oldham's System, in Civil Engineer and Architect's Journal, No. 18, Vol. ii.
9. Report of Committee of House of Commons on Warming and Ventilating, 1836. Inman's Digest. Weale.
10. Essay in Quarterly Journal of Science, April, 1822, by Mr. D. Gilbert.
11. Paper in Annals of Philosophy, June, 1822, by Mr. Sylvester.
12. Experimental Inquiry on Warming and Ventilating, read before Royal Society, June, 1836.
13. Report on Custom-House Warming and Ventilation, as performed by Mr. F. A. Bernhardt. Andrew Ure, M.D.: Architectural Magazine, January, 1836.
14. Lectures on Heat, at Royal Institution, by Professor Brande.
15. Outlines of Warming and Ventilating, by Dr. Reid.
16. Alexander on Ventilating, &c. of Meeting Houses, 4to. Weale.

X.—*The Patent American Steam Pile-Driving Machines.* *By* Mr. G. Spencer.

These machines, which have recently been made the subject of a patent in the United Kingdoms, and other European countries, by Colonel Joseph Cowden, of New York, are now in successful operation in America, in the formation of railways, locks, canals, coffer-dams, &c. More than 200 miles of the New York and Erie Railroad is constructed upon piles driven by these machines: on the Utica and Syracuse Railroad, and on the New Orleans and Nashville Railroad, they have been of extensive use: the road having to be carried over extensive prairies, any other than the pile plan would have proved almost impracticable from the enormous cost of construction.

A great advantage was found to result from their use, in the rapidity with which the works were completed: as an ordinary circumstance, one machine, tended by an engineer and his assistant, with five men, could easily average one hundred piles, 15 feet in length, in one day. Sixteen machines were at work at one time on the New York and Erie Railroad, and averaged 1 mile of piles per month for each machine: the piles were driven 5 feet apart.

The machine was first used at the Surrey side of the new Suspension Bridge erecting over the Thames at Hungerford Market, and excited considerable curiosity in the public, and approbation from the profession, although the one used there, being the No. 1 machine, as shown in Plate XXXV., was much too heavy to exhibit its powers to advantage.

DESCRIPTION OF THE MACHINE.

There are three patterns of this machine.

The No. 1 machine (Plate XXXV.) is large and commodious for railways and heavy embankments. This machine drives two rows of piles simultaneously.

The No. 2 machine (Plate XXXVI.) is a more compact arrangement of the same parts as the No. 1 machine, and is used principally in coffer-dams.

The No. 3 machine (Plate XXXVII.) is of a smaller size, and is used in all cases where a single row of piles is to be driven.

Machine No. 1 consists of a strong horizontal wood framing, mounted on three pair of railway truck wheels, and carrying on one end, the boiler and pumps; in the centre, the two cylinders and winding gear; and on the other end, the ladders and two pair of leaders similar to those used in the common machines; and underneath, the saw apparatus and cistern.

In Plate XXXV., fig. 1 is a side elevation; fig. 2 is an elevation in front of leaders; fig. 3 is a section taken in front of the winding gear, and showing the communication of the power to the saw; fig. 4 is a plan, top of leaders and ropes removed.

References to Plates.—Similar letters show similar parts.

a Boiler, formed of ⅜-inch plates, and having fifty copper tube flues $\frac{3}{32}$ inch thick, calculated for 120 lbs. per square inch, but generally used at 80 lbs. per square inch.

b Safety valve.

c Throttle valve.

d Copper steam pipe, 1⅛ inch diameter.

e Cylinders, 5½-inch bore, pistons working without packing; stroke 1′ 2″.

f Valve rods, worked by excentrics on shaft.

g Connecting rods.

h Cranks, placed at right angles to each other on shaft.

i J Pinion and spur, communicating motion to drum shafts.

k Drum shafts.

l Hammer-lifting drums, shown in detail, Plate XXXVIII. figs. 1 and 2, consisting of an end piece keyed to the shaft, and always revolving with it, and the loose drum, which, being brought in contact with it by the lever, is thus made to revolve, and, winding the rope, raises the hammer.

m Friction band, to hold loose drum when not winding rope.

n Pile-raising drum, keyed to shaft.

o Pulley for raising pile.

p Pulley for raising hammer.

P Monkey.

q Hammer, weight 16 cwt.

r Stay for supporting hammer while raising pile into its place.
s Pile stay.
t Wrought iron pile guides.
u Bevel gear for working saw.
v Saw pulley.
w Saw, 4 feet diameter, ¼ inch thick.
x Lever to gear bevels with.
y Handle to work pump by hand.
z Pump rod, worked by spur nave.
a′ Cistern.
b′ Progressing pulley.
A Lever to bring drums into gear.
B Iron arc, on which slides the saw beam.
D Guide ropes for supporting single machines.

The machine will be best understood by following it through its several actions, which are,

1. Raising the pile to its place.
2. Driving the pile.
3. Drawing out the pile.
4. Sawing off the piles to any required level.
5. Moving the machine forwards or backwards.

To raise a pile.—The hammer is secured by the stay being drawn under it, as shown in figs. 1 and 2; the dog is fastened to the pile (fig. 3), from which a rope passes through two small guide pulleys, over the pulley (*o*), and descends to the small drum (*n*), round which it is coiled twice, and held by a man; motion is now given to the drum shaft, and the pile is raised to its place, and secured by the loose stay.

To drive a pile.—Steam being admitted from the boiler (*a*) through the steam pipe (*d*) to the cylinders (*e*), the connecting rods (*g*), by acting on the cranks (*h*), cause the shaft (*k′*) to revolve; on this shaft is keyed the pinion (*i*), working into the spur wheel (J), which spur is keyed to the drum shaft (*k*), causing it to revolve. The drum being held against the fixed end by the lever (A), revolves with it and winds the rope on to it until the clippers reach the top, when the hammer, being disengaged, falls on the pile: the drum is then thrown out of gear, and the monkey, by its own weight, unwinds the rope from the drum, and descends to the hammer, and, taking hold of it, is ready to be again raised: this operation is easily performed five times in one minute by each hammer, and usually goes on without intermission until both piles are driven.

To draw a pile out.—Chain tackle is secured to the pile, passing over the pulley (*o*) down to the drum (*l*), to which it is secured; the power being now applied, the chain is wound on the drum, thus drawing the pile out.

To saw off the piles to any required level.—The saw (*w*) being adjusted to the required level by the adjusting screws, motion is given to it by the pulleys (*v* and *v*′) and the band which communicate with the bevel gear (*u*) by the vertical shaft on which the small bevel slides, and is pressed into gear by the foot lever (*x*); the saw beam is made to slide laterally on the iron arc (B), and, when working, is pressed against the pile by a man leaning his weight against a rod placed on the beam end.

To move the machine forwards or backwards.—To move forwards, a hook is made fast to a driven pile, and a rope attached to it is passed round the small pulley (*b*′) to the small drum (*n*), round which it is coiled twice, and the end held tight by a man; motion being now given to the drum (*n*), the machine advances. To move back, the rope is passed direct from the pile to the drum (*n*).

The machine No. 2 is a compact arrangement of the same parts as the No. 1, with the exception of the boiler, hammers, and saw, which are smaller. The weight of hammer being 10 cwt., the boiler is reduced one-third in capacity. The leaders in this pattern are placed 4′ 8½″ from centre to centre. The pump, which is not shown in the drawing, is placed on the other side of the boiler, and is worked in the same manner as in No. 1.

This pattern is chiefly used for coffer-dams and light embankments, and is worked in the same manner as No. 1, but may be worked by fewer hands.

In Plate XXXVI.

Fig. 1 is a front elevation of the machine.

Fig. 2 is a side elevation.

Fig. 3 is a section taken in front of working gear.

The machine No. 3 consists of a single pair of leaders, strongly bolted to a horizontal framing, formed by two sills firmly braced together, and carrying the boiler, working gear, and saw apparatus, and running on two pair of truck wheels, placed 5 inches apart. The hammer, which is 10 cwt., is raised in the same manner as in the other patterns, by means of a loose and fixed drum, which, being brought into contact by a hand lever, revolve by friction. This drum is given in detail in Plate XXXVIII. figs. 3 and 4. The pump, which is not shown in the drawing, is placed on the other side of the boiler, and is worked by an excentric on the shaft. The machine is supported by the guide ropes (D), which, being secured to a stake, and passing over the blocks down to the belay pin, are lengthened or shortened as the machine advances or recedes.

This machine is used in all cases when a single row of piles is to be driven.

In Plate XXXVII.

Fig. 1 is a front elevation of the leaders and saw apparatus. The guide ropes are shown here in action.

Fig. 2 is a side elevation of the machine, showing the machine in the act of raising the hammer.

Fig. 3 is a section taken in front of the working gear.

In Plate XXXVIII.

Fig. 1 is an elevation of the drum of Nos. 1 and 2 machines.

Fig. 2 is a section of the same.

Fig. 3 is an elevation of the drum of No. 3 machine.

Fig. 4 is a section of the same.

Fig. 5 is a front elevation of throttle and safety valves.

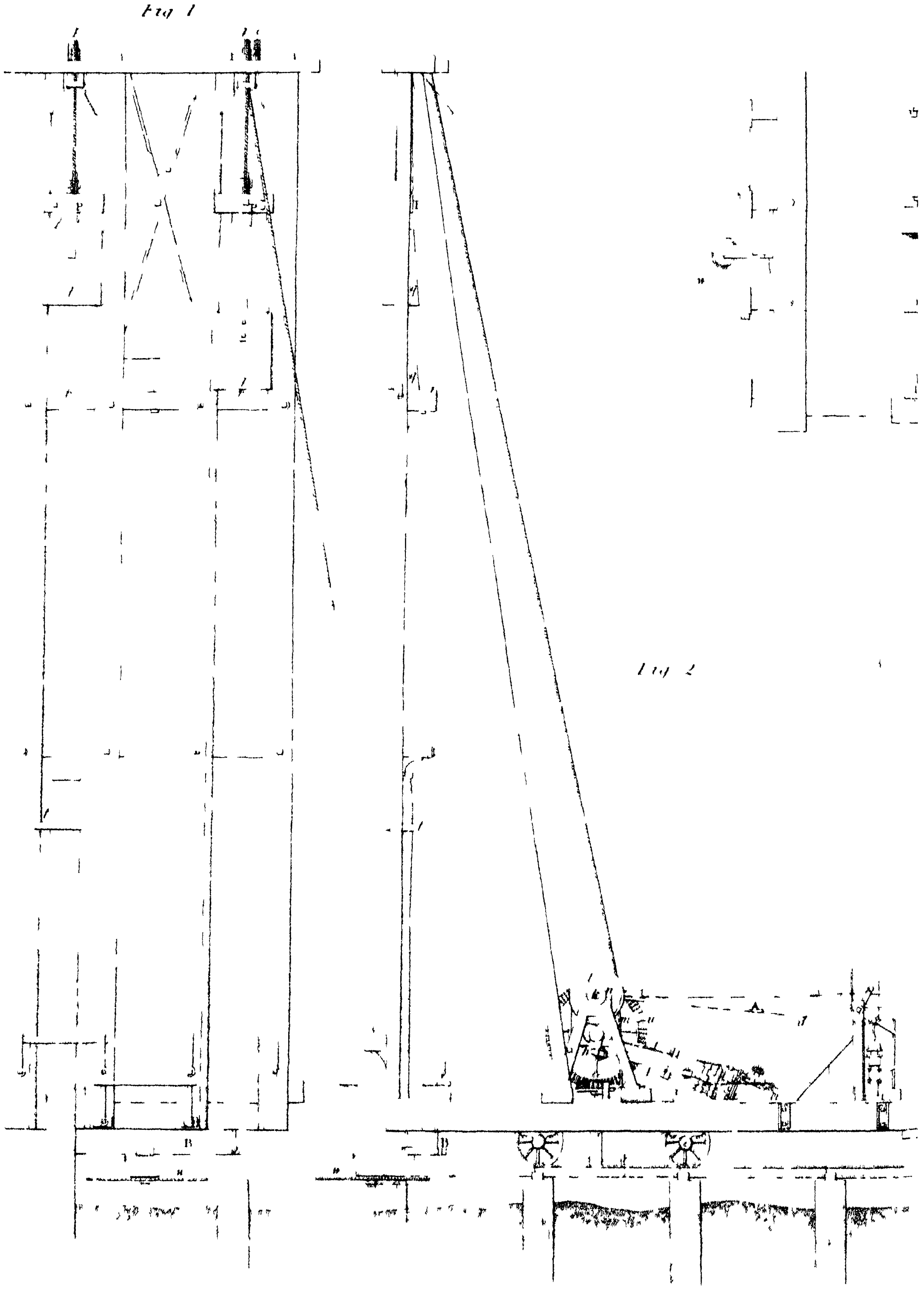
Fig. 6 is a side elevation of the same.

Fig. 7 shows the connexion of excentric and valves, the crank, connecting rod, parallel slides, cross head, and the cylinder.

Fig. 8 shows the same in plan.

Fig. 9 is a section of cylinder, piston, valve, and steam chest.

PATENT AMERICAN STEAM



DRIVING MACHINE, No. 1.

Fig. 1

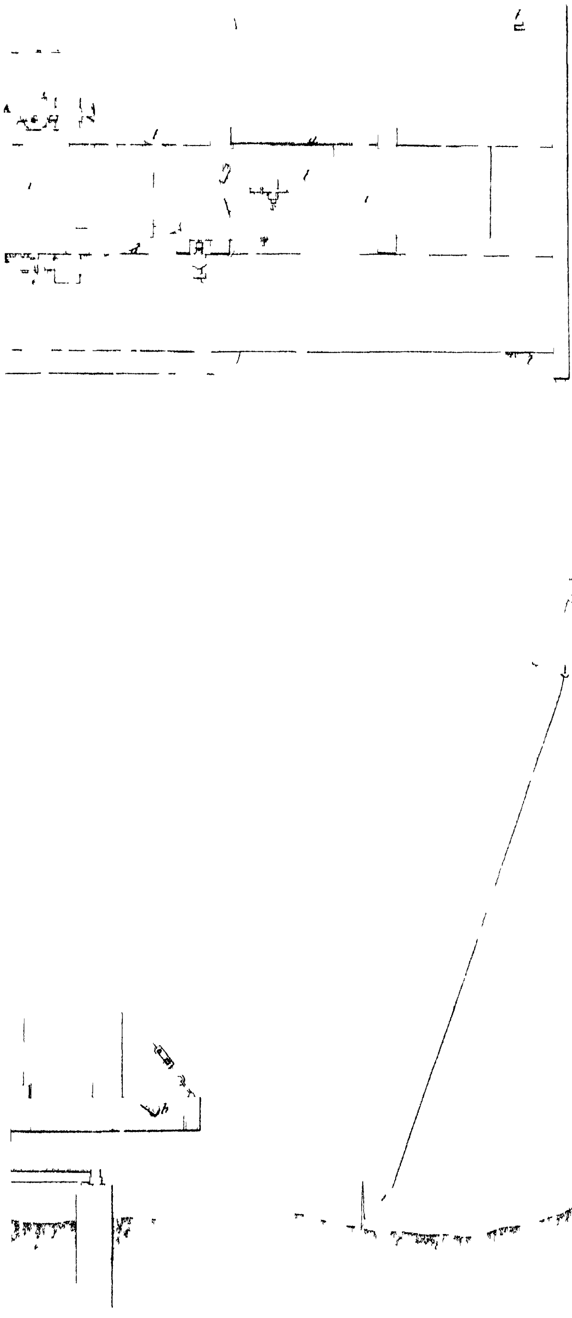
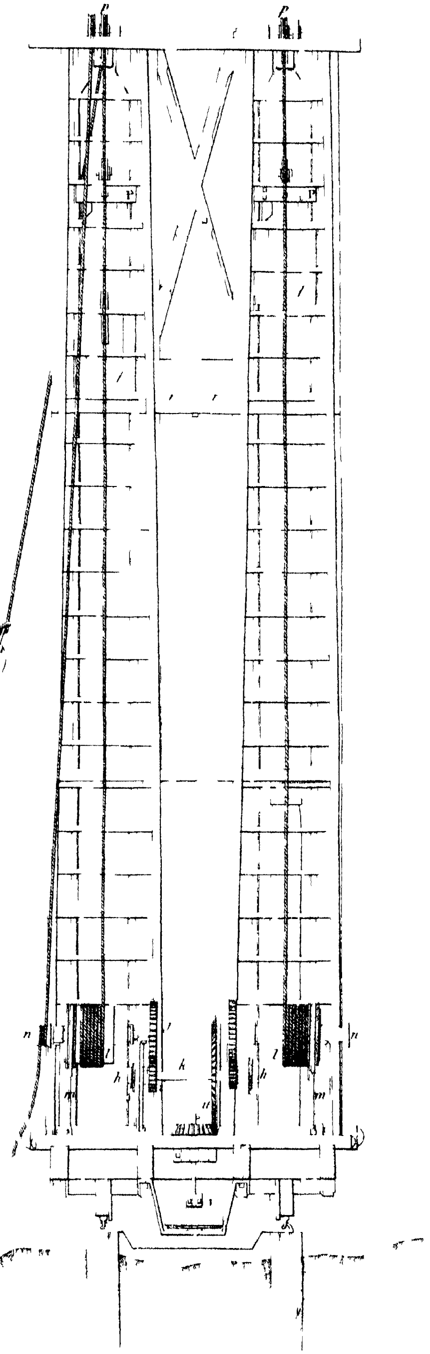


Fig. 3



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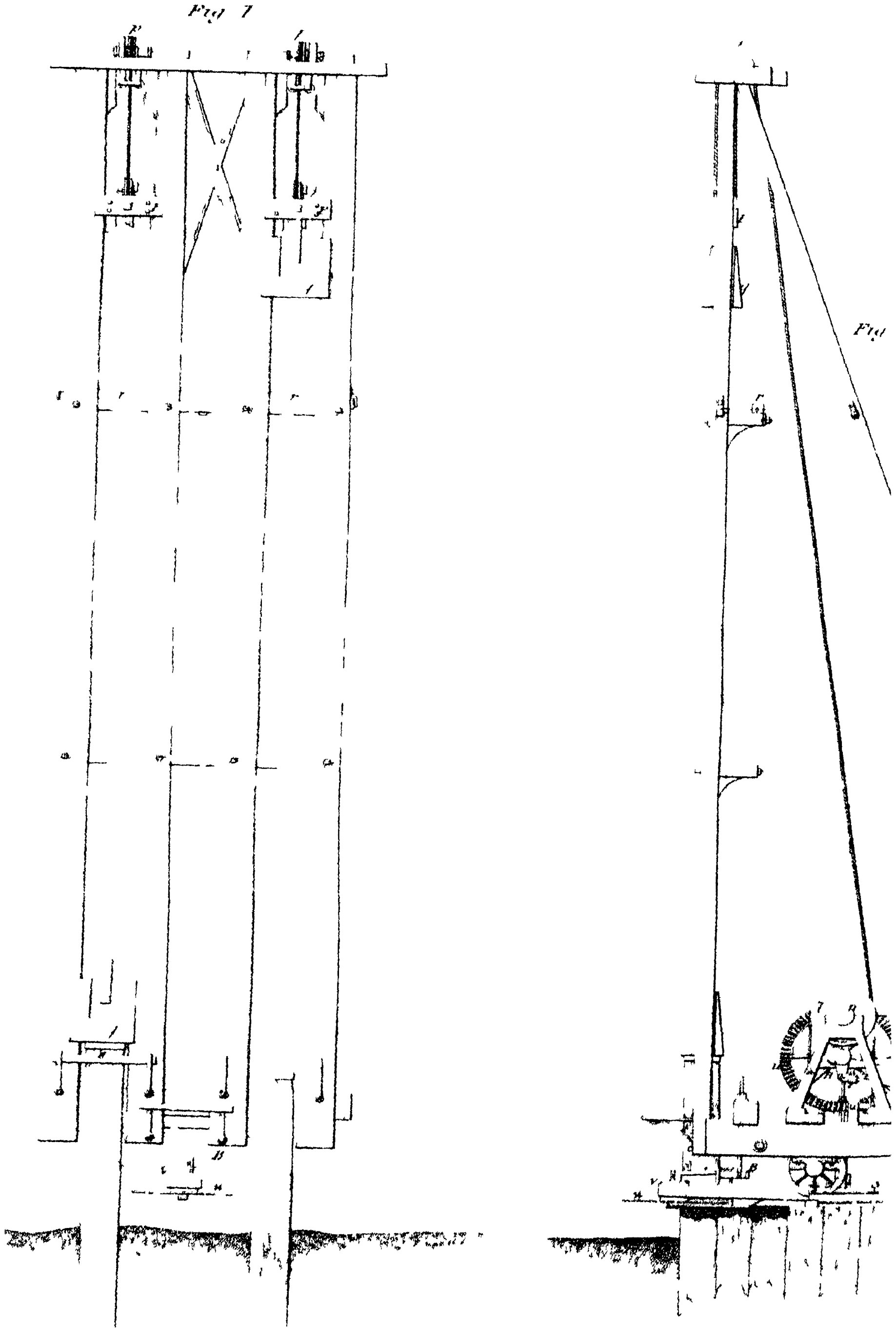
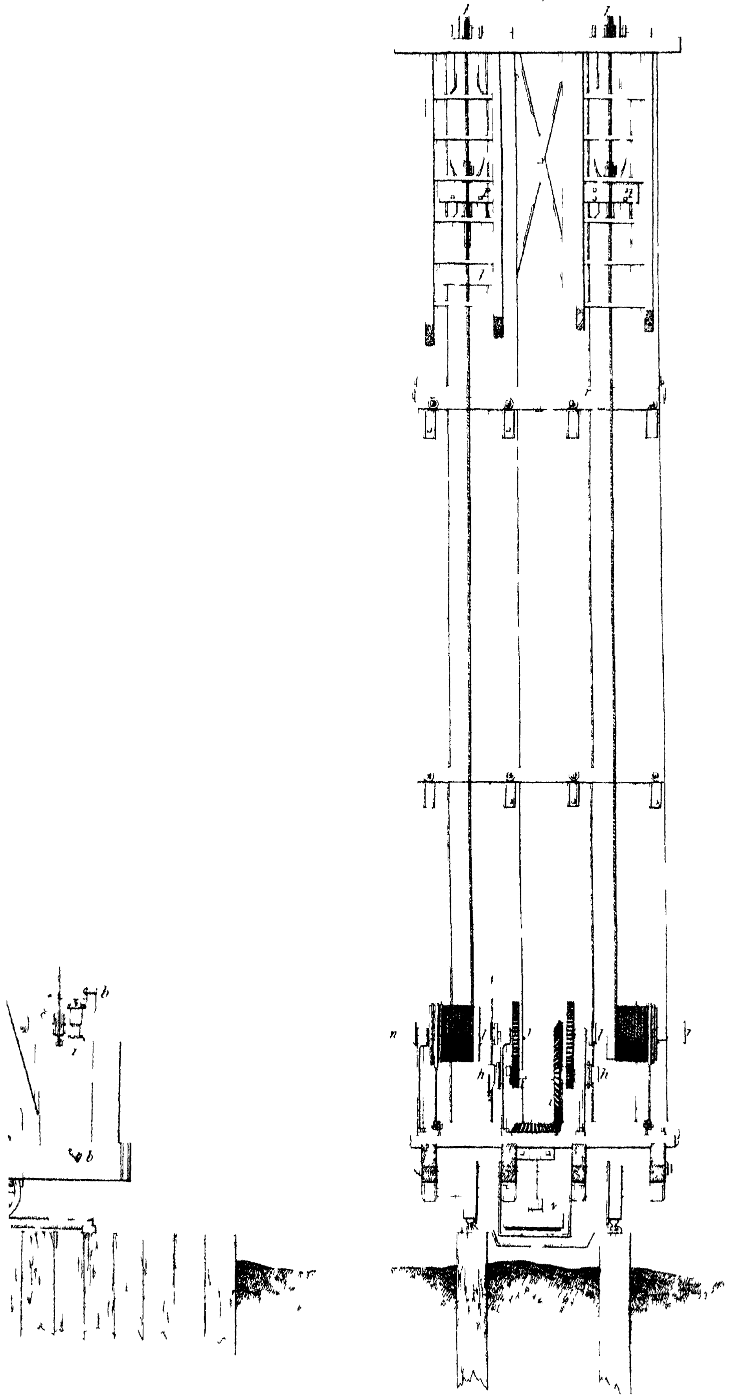
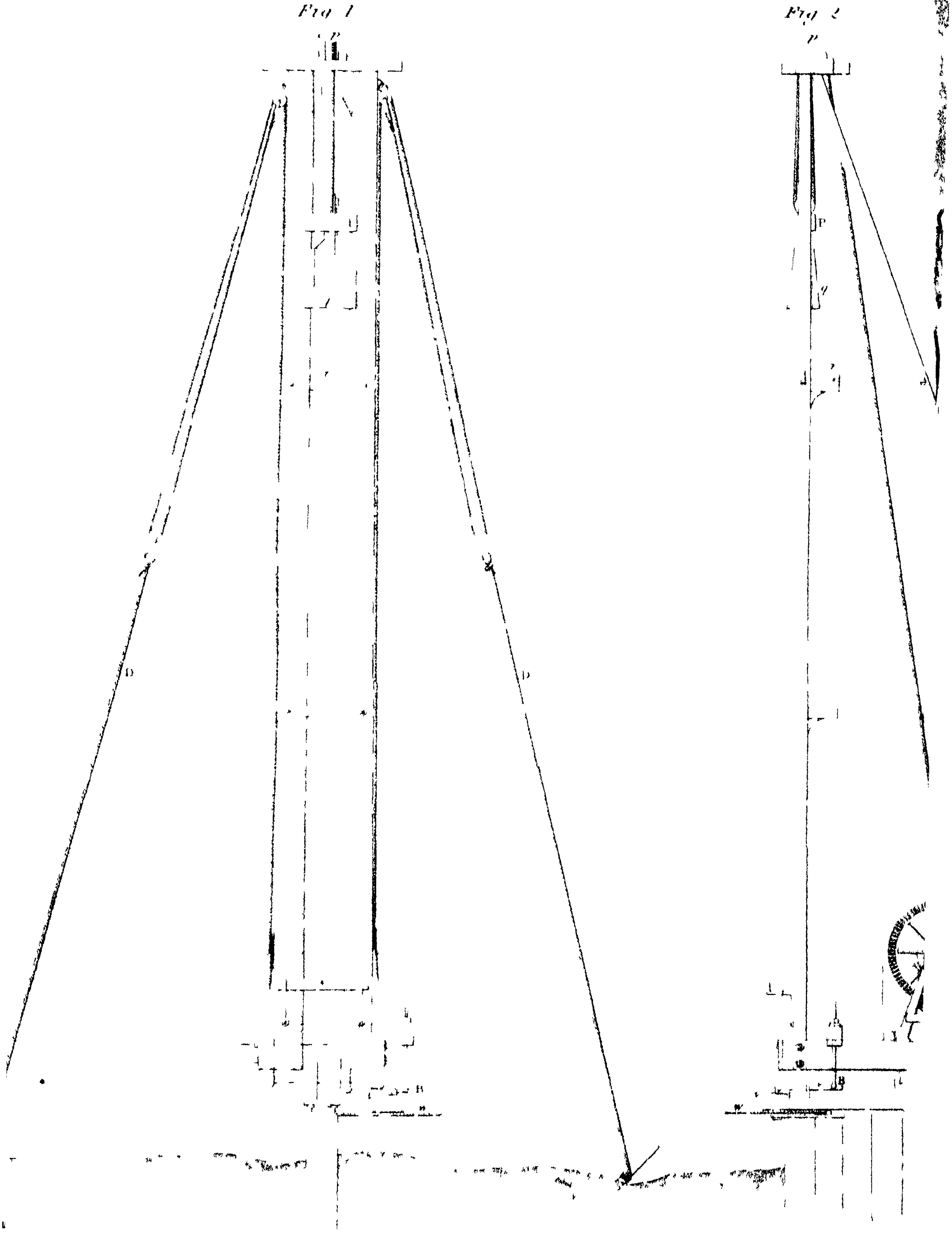


DRIVING MACHINE, No. II.

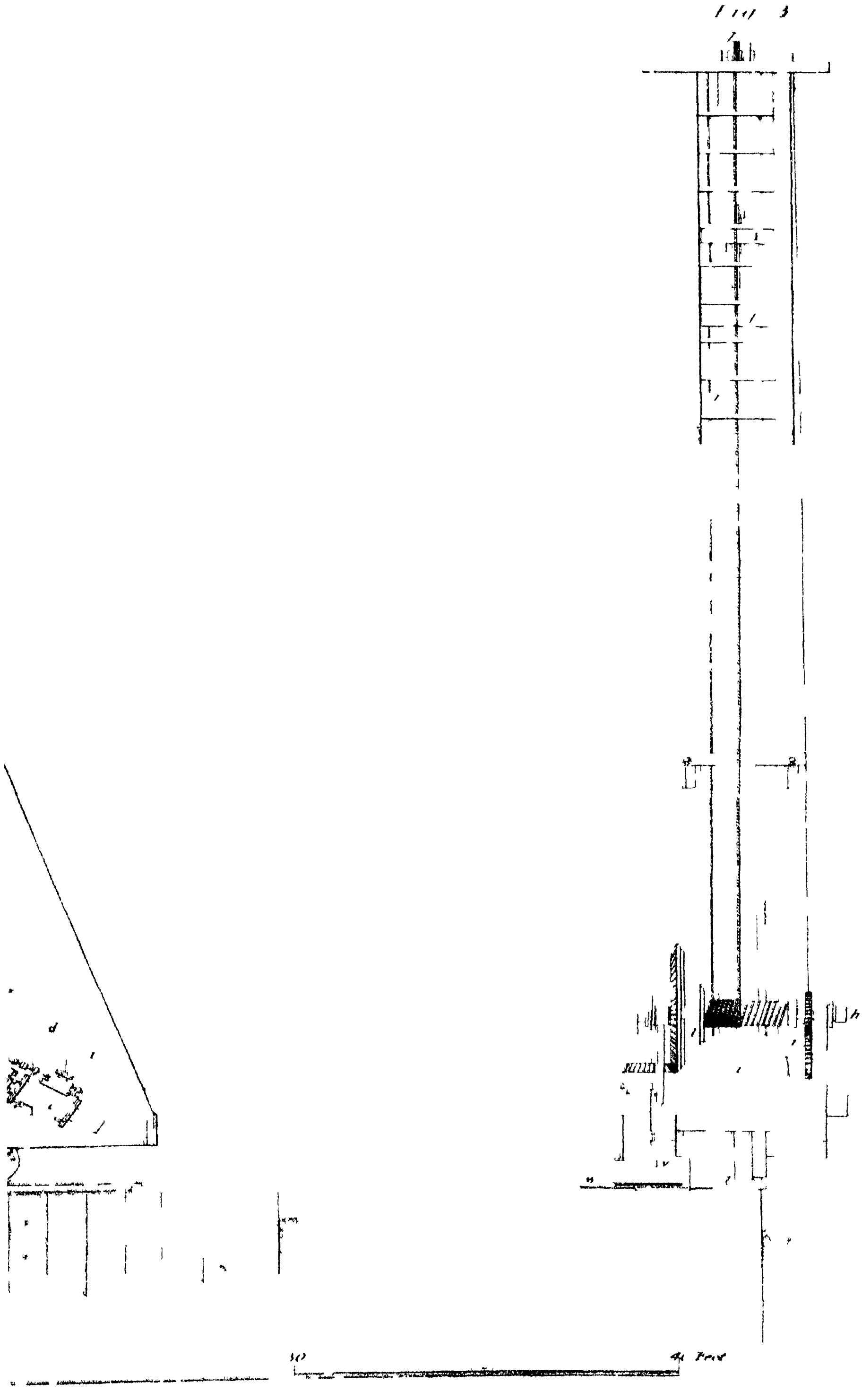
Fig. 3



PATENT AMERICAN STEAM



DRIVING MACHINE, No. III.



PATENT AMERICAN STEA

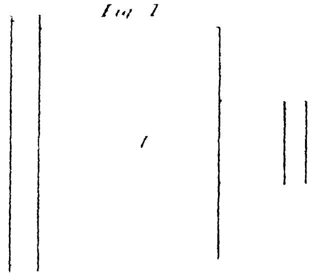


Fig 1

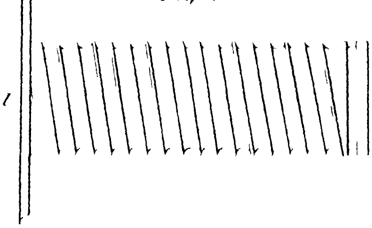


Fig 3

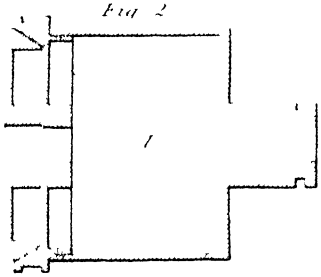


Fig 2

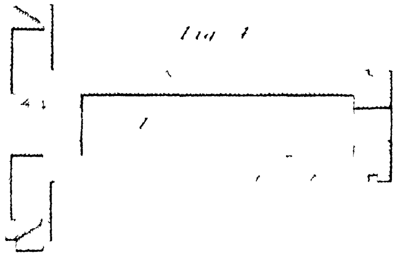
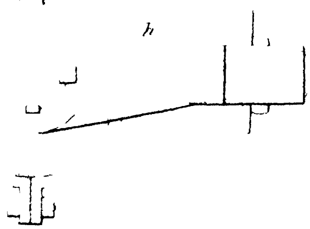


Fig 4



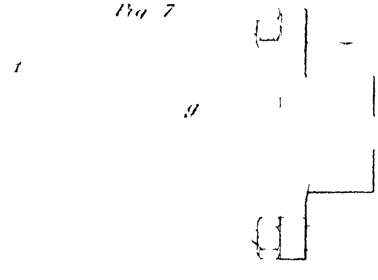
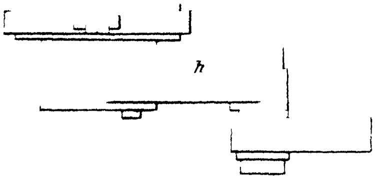


Fig 7



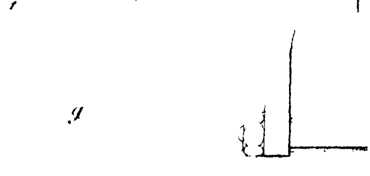


Fig 8

NEW YORK

Fig 2

Elevation

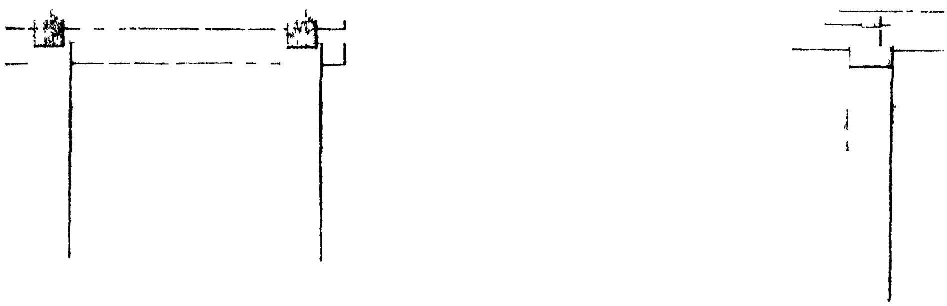
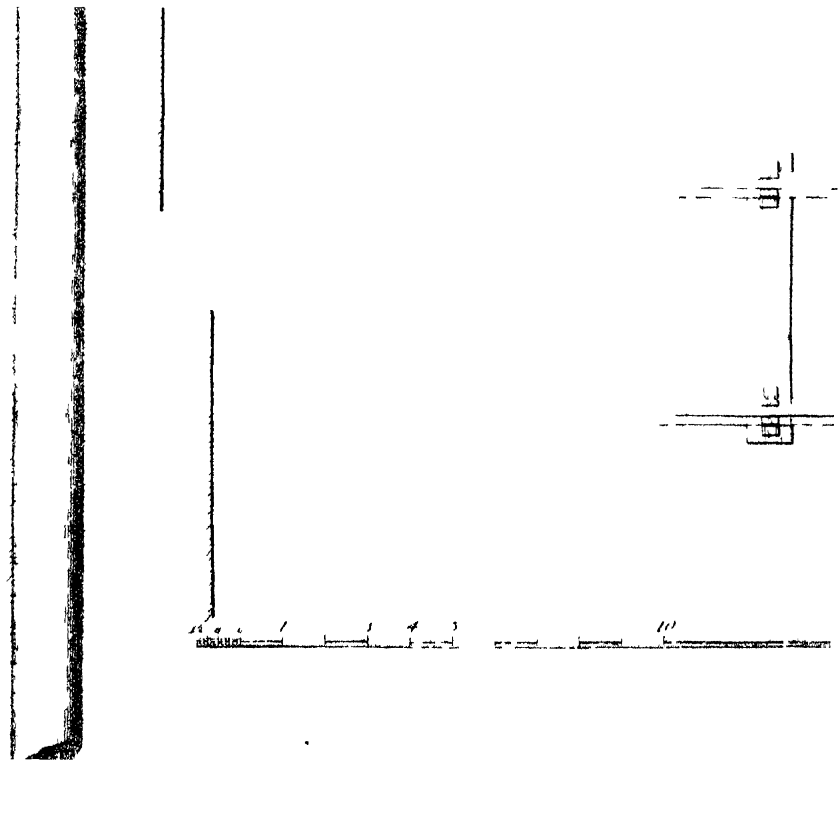
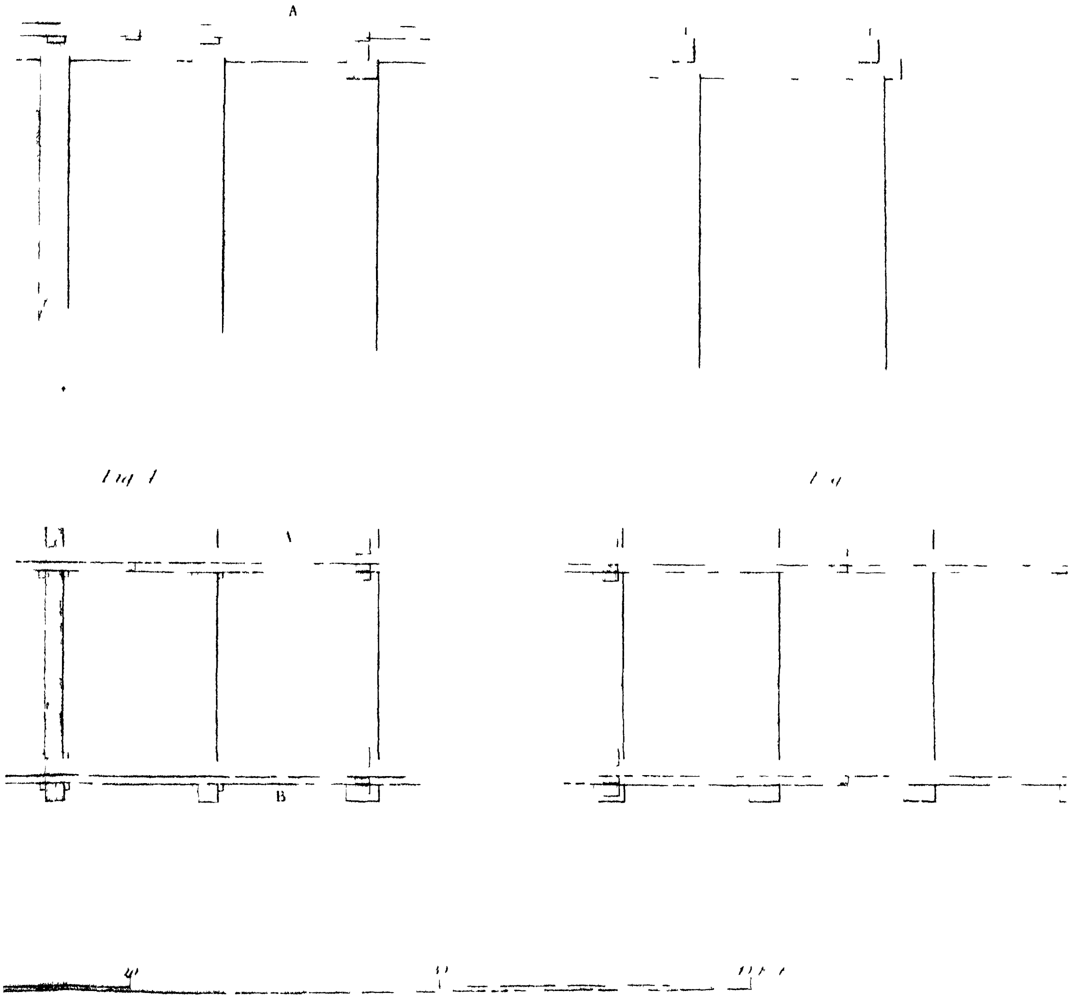


Fig 6



ND ERIE PILE RAILROAD.



The American Railroads formed on a Foundation of Piles.

Since the introduction of the locomotive pile-driving machine in the United States of America, wood piles, as a foundation for railways, have been adopted on several important lines in that country.

More than 200 miles of the New York and Erie Railroad, which connects Lake Erie with the Hudson River, at Tappan, 20 miles above New York, is formed upon this plan, and is said to answer well.

On the Utica and Syracuse Railroad, and on the New Orleans and Nashville Railroads, this plan has been found very economical, large tracts of prairie lands having to be crossed (by the road), which would be inaccessible to the ordinary modes of construction.

Plate XXXIX. represents two plans of pile road as used on the New York and Erie Road.

Fig. 1 is a longitudinal elevation of the road.

Fig. 2 is a section of the same at A B.

Fig. 3 is a section of the same at C D.

Fig. 4 is a plan of the same.

Fig. 5 is a plan of another mode, described below.

Fig. 6 is a section through the pile, cross bracing, and longitudinal bearings for the rails, connected by an oak trenail 3 feet by $2\frac{1}{2}$ inches diameter.

The piles being driven and cut off to the proper grade by the machine, the cross bracings (*a*) are grooved to admit the pile head one inch, as shown in figs. 3 and 6; the longitudinal sills are then let one inch into these cross bracings and the two intermediate pile heads, thus forming a continuous bearing for the rails.

The chairs are let into the sills, to allow the rails to bear on the sills throughout.

At the middle of the rails, which are in 15-feet lengths, are placed iron stay chairs, formed to fit into an indent cut out of the lower flanch of the rail, and being spiked to the sills, act against the longitudinal strain of the rails.

The plan shown at fig. 5, and which has the same section as fig. 3, has been thought to be an improvement; and a part of the New York and Erie

Railroad has been formed on this plan, every pair of piles being connected by cross bracings $6'' \times 12''$.

In *Excavations*, the road is formed 12 feet wide at the bottom, and the slopes 1 foot vertical to $1\frac{1}{2}$ horizontal, with a ditch 1 foot deep and 3 wide at the centre between the rails, as shown in fig. 2.

In *Embankments*, when the piles are driven, the earth is brought and filled up to within 2 or 3 feet of the pile tops, and a road formed, 10 feet wide at the top, sloping down on each side $1\frac{1}{2}$ horizontal to 1 foot vertical, as shown in section, fig. 3.

Below are given some extracts from a report made on the subject of the New York and Erie Railroad by Charles B. Stewart, Esq., division engineer of the Susquehanna.

" A road thus constructed, resting upon piles from 2 to 4 feet above the surface of the ground, combines in a great degree *cheapness* and *permanency*, the two most essential requisites in the construction of railroads; and is free from the obstructions and dangers incident to a graded road, by the accumulation of snow during the winter months, from derangements by frost, and damage by rains and floods, and from the accidents arising from cattle and other animals being found upon the track when the trains are passing at high rates of speed.

" The *permanent* and uniform foundation it affords during all seasons of the year cannot be too highly appreciated; and for roads destined to transport heavy goods, lumber, coals, iron, &c., its *decided superiority* over the usual modes of constructing railroads in this country cannot be questioned.

" Its merits have been practically tested upon the Syracuse and Utica Railroad; and from the opportunity afforded me, during the construction of that work, as well as the past experience upon this division, I have no hesitation in strongly recommending the adoption of this plan upon any road, where-ever the nature of the soil and the surface of the country render such a structure applicable.

" Of the 109 miles of piled road between Binghampton and Hornesville, $44\frac{2}{3}$ miles required to be graded by excavations and embankments, and the remaining $64\frac{1}{3}$ is less than 3 feet above the surface of the ground: the amount of embankments is increased by the necessity of keeping the grades above the river freshets upon the bottom lands, and placing the river bridges out of danger of the highest floods."

Mr. Brainard, who has been engaged to superintend the introduction of the machines in Great Britain, he having been employed in forming the above lines in America, states—

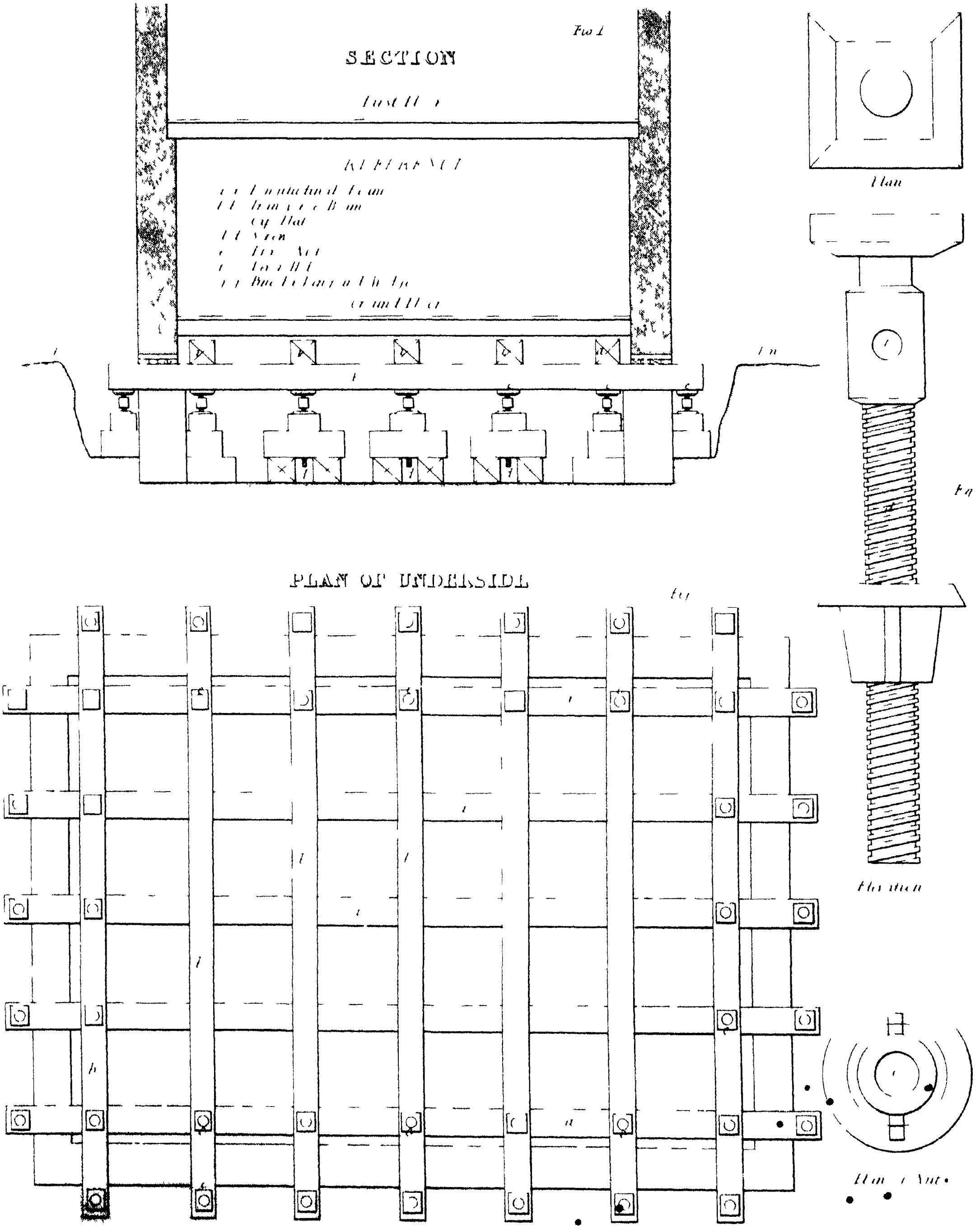
" When the grade of the road does not exceed 5 or 6 feet above the surface, and the piles not exceeding 20 or 25 feet in length, we can average 80 piles per day; but with lower grade, say 3 or 4 feet, and piles 12 or 15 feet in length, we can average 100 piles per day ; and I have on the Utica and Syracuse Railroad, New York, driven 200 piles of the last-mentioned length in one day, by the help of some extra hands.

" I have driven timber 60 or 80 feet into the ground, in marshy places, in order to get a solid foundation : this is done, if necessary, by dowelling the timber together ; and in this manner we are enabled to pass through swamps and marshy places, where we could not otherwise get a solid foundation "

XI.—*Description to accompany the Plans of the Method of Raising Buildings by Screws, in Canada and the United States.* *By* T. HOUNSLOW, F.W., R.E.D.

IN raising a stone house with cut stone front, the first part of the operation is to break holes, about 2 feet square, through the front and rear walls, from 3 to 6 feet apart (the distance being regulated by the size and consequent weight of the house), under the cut stone; and opposite each other, square logs of elm or other tough hard wood, 14 or 15 inches square, are then put through, of such lengths as to project 18 or 20 inches outside the walls. Similar holes are then made in the end walls, and logs put through in like manner, either above or below the others. In the accompanying plan, fig. 2, the longitudinal beams are shown above the others. Pieces of 3-inch pine are put in above these logs, and wedges driven between them and the logs, so that every part of the walls above may rest equally upon the beams. The supports have next to be put in for the screws, as shown in section, fig. 1. The ground these supports rest on must be very solid, and if found not sufficiently so, logs of hard wood or other materials must be employed to give a good foundation for the screws. These are then put into their places; they consist of very large and powerful screws, working in brass nuts (fig. 3), and the head, which is of steel, polished, rolling in an iron cap-plate with steel plate in the hollow shown. The nut has two projections or flanges to keep it from turning in the wooden block in which it is set to be used, and the screw is turned by three or four men with a lever 6 feet long. Fig. 2 shows the *under* side of the logs, sufficient for raising a house 40 feet by 28, two stories high, with the cap-plates for the screws. When the screws are all fixed, the operation of raising the house commences by raising the three screws at one corner of the house as tight as possible; then the pair of screws (one inside and one outside) next them,

Mode of raising Buildings
in
CANADA.



either in front or at the end, are raised as tight as they can be; then the next pair in like manner, and so on, one pair at a time, all round the building. The powerful strain produced in this manner by so many screws, is generally found sufficient to start the house from the foundation; and by following the same method round the house, never raising more than one pair of screws at a time, such a house as the one alluded to may be raised 12 inches in a day. The system of working all the screws simultaneously has been found not to answer. It shook the house and cracked the plastering, and was found not to produce so much effect in raising as by the method above described. As the house is raised and the bearing comes on the screws, care must be taken by packing and wedging from the foundation, that the building does not topple or slide, as it might do if left to the screws alone. If the screws are not long enough to raise the house as much at once as is required, the log supported by one pair of screws may be packed from below, the screws loosened, and the nuts raised higher by blocks of wood, upon the foundations of the supports: the screws are then to be replaced, the next pair raised in the same way, and by degrees all the screws round the building, taking care to move only one pair at a time, and that the log they support is relieved from them by wedging from below, before they are removed.

The expense of raising such a house as the one alluded to, 4 feet, including the timber (which is afterwards available) and the underpinning of coarse rubble masonry, is about £300.

On this method, brick houses, 50 feet by 30 feet, three stories high, have been raised 3 feet; and in some instances, resting on a platform and moving on greased ways, have been actually taken across a street, and turned round to face it by similar screws.

Two houses, one two stories, the other three stories, forming a block 80 feet front by 30 deep, with cut stone front and end, coarse rubble back and brick gable, are now in course of being raised 4 feet, in Montreal, to avoid the spring floods in the low part of the town; the expense of which will be about £400.

T. Hounslow, F.W., R.E.D.

Sept. 18, 1841.

XII.—*Account of the Demolition and Removal by Blasting of a Portion of the Round Down Cliff, near Dover, in January*, 1843. *By Lieut.* HUTCHINSON, *Royal Engineers.*

THE Round Down Cliff is situated two miles to the westward of Dover. Its summit is about 380 feet above high-water mark, and 70 feet above that of the Shakespeare Cliff, which lies three quarters of a mile nearer to the town. It is composed of a compact chalk, principally without flints, forming the lower bed of the chalk formation. The dip inclines from W. to E. about 40 feet in a mile. The base jutted out to seaward considerably beyond the general line of cliff to the westward, under and along which (from the Abbot's Cliff Tunnel towards Folkestone) a distance of two miles of the South Eastern Railway is passed on an open embankment, defended by a substantial retaining wall of concrete.

The Shakespeare Tunnel (which forms the portion of the same line nearest to Dover) has been for some time completed, and its mouth or entrance from Folkestone is about 400 feet to the eastward of the central part of the base of Round Down. This intervening point, of about 300 feet in length, was therefore to be passed either by a tunnel or an open cutting: the former had been commenced, and the preliminary drift-way formed on the upper level, when heavy slips occurring on either side, which partially extended to the cliff in question, materially shook it and impaired its stability;—the idea of tunnelling through it was therefore abandoned, and it was decided to remove this point by blasting, for the purpose of continuing the open railway and sea wall up to the mouth of the Shakespeare Tunnel.

Mr. Cubitt, the talented chief engineer of the South Eastern Railway, who had already formed a general plan of the mines, and to whom is due the primary idea of using powder to the extent which was found necessary, having applied (by authority from the Directors) to the Master-General and Board of Ordnance for my being employed on this operation, I was accordingly directed to take the principal charge of the execution in conjunction with Mr. Wright, the resident engineer. The mode that naturally presented itself for carrying this object into effect was to employ large charges, to be placed a little above the intended level of the railway, which, by blowing out the base of the cliff in their front, would cause the downfall of the superincumbent mass; and a considerable fissure which was visible, extending from an existing back slip on the top, at from 80 to 150 feet from the edge to about half-way down the cliff, led to the expectation that the fall consequent on the explosion would follow this line. The result of the operations fully proved the correctness of this idea.

The experience gained in the mining operations, which have been very numerous and extensive since the commencement of this line of railway, has led to the adoption of a charge in lbs. bearing a proportion of $\frac{1}{32}$ of the cube of the line of least resistance in feet: this corresponds with the rule laid down by Sir J. F. Burgoyne in Vol. IV. of the 'Professional Papers,' containing his Treatise on Blasting, and has been found sufficient on the railway works at Dover for blasts which have been fired from time to time in various parts of the chalk cliff, with charges varying from 500 to 1200 lbs. This calculation was therefore adopted in the present instance; and as the length of face intended to be blown down was considerable (300 feet), it was decided to use three charges,—one in the centre (at the back of the most salient part of the cliff), the other two at the distance of 70 feet on either side of it. This left a mass of about 80 feet at the ends to oppose a lateral resistance, and to throw the principal force of the explosion to the front. The position of the chambers on plan was intended to be about 5 feet in rear of the centre line of the railway, and at 3 feet above its level; but this arrangement was slightly altered in the two end chambers, by retiring the west and advancing the east, in order to make their lines of L. R. equal, which was considered desirable: this is shown on the accompanying plan of Plate XLIII
the chambers.

Accurate sections had been made of the cliff at horizontal distances of 25 feet apart, taken by dint of immense labour, benchings having to be cut round the cliff at every 30 feet in height, similar to a series of contours, for fixing the instruments and staves at each successive stage of levelling. The positions of these sections had been very accurately marked up the face of the cliff by Mr. Wright, the resident engineer, and they were afterwards filled in by Mr. Hodges, the engineer acting under him at Dover. The lines of L. R. were thus found to be as follows:

Centre, 72 feet to face of cliff.
E. and W. 56 feet to ditto.

On these data the charges in lbs. for the two end chambers were accordingly calculated at $\frac{1}{32}$ L. L. R.^{3}; but as the craters formed by the three mines would considerably overlap each other, the charge of the centre chamber was calculated with a line of L. R. 12 feet less than that drawn to the nearest surface of the cliff; it in fact became the line drawn to the nearest point of the two adjacent paraboloids of explosion, and the quantity of 6750 lbs. was therefore obtained by the same calculation, using a line of L. R. of 60 feet: this we called 7000 lbs., and 500 lbs. were afterwards added as a measure of precaution. Thus the total quantity of powder was as follows:

Centre chamber	7,500 lbs.
Two end ditto, 5500 each	11,000 ..

Total 18,500 lbs., or about 8 tons 5 cwt.

The drift-way already mentioned as being cut through the point to be removed was made use of for excavating to the chambers; it was about 4 feet wide, and 5′ 6″ high; but as it had been excavated on the upper level of the intended tunnel, it was necessary to sink shafts, 17 feet in depth, to arrive at the level of the floor of the chambers, which were to be 3 feet above that of the railway. These shafts were in the form of truncated cones, 3 feet in diameter at top, and 5 feet at bottom: this dovetailed form offered a more perfect resistance against the tamping being blown out. On arriving at the required depth of 17 feet, branches 5′ 6″ high were struck out at right angles to the drift-way, and carried to the points determined as the position of the chambers. These branches were also made of a dovetailed form, for the same object as in the shafts, or 2 feet wide at the shaft, and 4′ 6″ at the chamber. The chambers were then excavated at right angles to the branches or parallel to the drift: in forming them an oblong figure was preferred to the cube, and they were excavated of the following dimensions, viz.:

	high.
Centre	13′ 0″ × 5′ 6″ × 4′ 6″
Two ends	10′ 0″ × 5′ 6″ × 4′ 0″.

These preliminary arrangements having been decided, the important point of firing the mines simultaneously, upon which the whole success of the operation depended, was next to be considered; and this could only be done by means of voltaic electricity. My previous employment under Major-General Pasley at Spithead had given me experience on this most interesting subject; but as the present operation would be on a much more extensive scale than any to which I had hitherto been accustomed, and as the locality, height of cliff, inclement season, &c., together with the total want of apparatus, and my being at the same time employed on the varied duties of the Royal Engineer Department at Dover, all added to the difficulty and labour of the undertaking, the task was by no means an easy one.

Four men were immediately sent for: lance-corporal Rae and private Thomas Smith, Royal Sappers and Miners; pensioners, J. Leary and W. Gordon, late of R. N. They had been previously employed under me at Spithead, on the construction and management of voltaic batteries and the preparation of voltaic wires, which duties were assigned to them on the present occasion; Leary, a very intelligent smith, having the construction of the batteries, and Gordon that of the wires, assisted by railway labourers.

The work then proceeded with great activity. The voltaic batteries were commenced, for which fifty of Daniell's cylinders were ordered to be constructed; this number was afterwards increased to fifty-four, so as to give eighteen for each mine: these cylinders were of sheet copper, 32 oz. to the foot superficial, 1 ft. 10 in. long, and $3\frac{1}{2}$ inches in diameter. They were in sets of six, each set being in a deal box $1' 4'' \times 1' 0'' \times 1' 9''$ high, with a lid 4 inches deep. The zinc rods were supplied from London, and the greater part of the brass milled heads and screws. The rods were $1'$ $8''$ long, and $\frac{3}{4}$ inch in diameter.

Daniell's, also called the constant battery, differs from the common plate battery, which is too well known to require description, by copper cylinders and zinc rods being used in lieu of plates of copper and zinc, also by two liquids being employed, separated by a porous partition, usually of animal membrane (the gullet of the ox), and sometimes formed of plaster of Paris. The liquid into which the zinc rod is plunged is (as in the plate battery) diluted sulphuric acid, in the proportion of 1 of acid to 8 of water. That on the outside of the membrane next the copper cylinder is a saturated solution of sulphate of copper. By this arrangement *copper* will be released from its sulphate and deposited on the copper cylinder, the negative metal.

The deposition of copper on the negative metal prevents the deposition of zinc. The continuous action of the battery is preserved by amalgamating the zinc with mercury and supplying the solution with crystals of sulphate of copper. The former prevents the acid from acting chemically on the zinc and destroying it uselessly; the latter keeps up the strength of the solution, which is being constantly exhausted by the reduction of the copper.

The connexions of Daniell's battery are formed by short pieces of copper wire, $\frac{1}{5}$th of an inch diameter, and from 4″ to 6″ long, which are passed through the copper branch attached to one cylinder to the head of the zinc rod in the next cylinder; they are then firmly fixed and secured by means of binding screws with milled heads. The connexion between each metal is thus made throughout the series of any number of cylinders and rods that may be required, and it will be found that the head of the first zinc rod and the branch of the last copper cylinder will be disconnected or unattached from any other, and copper wires passed through these will form the poles of the battery;—the zinc pole negative, the copper positive.

These are the main features of Daniell's battery; and its improvement on the common plate battery (which consists of a series of zinc and copper plates connected by copper wires immersed together into cells of diluted acid) is, first, that the deposition of zinc on the copper is prevented, which, in the plate battery, causes counter-currents which weaken the force; second, that in the plate battery the acid very speedily becomes saturated with oxide of zinc, and all action ceases, which is prevented in Daniell's by the amalgamation of the zinc rods. Hence Daniell's battery is preferable for all purposes where much constant action is required; but as this is not the case in mining or blasting, where a momentary action only is wanted, and that of a very powerful nature, which it was supposed would be offered by the greater surface of zinc in the plate battery, it became a question in our operations,—especially as the power of Daniell's appeared to be much weakened by the low temperature of the season,—which of the two kinds would answer the best. A battery of twenty plates was therefore constructed under Mr. Wright's superintendence, a drawing of which is annexed, the plates being 10 inches by 7 inches.

The solution was not quite so strong as in Daniell's, being about 1 to 12. The power of this battery was very great, being equivalent to twenty-four of Daniell's cylinders, which we tested by trying the length of platinum wire that would be ignited by each to a heat sufficient for firing gunpowder: this length was found to be 7 inches.

The plate batteries appearing to answer so well, directions were given to construct six. The dimensions of the boxes containing them were 3′ 2″ × 12″ × 8″ deep; they were of 1-inch deal, grooved and tongued, and divided into twenty cells, $1\frac{1}{2}$ inches wide, by partitions of $\frac{3}{8}$-inch deal; the cells were payed over with a water-proof composition of spirits of wine and sealing-wax.

The twenty pairs of plates forming the series, each composed of a zinc plate $\frac{3}{8}''$ thick, in the centre of a rectangular case of copper 10″ long, $1\frac{1}{8}''$ wide, and 8″ deep without top or bottom, were united in sequence by stout copper wire attached to the zinc plate of one pair and the copper plate of the adjoining pair. The wire was let through the zinc plate, and riveted and soldered to the copper, and the connexions of zinc and copper were finally formed by twisting the two wires from each metal firmly together, which thus projected 4″ above the top of the plate. Lastly, the whole were let into a stout wooden frame with ends or handles projecting 6″, for the purpose of lifting and immersing the plates into the trough simultaneously. The wires from the zinc plate of the first pair, and from the copper plate of the last pair, form the poles of the battery, which may be connected with another series, if more power is required than would be given by one.

During the construction of the batteries, that of the voltaic wires had been rapidly proceeding. It had been at first intended to have used only one set of wires to pass through each chamber in succession, and to fire the whole by one powerful battery. The result of the experiments detailed below showed that this mode would be uncertain, except for a short length of wire, and it was finally determined to use three sets of wires and three separate batteries. The total length of single wire thus required was 6000 feet, being 2000 feet for each mine, and it was ordered $\frac{1}{8}$th of an inch in diameter. The method of preparing the conducting wires was on the same principle as that adopted for the works at Spithead, but the precautions which in a submarine operation would have been necessary to defend the wires from contact with water,[1] were not here required. We had principally to guard against the destruction to the covering by friction against the cliff, and the chance of their lying in snow, in case of a fall previous to the explosion.

[1] Water being a conductor, much of the electric fluid would be carried off by it, if the wires were bare in any part under water.

The wires, after having been payed over with a water-proof composition of eight parts of pitch to one of bees'-wax and one of tallow, were covered with a coarse cotton tape, bound round the wire while the composition was hot.

The two wires, thus prepared, were laid on each side of a 1½-inch rope, by

which they were insulated; and to prevent their shifting or coming in contact, they were racked and bound in their relative positions by stout packthread, a turn being taken round each wire at every racking. The whole was then served with 2-yarn spun yarn, and again payed over with the water-proof composition. Gordon, with a labourer, working extra hours each day, finished 90 feet running of conducting wire thus prepared in fifteen hours, or 6 feet lineal per hour. The wires were sent from Birmingham in 30 to 50-feet lengths; these were connected by twisting 6 inches in length of the ends firmly together, which were afterwards brazed. Each set of wires, when completed, was coiled on a drum and mounted on a carriage with iron trucks; the diameter of the drum was about 3 feet, and its breadth the same, which allowed twenty-six single coils of the wire to be made upon it.

Our apparatus being prepared, it became necessary to make a few experiments previously to firing the mines. These were carried on in the Shakespeare Tunnel, about three-quarters of a mile from Dover, which was convenient from its length, and from the facility with which the light could be obscured.

For these experiments a number of cartridges or bursting charges were necessary, some of which were made of tin and some of paper; they were cylinders 4 inches long and 1 inch in diameter, holding about 1 ounce of powder. The priming wires of the cartridges, so called to distinguish them from the main or conducting wires, were 1 foot long, projecting 9 inches from the end of the cartridge; they were passed through grooves cut into the sides of a cork about 1½ inches long, which formed the top of the cartridge; their ends were clenched against a thin piece of wood near the bottom of the cartridge, but which did not occupy the whole of the interior space. The platinum wire to be ignited by the current of electricity, was fixed across the copper wires about the centre of the cartridge, which was then filled from the bottom with the finest sporting powder, thoroughly dried and heated, and closed by a bung of cork. The top and bottom of the cartridge were then payed over with a water-proof composition.

In carrying on experiments for blasting operations, the above precautions in preparing cartridges are absolutely requisite. It might at first sight appear unnecessary, for *experiments only*, to do more than fix a piece of platinum across the conducting or priming wires, and cover them with a small quantity of loose powder; but in this way failures would certainly ensue, for the powder, if not thoroughly dry, would not be ignited by the fusion of the wire; in fact, a great cooling effect is produced on platinum wire by contact with powder in the least degree damp: hence the greatest care in thoroughly drying the powder is necessary, and for afterwards keeping it so, by enclosing it in an air-tight case. Platinum wire to be used in cartridges, or any other description of bursting charges, should be from 1 inch to 1½ inches long.

Cartridges, previously to their being used, should be proved either by the "galvanometer" or by the water-test, to ascertain that the platinum wire is perfect, and the circuit unbroken. The principle of the galvanometer is founded on the discovery made in 1820 by Oersted, the Professor of Chemistry at Copenhagen, of the influence of galvanic electricity on the magnetic needle. If an electric circuit be formed by means of a pair of voltaic plates of zinc and copper, with a conducting wire led from one to the other in a rectangular course, and a magnetic needle be suspended within the rectangle, should the rectangle point north and south, the needle, on the circuit being completed, will be instantly deflected, and place itself at right angles to the coil, and point east and west. Should the coil of wire surround the needle in the same horizontal plane, the needle will move vertically, and its northern end will be elevated or depressed according to the order in which the ends of the rectangle are attached to the voltaic plates. The deflecting power of the conducting wire is greatly increased by insulating it with silk or thread, and coiling it several times round the needle.

On this principle the galvanometer used for our operations was constructed. As it was required to be portable for the purpose of testing the wires and charges in their different situations, the needle and voltaic pair were enclosed in a small box about 4 inches long, 2 inches broad, and 1½ inches deep, the needle being in one compartment of the box and the battery in the other; the coil round the needle was 1½ inches in diameter, formed of fine bell wire, about 6 feet in length, insulated with thread; the voltaic pair consisted of a copper trough $1\frac{3}{4}$ inches long, $\frac{3}{4}$ inch wide, and $1\frac{1}{4}$ inches deep, in which was inserted a zinc plate about $\frac{1}{4}$ inch thick, with a small space all round between it and the copper: the inner end or commencement of the coil of wire was attached to the copper trough, the other end was led outside the box; this formed the copper pole, and another wire soldered to the zinc plate formed the zinc pole. A small quantity of diluted acid, carried in a phial in the pocket, was sufficient to excite electrical action in the plates; and, after watching the needle and seeing that it was quite steady, on the circuit being completed by connecting the ends of the priming wires of the bursting charge with the poles of the galvanometer, if the charge was perfect, the voltaic influence was very apparent, the needle being sensibly affected,—dipping and deflecting considerably. This test of the goodness of cartridges, or of the platinum wire across the centre of the priming wires being unbroken, is a very excellent one, and I consider it superior to the water-test used at Chatham (which is on the principle of water being decomposed by the electric action), as being more quickly performed, and requiring a less powerful apparatus.

It may be needless to state, that in using the galvanometer a feeble current of electricity passes entirely through the circuit of wire and the bursting charge, but not sufficient to ignite the platinum wire contained within it. A portable one of the kind described above, and of which a drawing is annexed, was found powerful enough to test a bursting charge at the end of a conducting wire 200 feet long, but it was too weak to form a satisfactory test at much beyond that length; and for our total length of wire with which the mines were fired, of 1000 feet, it was found necessary to unite to the small battery within the box one cell of Daniell's battery, which then made the action very apparent.

The experiments alluded to above, preliminary to the firing of the mines, were carried on in the Shakespeare Tunnel on the 13th and 17th of January, and results were obtained as shown in the record annexed.

As the temperature of the season during which these experiments were carried on was very low, about 40° of Fahrenheit, it was found necessary (on account of some failures which could only be attributed to this cause) to raise it considerably near the batteries, by means of fires of coke in portable braziers. We thus obtained a temperature of from 70° to 80°, which sensibly increased the power of the batteries, and any diminution in this temperature was immediately felt by a corresponding loss. The experiments having been concluded, it was decided to fire the mines by three separate wires with two bursting charges to the end of each, and to employ our whole force of batteries against them. The idea of having two bursting charges originated in the necessity of communicating ignition to such large masses of powder, in two separate places; and it was also a measure of precaution in the event of one failing. We had now fifty-four cells of Daniell's and six plate batteries; and the combination of three sets of Daniell's containing eighteen cells, with two of the plate batteries, was adopted for each mine. This arrangement is shown in the annexed drawing, where the two plate batteries are in rear, next to them Plate XLIV two six-cell batteries (Daniell's), and in front, completing the series, one six-cell Daniell's battery; the poles of the combined battery being led from the two end cells. The direction of the arrows shows the course of the electric current entering at the negative pole (zinc), passing through the nine cells of Daniell's on the left, through the two plate batteries, then through the nine cells of Daniell's on the right, and leaving at the positive pole (copper). The wire connecting the plate batteries with each other, and with Daniell's, was about $\frac{1}{12}$th of an inch in diameter, and should be insulated by being covered with thread. The power of a battery thus arranged is very great. On connecting the poles, a brilliant flame is emitted, and steel wire quickly fused. There is no doubt that a weaker battery would have answered our object, but having the means, I was anxious to employ all the power possible.

Directions were now given for the construction of a wooden building on the slope leading from the top of Round Down Cliff, to contain the batteries. This was made 20×15 feet, and placed nearly in a line with the centre section, about 200 feet from the edge of the cliff. Several charges were fired from this spot on the three separate wires, by the three batteries arranged as above; this was done principally to practise simultaneous firing. The wires were led down the cliff and into the chambers, and two bursting charges were attached to each; every thing, in fact, being the same as if for firing the mines.

Mr. Wright took the east wire, Mr. Hodges the west, and I took the centre, and gave the words of command, which were arranged to be as follows:

1st. Ready,—each person firing took one side of the conducting wire in his left hand, and attached it to the left-hand pole of the battery.

2nd. One—Two—Three—Fire! A distinct pause being made between the words, similar to time or cadence in music, so that when the last word "Fire" was given, each person, having kept the time, was able to place the right side of the conducting wire on the right-hand pole of the battery, and thus complete the circuit at the same instant. In this way we arrived at so much perfection in simultaneous firing, that, seven times out of eight, the assistants below, who were watching the explosions and attaching fresh bursting charges, passed the word up the cliff, that the *six charges* had gone off as *one shot!*

Every thing being thus perfect and complete, a Report was made to the Directors, and Thursday, the 26th of January, was fixed on as the day for the explosion, at 2 P. M.

The powder, in one hundred and eighty barrels, had arrived some days before. It was procured from the Battle Mills in Sussex, and was deposited at the west end of the Shakespeare Tunnel, a space having been partitioned off for its reception. Deal cases had been constructed within the chambers, for containing the powder, of the following dimensions:

Boxes. Centre 11′ × 4′ 3″ × 3′ 6″
Ends 10′ × 2′ 8″ × 3′ 3″

These boxes were of $1\frac{1}{4}$-deal, rough dovetailed, and pinned with wood pins. The vacant spaces thus left between the box and chamber, of about 6 inches at the sides and 1 foot at the ends, and 2 feet between the top and crown of the arch, allowed for expansion of the gas which would be formed by the ignition of the powder,—increasing the bursting effect and diminishing the chance of the tamping being blown out.

The chambers were charged on Tuesday, the 24th; the powder was deposited in the boxes, in bags holding 50 lbs. each; the tiers above the centre were placed with their mouths downwards, those below it with the mouths upwards. In loading, fifty-four men were employed, who, after filling the bags from the barrels in the Shakespeare Tunnel, passed them from hand to hand into the drift-way, and thence into the chambers, which were thus charged in three hours, at one hour for each. Light was thrown into the chambers during this operation by oil lamps with reflectors, measuring 1 foot 6 inches by 9″ × 6″, with stout plate glass in front, and two thicknesses of gauze wire above and below the flame. Their safety had been tested previously, by throwing powder over them while burning. The lamps were fixed at the ends of the branch, opposite to, and on a level with, the chambers.

The bursting charges for the chambers had been prepared the day before;

they were on the same principle as the cartridges already described, but were larger, being 9 inches long and 2 inches in diameter; the top and bottom were secured by cork bungs. The priming wires, $\frac{1}{12}$th of an inch in diameter, projected 1 foot 6 inches beyond the top. They were passed through a slip of wood $1\frac{3}{4}$ of an inch square and $\frac{1}{2}$ an inch thick, inserted at about the centre of the tube, and their ends were clenched on a circular piece $1\frac{3}{4}$ of an inch diameter, lying over the lower cork bung. The platinum wire was fixed halfway between the two. The powder (finest sporting) was poured in from the top. The upper bung being in halves, one-half was removed for this purpose, and refixed when the tube was filled; the top and bottom were then payed over with a water-proof composition.

Two of these bursting charges, after having been tested by the galvanometer, were attached to the end of each of the conducting wires, which were stripped for the purpose to about 2 feet from their ends, and brightened with sand paper. One bursting charge was connected with the end of the wire by twisting 6 inches of the priming wire several times round, and afterwards securely frapping with bell wire. The other was fixed in the same manner about a foot above it; the wires were then perfectly insulated and covered with spun yarn. The bursting charges were extended to about 3 feet apart, and were buried in the centre tier of loose powder in the box. The conducting wires were then carried from the chambers along grooves cut in the sides of the branches, shafts, and drift-way, and covered with wooden troughs. Two of the wires from the east and centre chambers were led out of the east end; the third, from the west chamber to the west end of the drift-way. They had been previously cut to these lengths from the main wires, and were thus left until the following morning.

The tamping of the mines was commenced immediately after. A dry wall was built in chalk across the end of each chamber, and the branches and shafts were afterwards filled in with the same material, which was extended in the drift-way to 10 feet on each side of the top of the shafts. The tamping occupied about twenty hours, with four men to each mine.

On Thursday, at 10 A. M., the three lengths of wire in the drift-way having been most satisfactorily tested by the galvanometer, the main wires, which had been let down the cliff the previous evening, were connected with them in the usual way, by twisting the ends together, frapping with bell wire, and afterwards covering and insulating them with yarn; and the total lengths of conducting wire were then tested from the top. The galvanometer, as above stated, was not powerful enough for this purpose, and one cell of Daniell's had to be added to it.

The ends of the wires were then led into the battery-house, and the three sets of batteries arranged as above described. Some little delay occurred in arranging the eastern battery, caused by a defect in one of the milled heads of a set of Daniell's cylinders; this was soon discovered and rectified.

The signals for firing had been determined as follows, copies of which were printed and circulated. First signal, fifteen minutes before firing, all the signal flags will be hoisted. Second signal, five minutes before firing, one gun will be fired, and all the flags will be hauled down. Third signal, one minute before firing, two guns will be fired, and all the flags (except that on the point to be blasted) will be hoisted again. The signals were accordingly made by maroons, each consisting of 1 lb. of powder, (excepting that first fired, which contained 45 lbs.) in coarse brown paper, closely bound and compressed by spun yarn, lighted by a short length of Bickford's fuze, which gave a sufficiently loud report to be heard distinctly at the distance of a mile.

At twenty minutes past two the circuit was completed at each battery by the words of command detailed above, and the mines were fired simultaneously. The ignition was not followed by a loud report,[2] but a deep hollow sound indicated that the explosion had taken place.

As I was in the battery-house in charge of the ignition, I could not witness the effect of the explosion; but Captain Denison, of the Royal Engineers, who was present, and saw it from below, states his impression of the effect to have been, "That the bottom of the cliff yielded very gently to the force of the

[2] Sir John Herschel, in a Paper containing an account of the explosion, makes the following remark on the slight sound perceptible. "The remarkable absence of noise and tremor which characterized this operation is explained by the structure of chalk as a material, and by the rifty state of the cliff as a body. Of all substances, perhaps, chalk is the worst adapted for conveying sound, and the best for deadening the vibration propagated through it by a heavy blow. The initial hammer-like impulse of the newly created gas on the walls of the chambers of the mines (of which there were *three* simultaneously exploded) was doubtless thus deadened by traversing at least 70 feet of chalk, even in the shortest direction or line of least resistance; and this must have taken place before the mass could have been sensibly moved from its seat by the expansive force generated, which, however vast, proved incapable (as it was expressly provided it should be) to communicate to its enormous load any greater velocity than barely sufficient to lift and bulge it outwards, leaving gravity to do the rest."

powder, assuming a curved form beyond the general face; then the upper part began to give way, and finally the whole slid out into the sea, carrying every thing before it in the most magnificent manner."

Those who witnessed it from above compared the appearance of the fall to that of lava flowing from the side of a mountain, assuming a gently undulating wave-like motion, as the mass slid along the bottom and into the sea. So gradual was the descent, that the flag-staff on the top was not disturbed, but retained its position till it reached the bottom. The fall of the mass was made exactly on the line which had been hoped for, extending from the back slip, and fissure on the surface, to the line joining the vertex of the three craters, all the intervening portions of which were swept away in nearly a straight line.

Below, the appearance of the fall was most imposing. The surface covered was ascertained from after measurement to be 15½ acres, varying from 15 to 25 feet in depth, about 400,000[3] cubic yards having been removed. Immense masses of chalk were scattered over it, some of which could not have weighed less than from 20 to 30 tons. One large block fell just within the entrance of the Shakespeare Tunnel, without injuring any of the brick-work, though the distance from this point to the eastern mine was only 330 feet.

A great portion of the wires was saved after the explosion. The western wire, which was probably not so securely picketed on the top as the east and centre, was carried entirely down the cliff, and found afterwards among the debris below. The two others, though much injured by the falling chalk, were held by being firmly lashed to pickets above, and the greater part of them secured.

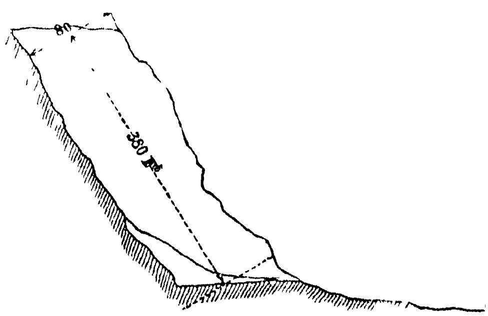
Not the slightest accident had occurred since the commencement of the work.

Thus terminated this important mining operation, which was calculated to

[3] Section of cliff removed. Calculated as a rectangle, mean area $380 \times 80 = 30,400$ and $30,400 \times$ length of face $360 =$

$$= 10,944,000 \text{ cub. ft. } \frac{10,944,000}{27} =$$

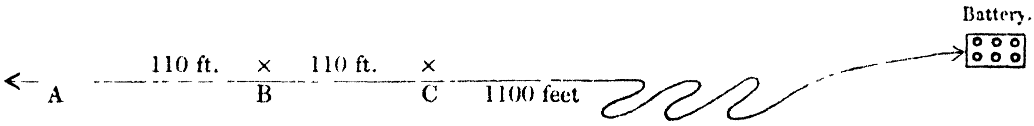
$= 405,350$ cubic yards nearly.



have saved the South Eastern Railway Company £7000, compared with what it would have cost to have removed the mass by hand labour,—the most extensive in the means employed, and successful in results, of any ever undertaken or recorded in the annals of history.

Record of Experiments with the Voltaic Battery, carried on in the Shakespeare Tunnel, Dover, 13th and 17th January, 1843.

In the first series of the following experiments, one of the main conducting wires, 1100 feet long, (afterwards used in the blast at Round Down,) was opened at three points at the same distance as the lengths between the chambers, and cartridges or bursting charges attached at those points, thus,



Main conducting wire 1100 feet long.

These experiments were tried to prove the rather disputed question of the power of a single battery to fire several charges simultaneously on the same wire.

In the second series, three sets of batteries and three separate wires were used,—the system which was afterwards adopted in firing the charges themselves.

Section of the Face of the ROUND DOWN CLIFF through the Chambers of the Mines

100 — 500

Scale of Feet

Reference

AAA [illegible]

CC [illegible]

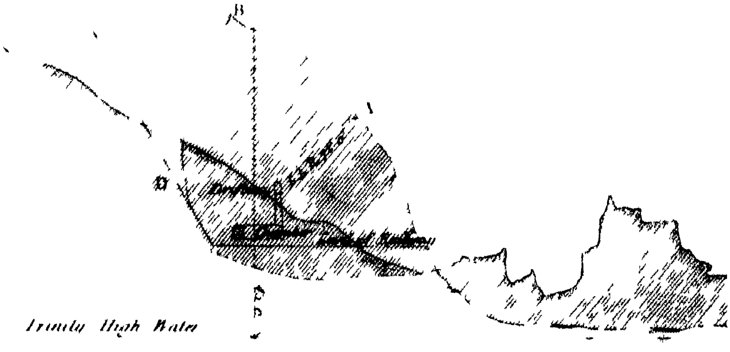
DDD [illegible]

EEE [illegible]

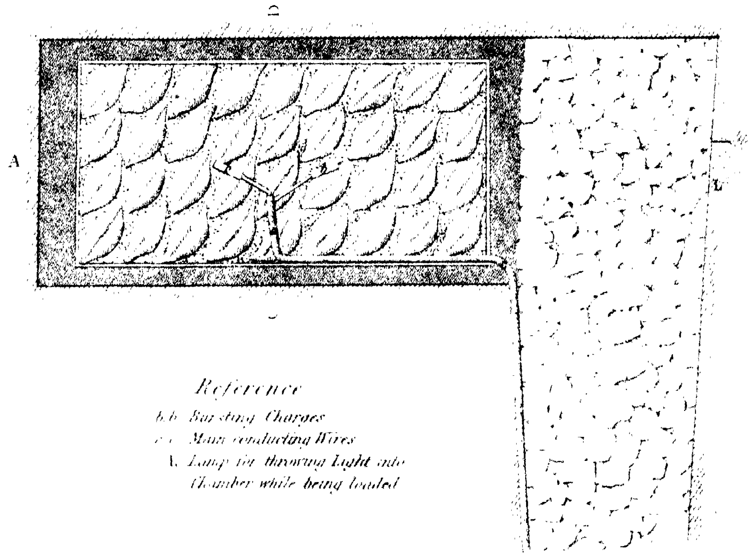
BBB [illegible]

C

Section through Centre Chamber



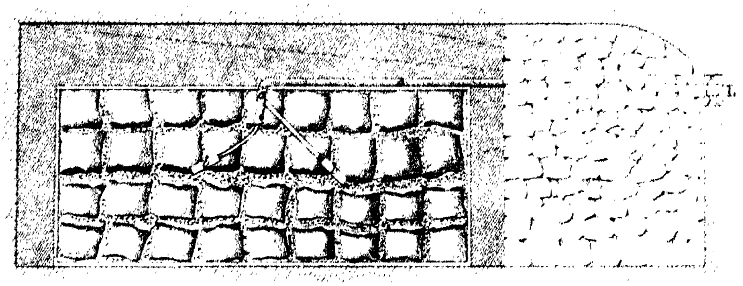
Plan of the Centre Chamber
shewing the Box, Powder Bags, Conducting Wires and Bursting Charges, with the Tamping in Part of the Breach.



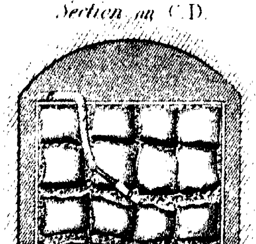
Reference

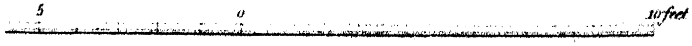
b. b. Bursting Charges
c. c. Main conducting Wires
L. Lamp for throwing Light into Chamber while being loaded

Section on A B



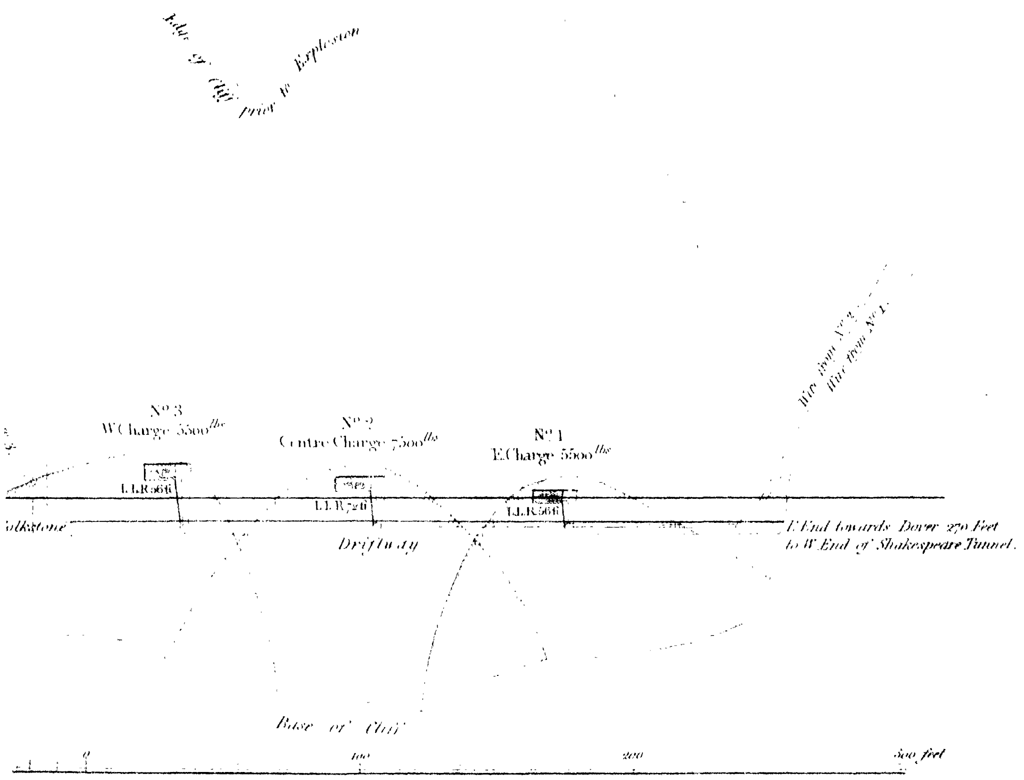
Section on C D.



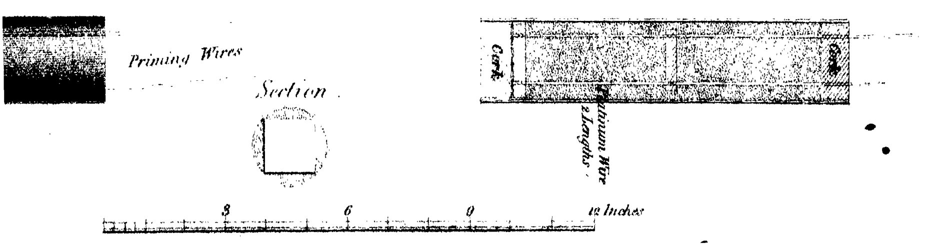


ROUND-DOWN CLIFF.

probable Horizontal effect of each of the Mines employed in the demolition.



Bursting Charge
inserted in Chambers.

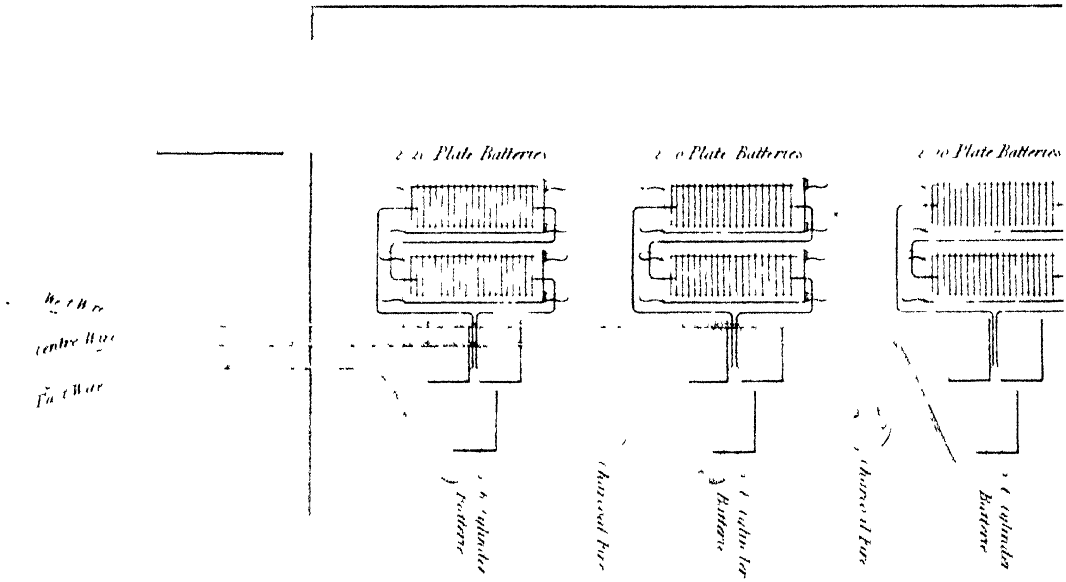


ROUNE

Details of Ba

Battery House

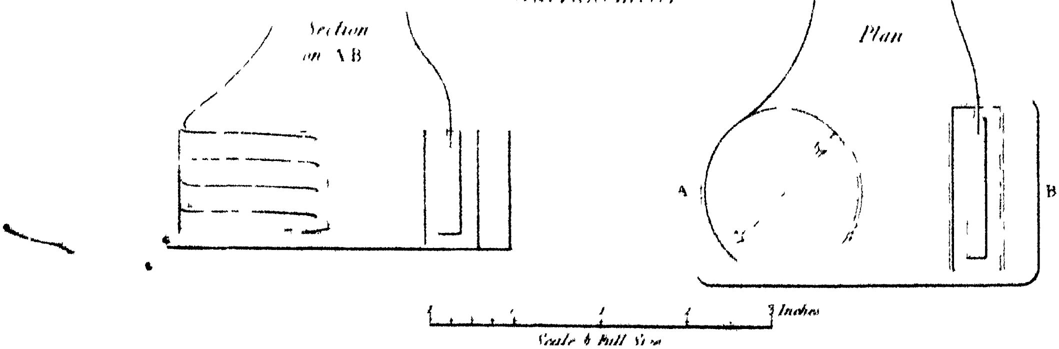
Shewing the general arrangement of Batteries



N B The wires were led through an opening in the Roof left for Ventilati

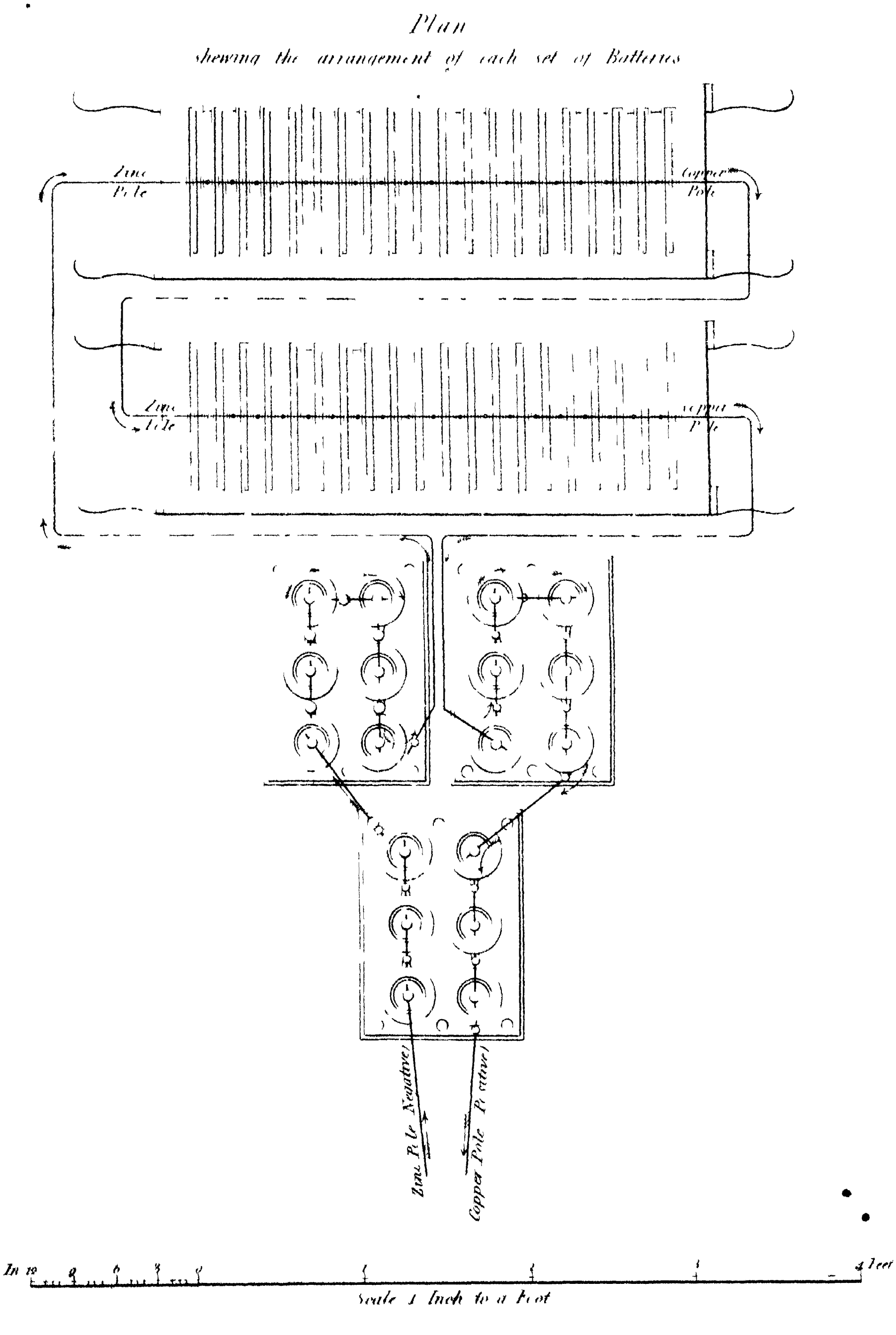
Scale of Feet

Galvanometer



CLIFF.

the Demolition



ROUND

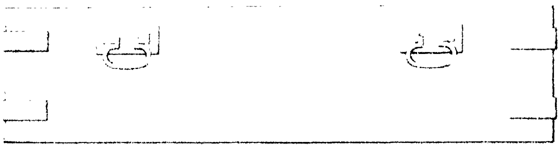
Details of Ba

Reference.

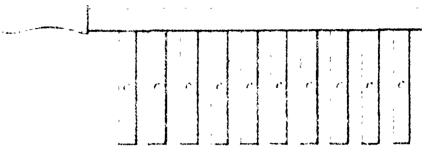
c c c Copper Trough.
z z z Zinc Plate
w w w Wedges for Insulating the Zinc Plate.

Details of a 20 Plate Battery

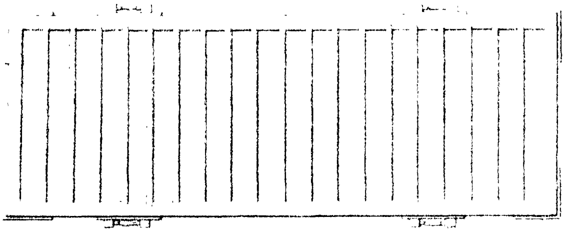
Elevation of Trough



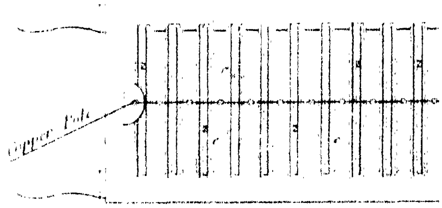
Elevation of Frame

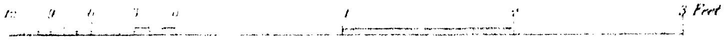


Plan of Trough

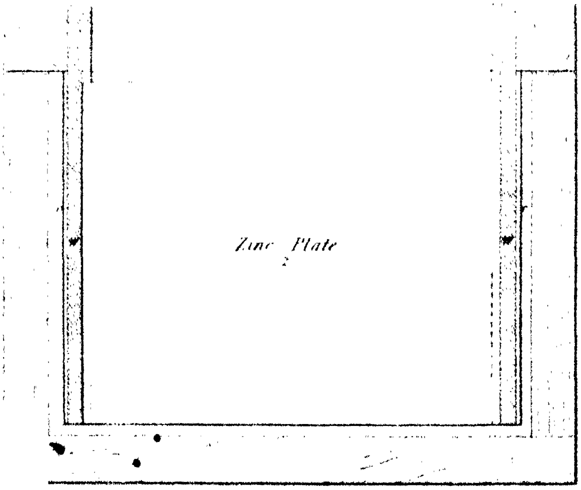


Plan of Frame with Pla

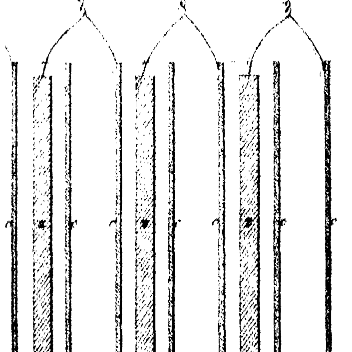




Section of Frame and Trough
shewing a Pair of Plates inserted



Section of 3 Pair of Plates
shewing the method
of connecting the Sequence.

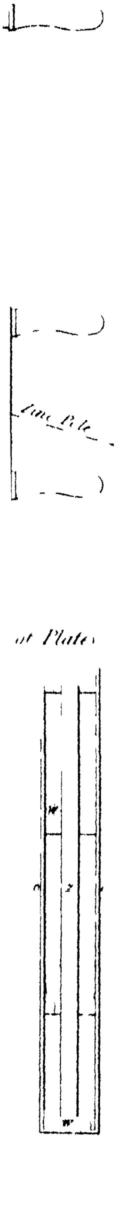


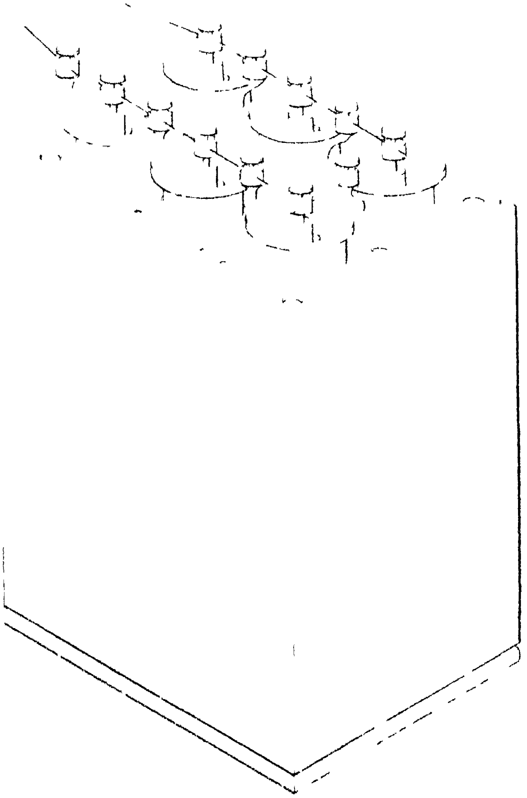
CLIFF.

the Demolition

Details of Professor Daniell's Cylinder Battery

Isometrical view of 6 Cylinder Battery connected





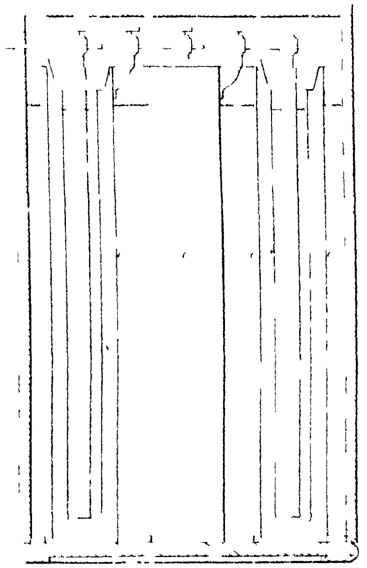
Section through Box on Line ABC

Reference

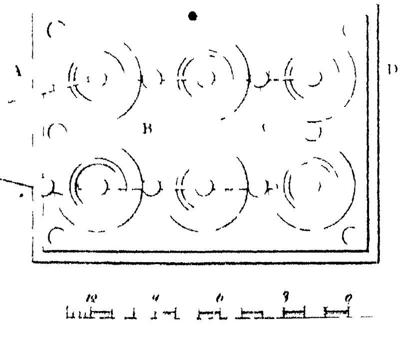
c Copper Cylinders

s Solution of Sulphuric Acid in water with Sulphate of Copper

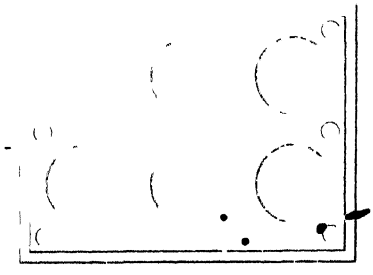
Zinc Rods within Ox Gullets containing dilute Sulphuric Acid only



Plan of Battery connected



Plan of Box



No. of experiments.	No. of batteries in action. Daniell's 6-cylinder battery.	No. of batteries in action. 20-plate battery.	No. of bursting charges attached at A	B	C	Bursting charges exploded at A	B	C	Length of platinum wire heated.	Remarks.
										Each battery of Daniell's was composed of 6 cells; each of the plate batteries, of 20 pairs of plates measuring 10 inches by 7 inches. Wherever platinum wire is recorded as heated, it was applied to the poles of the batteries.
1	..	3	1	1	1	1	1	1		
2	.	1	1	.	..	1	..	.	7 in.	
3	..	3	2	2	2	..	..	2		
4	.	4	2	2	2	2	2	2		Not quite simultaneously.
5	4	..	1	..	..	1	.	.	7 in.	This proves that four 6-cell batteries of Daniell's are equivalent to one 20-plate battery. The charge fired was similar to those used at Spithead.
6	4	..	2	..	..	2	.			Do. Do.
7	4		1	1	1	1	1	1		A decided interval between the reports.
8	4		*2	..	..	..	..	..		* Another length of wire had been added, making 2400 feet in all.
9	..	4	*2	..	..	2	..	..		Do. Do.
10	4	6								7 inches of steel wire (No. 20 gauge) ignited; copper bell wire fused at the poles.
11	4	6	2	2	2	..	..	..		Cartridges made with thin slips of platinum foil, for want of wire.
12	4	6	1	1	1	1	1	1		Made with platinum wire.
13	4	6	2	2	2	2	2	2		A beautiful experiment; the six charges went off like a well-delivered volley of musketry.

No. of experiments.	Daniell's B′	B″	B‴	20-plate B′	B″	B‴	Attached at B′	B″	B‴	Exploded at B′	B″	B‴	Length of platinum wire heated.	Remarks.
														Firing with 3 SEPARATE WIRES by 3 SERIES of COMBINED batteries.
1			4	3	3	..	2	2	2	1	2	1		Supposed to be a mistake in manipulation, as the cartridges were good.
2			4	3	3	..	1	1	1	1	1	1		Simultaneous.
3			4	3	3	..	2	2	2	2	2	2		A slight interval.
4			4	3	3	.	2	2	2	2	2	2		Do.
5	3	3	3	2	2	2	1	1	1	1	1	1		Same arrangement of batteries as used in blast.
6	3	3	3	2	2	2	2	2	2	1	2	.		Combined battery B‴ was disarranged.
7	3	3	3	2	2	2	2	2	2	2	2	2		
8	3	3	3	2	2	2	2	2	2	2	2	2		This experiment was repeated from 15 to 20 times, during which only 2 cartridges failed, and those were found to have been imperfectly made.

In addition to the above, several experiments had been previously tried for firing a number of charges simultaneously on the same wire, by merely connecting, across the parts opened, with platinum wire in lieu of attaching cartridges; these were, however, attended with the same uncertain results.

In the second series of experiments the batteries are marked B′, B″, B‴.

G. R. HUTCHINSON,

Lieutenant, Royal Engineers.

February 6, 1843.

XIII.—*Report of Experiments made with a Shot Furnace at Malta.*

The following Report of some experiments made with a shot furnace lately constructed at Malta, having been forwarded to the Inspector-General of Fortifications by the Commanding Royal Engineer, the Master-General and Board of Ordnance have, upon the recommendation of the Inspector-General, permitted its insertion in the present volume.

The plans and sections (Plates XLV. and XLVI.) which accompany this Paper, with the references and estimate, will sufficiently explain the construction of the furnace; and the following Report has been made of the effect produced.

Report of Experiments made with a Shot Furnace lately constructed at Malta.

First Experiment, Oct. 7, 1842.

Weather dull and showery, wind in the most unfavourable quarter.

Sixty-nine 32-pounder shot placed in the furnace in three rows of twenty-three shot in each. Fire, of shavings, pieces of fir, elm, and oak, intermixed with coal, lit at 10 minutes after 2 P. M. Draught assisted during the whole process by the action of a middle-sized smith's bellows communicating with the furnace through an aperture in rear of the fire.

1st shot, drawn 25 minutes after the fire was lit; thrown on coarse shavings and covered with the same, ignited them in 3 minutes.

Powder being thrown on this shot, part of which was uncovered after it had been 1½ minutes in the shavings, ignited in 3 seconds. The same shot ignited powder in 12 seconds, after it had been removed from the shavings and exposed to the air 5 minutes.

2nd shot, drawn after 31 minutes, "dull red," ignited shavings in 47 seconds, and afterwards powder in $1\frac{1}{2}$ seconds; a second pinch of powder in 3 seconds.

3rd shot, drawn after 48 minutes, buried in two cubic pieces of fir timber, 11 inches square, scooped out to receive the shot, created no flame, ignited powder in 1 second, after it had been $7\frac{1}{2}$ minutes in the block of wood. After a lapse of 20 minutes from the time it was taken out of the furnace and placed in the block of wood, it still ignited powder in 1 second.

4th shot, drawn after 50 minutes, ignited powder in 1 second; second pinch of powder in $1\frac{1}{2}$ seconds; third pinch in 1 second; coarse shavings in $1\frac{1}{2}$ minutes.

5th shot, drawn after 1 hour, still "dull red," ignited powder instantaneously; buried in fir timber, it caused no blaze. After a lapse of 27 minutes, it ignited powder instantaneously; ditto, after 47 minutes. This shot was left buried in a block of fir timber, to be further reported on by the sentry under whose charge it was placed. (The shot had been 48 minutes in the block when consigned to the sentry, who reported that the block fell into fragments, and the shot rolled out, 5 hours after.)

6th shot, drawn after 1 hour and 10 minutes, "bright red," ignited shavings instantaneously; half-buried in a block of timber, ignited the same instantaneously, and the wood continued to blaze. A pinch of powder, thrown upon the surface 37 minutes after it had been drawn from the furnace, ignited instantaneously.

7th shot, drawn after 1 hour $17\frac{1}{2}$ minutes, immersed in a tub of cold water for 30 seconds, then thrown on the ground, ignited the first pinch of powder in 3 seconds; second pinch in 2 seconds; third pinch in $1\frac{1}{2}$ seconds.

8th shot, drawn after 1 hour and 27 minutes, kept immersed in a tub of water for 1 minute, would not afterwards ignite powder at all.

At 7 o'clock the following morning the furnace was too hot to allow of any examination.

SECOND EXPERIMENT, Oct. 13, 1842.

Artificial blast and fire as before.

1st shot, drawn 30 minutes after the fire was lit, ignited powder in 2 seconds and deal shavings in 3 minutes 35 seconds.

2nd shot, drawn after 50 minutes, "dull red," ignited powder in 1 second; buried in a block of Memel fir, 1 foot cube, leaving an open crevice, created no flame, but smouldered away for 1 hour, when the block blazed, and continued to flame till consumed.

3rd shot, drawn after 1 hour, "red," ignited powder instantaneously, shavings instantaneously; immersed in water for 30 seconds, it ignited powder in 16, 14, 7, 6 seconds. After this shot had been 5 minutes from the furnace, through the water, &c., it ignited powder in 9 seconds.

4th shot, drawn after 1 hour and 20 minutes, "white heat," ignited a deal block instantaneously; after having been immersed in water for 1 minute, ignited powder in 3 seconds. At this period, viz., 1 hour and 20 minutes from the time the furnace was lit, shots in succession were delivered from the furnace at intervals of 1 minute. After the twenty-sixth shot was delivered, the heat subsided without any apparent cause, which, upon examination the next morning, was found to arise from the blast having been obstructed by clinkers formed over the apertures for admitting the blast.

THIRD EXPERIMENT, Oct. 21, 1842.

The bars of the fire-grate had been widened from ¾ inch to 1½ inches apart; an air-hole with valve had been made in the furnace door, and an additional length of 10 feet given to the flue by a temporary chimney of wood. Fire and artificial blast as before. Weather perfectly calm. Fire lit at twenty minutes to 6 P. M.

1st shot, drawn after 30 minutes, "dull red," ignited powder instantly; deal shavings blazed in 15 seconds.

2nd shot, drawn after 32 minutes, ignited shavings in 7 seconds.

3rd shot, drawn after 34 minutes, immersed 30 seconds in water, ignited powder in 18, 11, 7, 5 seconds; after a lapse of 8 minutes, it fired powder in an instant.

4th shot, drawn after 38 minutes, "bright red," placed in a block of oak, created no flame.

5th shot, drawn after 47 minutes, "bright red," buried in a tub of coals, created no flame.

6th shot, drawn after 60 minutes, "white heat."

7th shot, drawn after 61 minutes, "white heat," blazed instantly in a block of red pine.

8th shot, drawn after 64 minutes, immersed 1 minute in water, then placed in a block of oak (which had been slightly charred by another shot), recovered its colour in 2 minutes, and ignited the block of oak in 10½ minutes.

9th shot, drawn after 67 minutes, buried in a bed of coals, created no flame. After a lapse of 38 minutes, the shot was partially uncovered, and found "good red;" a pinch of powder being thrown upon it, the coals blazed instantly.

10th shot, drawn after 70 minutes, "white heat," immersed 20 seconds in water, ignited powder instantly; placed in a charred block, caused the same to blaze after 1½ minutes. Shots were now drawn at intervals of 40 seconds (*i. e.* three shots in 2 minutes), all of which were of "white heat."

Memorandum of fuel expended in heating the shot furnace on the 24th of October, 1842:

Shavings and light chips of Memel fir, pieces of red pine . .	140 lbs.
Coals	126 „

The chimney being raised by masonry to 16 feet, and perfectly dry, a fourth experiment was tried without the artificial blast.

Fourth Experiment, Dec. 10, 1842.

Brisk breeze, and favourable to the draught.

1st shot, drawn 25 minutes after lighting, ignited powder in 10 seconds.

2nd shot, drawn after 30 minutes, ignited different pinches of powder in 5, 3, 3 seconds, and blazed shavings in 1 minute and 5 seconds.

3rd shot, after 35 minutes, ignited powder instantly, blazed shavings in 30 seconds.

4th shot, after 48 minutes, "red," blazed shavings instantly; put into a block of timber, caused it to blaze in 2 minutes.

5th shot, after 54 minutes, "bright red," put into a block, blazed in 35 seconds.

6th shot, after 1 hour, immersed in a barrel of cold water for 1 minute, did not afterwards ignite powder for some minutes.

7th shot, do.

One hour after the furnace had been lighted, a shot, placed in the furnace in immediate contact with the fire, was heated to a "white heat" in 10 minutes.

From the above experiments it will appear, that in calm weather, and in situations where the chimney cannot be carried conveniently higher than 10 feet, the artificial blast is of advantage, but not necessary when the wind is favourable, as the result of the 4th trial appeared nearly the same as that of the 3rd. The bars supporting the shot are slightly curved by the heat applied in the above experiments, but not so as to render them unserviceable; it, however, does not appear advisable, consistently with preserving the efficiency of a furnace as at present constructed, further to increase the degree of heat.

W. B. TYLDEN,
Lieut.-Colonel, Commanding Royal Engineer.
J. S. BASTARD,
Lieut.-Colonel, Commanding Royal Artillery.

Royal Engineer Office, Malta, Dec. 27, 1842.

Estimate of the expense required in building a furnace for heating shot according to the plan transmitted to the Inspector-General of Fortifications, with the Commanding Engineer's letter.

		£.	s.	d.
To remove 165 cubic feet of rubbish in clearing the foundation, 15·6 × 5·4 × 2 feet	at $\frac{3}{4}$d.	0	10	3$\frac{3}{4}$
125 cubic feet of masonry, common stone set in stone-lime and sand-mortar in building the foundation, 33 × 1·6 × 2 feet; 13 × 1·0 × 2 ,,	at 3$\frac{1}{2}$d.	1	16	5$\frac{1}{2}$
42 cube feet of rubble masonry 9 × 2·4 × 2	at 1$\frac{1}{2}$d.	0	5	3
360 cube feet of masonry, Malta hard stone of second quality, set in lime and sand-mortar in building the furnace, Walls { 33 × 5·0 × 1; 13 × 2·6 × 1 }; Roof 9 × 3·4 × 1; Step 5 × 1·4 × 8″; Flue 8 × 1 × 16	at 7d	10	10	0
44 cube feet of brick-work in lining the furnace with fire brick, 1 brick throughout, 8· × 11· × 4$\frac{1}{2}$″; 3· × 2·6 × 4$\frac{1}{2}$″; 2·6 × 4·6 × 4$\frac{1}{2}$″; 5·6 × 2· × 4$\frac{1}{2}$″	at 1s. 4d.	2	18	8
52 cube feet of rubble masonry in fillings in, 9 × 2·4 × 2·6	at 1$\frac{1}{2}$d.	0	6	6
		16	7	2$\frac{1}{4}$

	£.	s.	d.
Brought forward	16	7	$2\frac{1}{4}$
Wrought Iron work:—			
$44\frac{1}{3}$ feet run 3-inch round iron in 4 bars, each 11′ 1″ long, for runners = 1064 lbs. at 3*d*. per lb.	13	6	0
19 feet run $2\frac{1}{2}$-inch round iron in 28 bars, each 8 inches average length, for supporters to the runners = 380 lbs. . . . . at 4*d*. per lb.	6	6	8
$17\frac{1}{2}$ feet run 2-inch square iron in 7 bars, each 2′ 6″ long, for binding the supporters, = 245 lbs. . . . . at 3*d*. per lb.	3	1	3
$16\frac{1}{2}$ feet run $2\frac{1}{4}$-inch × $1\frac{3}{4}$ bar iron in 7 bars, each 2 feet 4 inches long, for the fire-grate = 231 lbs. . . . . . . at 3*d*. per lb.	2	17	9
4 feet run 3-inch square iron in 2 bars, each 2 feet long, for supporters to the fire-grate = 120 lbs. . . . . . . at 3*d*. per lb.	1	10	0
28 feet run 1-inch square iron, in 3 bars, each 5 feet long, and 4 bars, each 3′ 3″ long, to tie the masonry of furnace = 98 lbs. . . at 3*d*. per lb.	1	4	6
48 feet run $2\frac{1}{2} \times \frac{1}{2}$ flat iron, to go round the top of furnace and flue, as a bond to keep the masonry together = 222 lbs. . . . at $2\frac{1}{2}$*d*. per lb.	2	6	3
35 feet run $1 \times \frac{3}{4}$ bar iron, in 6 bars, each 5′ 4″ long, and 3 bars, each 1 foot long, for the trough for receiving the hot shot in front of the furnace = $87\frac{1}{2}$ lbs. at $3\frac{1}{2}$*d*. per lb.	1	5	$6\frac{1}{4}$
3 square feet $\frac{1}{2}$-inch plate iron in front of the doors through which cold and hot shot are let in and out = 57 lbs. . . . . at 6*d*. per lb.	1	8	6
3 iron tubes let into masonry with $\frac{3}{4}$-inch round iron rods to fit (to check the shot from rolling out), each 2′ 4″ long, with wooden handles = 30 lbs. at 6*d*. per lb.	0	15	0
1 iron tube let into the masonry, to convey the blast from the bellows to the furnace, 12 lbs. . . . . . . at 6*d*. per lb.	0	6	0
12 feet run 1-inch round iron for pokers, 42 lbs. . . . at 3*d*. per lb.	0	10	6
1 furnace-door of plate iron, $12\frac{1}{2}$ inches square in the clear, with frame of 3×1 flat iron, nuts included = 125 lbs. . . . . . at 6*d*. per lb.	3	2	6
2 similar doors of plate iron to ash-pit	6	5	0
1 door to admit shot to the furnace, $8 \times 9\frac{1}{2}$ inches in the clear, of plate iron, with frame 3×1 inch flat iron, nuts included = 96 lbs. . at 6*d*. per lb.	2	8	0
3 similar doors in front of furnace, to let shot out when heated . .	7	4	0
1 door to front ventilator of ash-pit, 6 inches square in the clear, of plate iron, with frame $2\frac{1}{2} \times \frac{3}{4}$-inch flat iron, nuts included = 63 lbs. . at 6*d*. per lb.	1	11	6
1 damper of plate iron on the top of flue, 1 foot square in the clear = 36 lbs. at 6*d*. per lb.	0	18	0
16 feet run of iron chain attached to damper on top of flue . at 9*d*. per ft.	0	12	0
	73	6	$1\frac{1}{2}$
Contingencies $\frac{1}{10}$th	7	6	7
	80	12	$8\frac{1}{2}$

W. B. TYLDEN,

Dec. 27, 1842.

Lieut.-Colonel, Commanding Royal Engineer.

Reference to Drawings of an Apparatus for Heating Shot. Proposed to be erected at Fort Ricasoli, Malta.

a Iron doorway, through which cold shot are introduced into the furnace.

b b b Iron runners, 3 inches diameter, 4½ inches apart, placed at inclinations of 1 inch to 1 foot, on which the shot roll.

c c c Uprights of iron, 2½ inches diameter, sunk in brick-work and bound together by

d d d Cross bars to support the runners on which the shot roll.

e Extra support to that portion of the iron immediately over the fire.

f f f Iron doors, for delivery of hot shot.

g Piece of iron projecting from the back of the door of outlet, to keep the first shot over the fire.

h Iron rod with wooden handle, working in a tube and abutting against the second shot, to check the line of shot from rolling out when the first shot is delivered.

i Stone trough, defended by strips of iron, into which the hot shot roll when drawn from the doors *f f f*.

k Iron grate for the fire.

l Cylinder of iron to receive the blast from the bellows (*m*), the nose of which is placed in

n The tube, to communicate the same through small apertures situated 2 inches over the fire-grate.

o Ash-pit.

p Front opening (6 inches square) to ash-pit, to be opened, when necessary, to assist the draught.

q Tie bars of rod iron, to bind the masonry.

r Furnace door, with valve to regulate the draught.

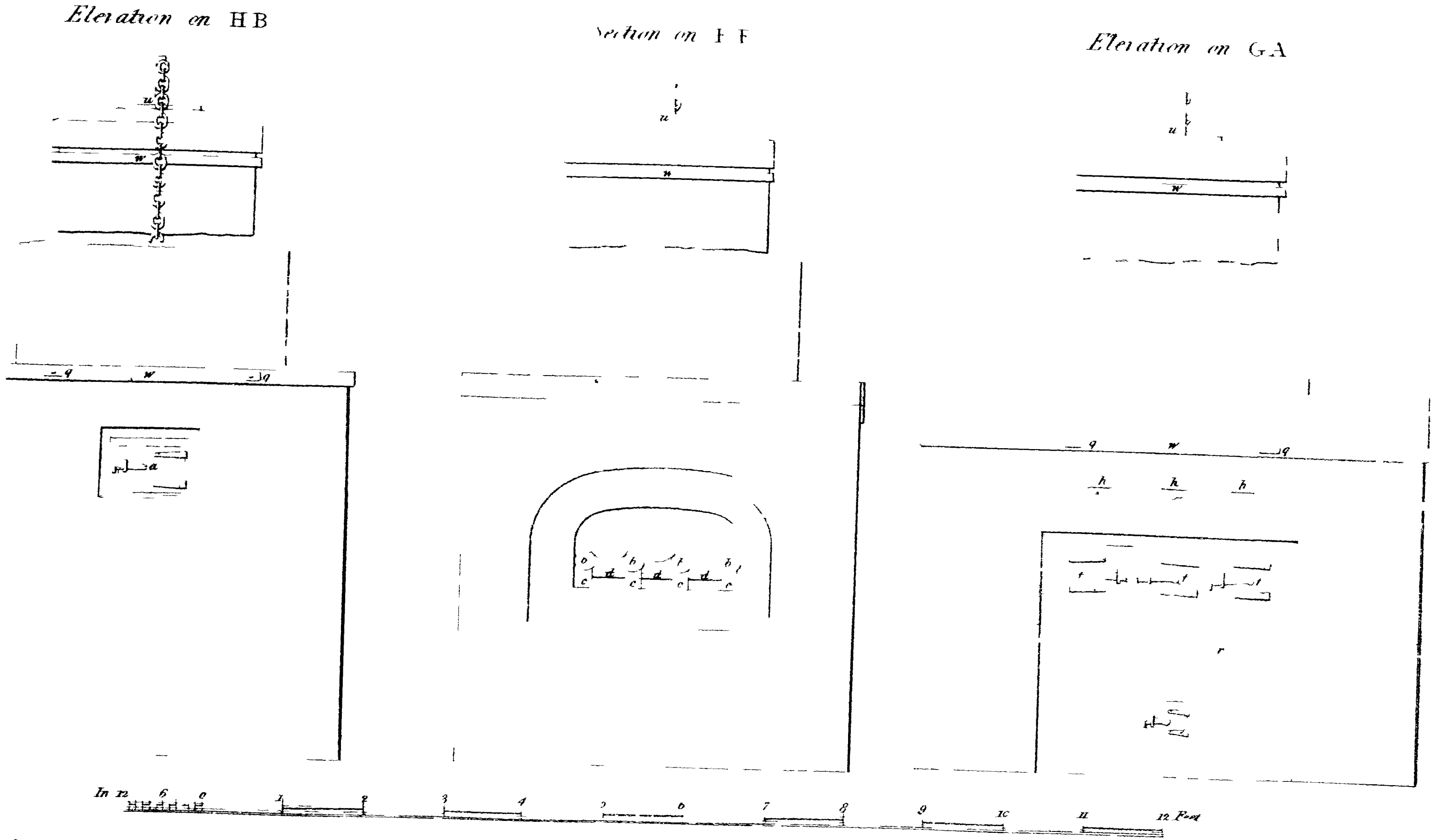
s s Doors to ash-pit, one of which will be shut according to the wind.

t Binders, to connect the brick-work with the masonry.

u Damper to flue.

w Binding of 2½-inch flat iron, to secure the masonry of chimney.

DETAILS OF A FURNACE FOR HEATING SHOT.



H Le Keux sc

XIV.—*Description of some Iron Roofs erected at different places within the last few years. By Captain* DENISON, *Royal Engineers.*

THE reduction in the price of iron within the last few years has led in many ways to an extension in its application to the purposes of construction: most especially is this to be remarked in the roofs which are so frequently erected over workshops, railway stations, and other similar buildings; where we find light wrought iron taking the place of either wood or cast iron, and considered as superior to both as regards lightness, and to the former, in addition, as regards durability: I have thought it desirable, therefore, to lay before my brother officers specimens of roofs which have been erected, with a short description attached to them, sufficient to explain the principles of their construction; and I have to thank William Crawshay, Esq., of Caversham Park, and Messrs. Fox and Henderson, of Birmingham, who have been kind enough to furnish me with the drawings from which most of the Plates are engraved.

Plate XLVII. is a plan and section of a roof erected by Mr. Crawshay over his extensive works near Newbridge, in Glamorganshire. The principals of this roof are formed entirely of flat bar iron of the dimensions shown on the drawing: the bars forming the struts and king and queen rods are riveted together at the points where they cross each other, and also to the principal rafters. The purlins are formed of angle iron, and are riveted together through the principal rafters.

The principals are 6 feet 11 inches apart: the common rafters are of wood, and the whole is covered with slate.

This roof is rather heavy, looking to the quantity of iron used in its construction, but it is cheap, the iron being all common bar iron, with but little work upon it. It is a very strong roof, as was shown by a portion of a fly wheel breaking its way through it, and merely leaving the gap through which it passed, without disturbing the rest of the roof.

Plate XLVIII. is an elevation of a principal of a roof of 64 feet span, proposed to be erected over the Depôt at Gloucester, in the line of the Birmingham and Gloucester Railway. I am not in possession of the details of the work, further than is shown in the drawing, which, however, is sufficiently explanatory.

Plate XLIX. shows one of the centre principals of the roof erected over the passenger-platform, &c., at the Birmingham terminus of the Birmingham and Derby Junction Railway: the entire roof extends a length of 314 feet, and consists of three principals or bays, forming the width of the station. The side principals are each of 27 feet span, resting at one end on the wall, and at the other on the longitudinal girders and columns which, as are shown on the Plate, support both ends of the centre principals, which are 27 feet 4 inches span. The rafters are cast iron of the double T section, the top table of which is uniformly $2\frac{1}{2}$ inches wide, and the lower table $3\frac{1}{2}$ inches at the middle, and tapered to $1\frac{1}{2}$ inches at the ends: the total depth of the rafters is uniformly $4\frac{3}{4}$ inches. Each rafter is trussed by iron rods $1\frac{3}{8}$ inches in diameter, passing within the suitably-formed end of a short cast iron strut attached to the middle of the rafter; the truss rods being received in cylindrical sockets formed at the head and heel of the rafter, and properly tightened up by gibs and cotters. The lower ends of these struts are connected together by a horizontal tie rod of iron, of $\frac{3}{4}$ inch diameter. The heads of the rafters have flanges, and are connected by bolts fixed through them.

Light is admitted to the station by glazed skylights that extend along the roof on each side of the ridge, and are raised above the rafters upon three standards of cast iron: the centre one of these standards is bolted on the heads of the rafters, and is formed at the upper end to secure a ridge-cap of cast iron that overhangs the sashes on either side, and throws the rain off. The other standards are bolted on the rafters, and are cast with oblique parallel grooves on the sides of them, into which louvre boards are fixed, leaving open spaces between them; by which mode the station is ventilated and the weather excluded. The standards support two small cast iron bearers, the cross section of which resembles the bottom and two sides of a box, as seen in the "Elevation of Ridge," &c.; and the sides of the skylight sashes, which are of cast iron, are formed with lips that overlap the sides of these bearers, as shown in the same figure on the Plate referred to, by which it will be seen that the joints of the contiguous sashes are thus rendered securely weather-proof.

The principals are placed at distances of 6 feet from centre to centre, and a diagonal bracing of iron rods is introduced in the centre part of the roofing in planes parallel with the slating of the roofs. This bracing extends over the space included between the five middle principals in each roof: thus,—a rod is connected to the heel of each of the second rafters from the central principal, and extends in a right-oblique direction towards the ridge of the central principal (where the four rods are bolted to the heads of the rafters), crossing over a space of 12 feet measured in the direction of the roof: where this rod is interrupted by the intermediate rafter, it is separated, and the ends are formed into corresponding eyes, and secured by a bolt passing through them and the rafter.

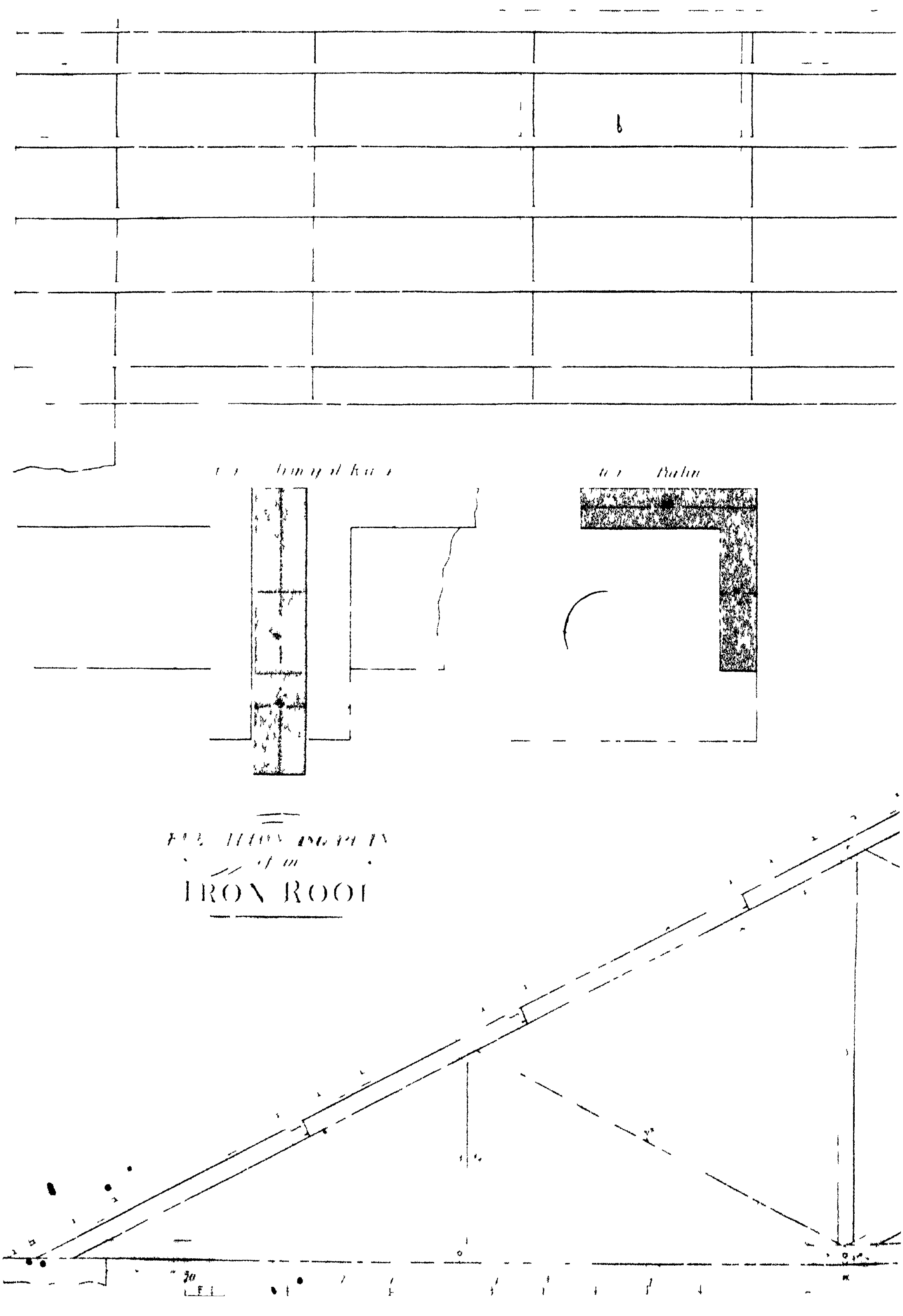
Plate L. shows a principal of the roof erected over the engine-house at the Manchester terminus of the Manchester and Birmingham Railway. The roof consists of three bays of 23 feet 8 inches clear span each, and extends a total length of 116 feet. The general arrangement of the rafters and rods is similar to that of the roof just described. In this roof, however, the rafters are of malleable T iron, with cast iron struts of more ornamental character; the form of them, it is presumed, is also better adapted for strength in the roof, by reason of the longer bearing of the rafters upon them. The lower truss rods, $1\frac{1}{4}$ inch in diameter, are forked at the ends to embrace the rib of the rafters, and connected with the rafters and with shoes on the walls by bolts and nuts. The lower ends of the struts are connected together by an iron tie rod of 1 inch diameter. The upper ends of the rafters and of the upper truss rods, which are $\frac{3}{4}$ of an inch in diameter, are connected by bolts with the lower end of a cast iron standard, which, with two others, also bolted to the rafters, supports a ridge-cap, bearers, sashes, and louvre boards, in the same manner as in the roof at Birmingham, already described.

In this roof, the two side standards that carry the louvre boards are cast with projecting brackets near the bottom, that support a thin capping-plate to exclude the weather from the joint at which the slating is begun. The principals are 5 feet 2 inches apart between their centres, and without any diagonal bracing.

Plate LI. shows a principal of the roof erected over the passenger-platforms,

&c., at the Manchester station of the Manchester and Birmingham Railway. The roof consists of three bays, the centre one being 51 feet 10 inches span, and the side bays 35 feet 4 inches span each. One of these is represented in the Plate, and should be shown resting in a small shoe on the wall at one end, instead of connected by a plate and bolts with another principal. The rafters are of malleable T iron, with two T iron struts to each rafter, of the section shown on the plate. The king rod is $\frac{3}{4}$ inch, and the two queen rods $\frac{1}{2}$ inch diameter. The tie rod, 1 inch diameter, is in two parts, each connected with one of the main struts and the king rod by a pair of circular connecting plates, with suitable bolts and nuts. The upper end of each queen rod is forked, and embraces the rib of the rafter, and also two pieces of plate iron which are bolted, one on each side of the rib of the strut; thus securing the rafter, the strut, and the rod together. The heads of the rafters are bolted to a cast iron king-head that has a socket within which the king rod is keyed, and is also connected with a ridge-cap that overlies the slating of the roof. The principals are 6 feet 8 inches apart between their centres, and are fully strengthened by diagonal braces throughout the whole of the roofing.

Plate LII. represents a design for a roof of 60 feet span, intended to be erected in Scotland, with rafters of a peculiar construction. These are shown as formed of two bars of iron, each $4\frac{1}{2}$ inches by $\frac{3}{8}$ths of an inch, secured together, so as to preserve an uniform space of $1\frac{1}{4}$ inch wide between them, by bolts at intervals passing through the bars and small cast iron studs placed between them. The struts are of malleable angle iron, $2\frac{1}{2}$ inches wide, placed with its faces at an angle of 45°: the king rod is $1\frac{1}{8}$ inch, and the two queen rods are $\frac{5}{8}$ inch diameter. That part of the tie rod between the queen rods is $1\frac{1}{8}$ inch diameter, and the other parts $1\frac{1}{4}$ inch diameter. The upper ends of the queen rods are forked to embrace the rafters, and the ends of the struts turned square to enter between the bars of the rafters, and bolts are passed through the queen rods, rafters, and struts. A circular plate with bolts connects the foot of the king rod with the tie rod and main struts. The "details of connecting plate" show the manner in which the lower ends of the struts are adapted to be bolted for this purpose. The upper ends of the rafters and of the king rod are connected by a cast iron king-head which supports a ridge-cap of the same material. The laths are of small bar iron, and are notched over the rafters in the manner shown.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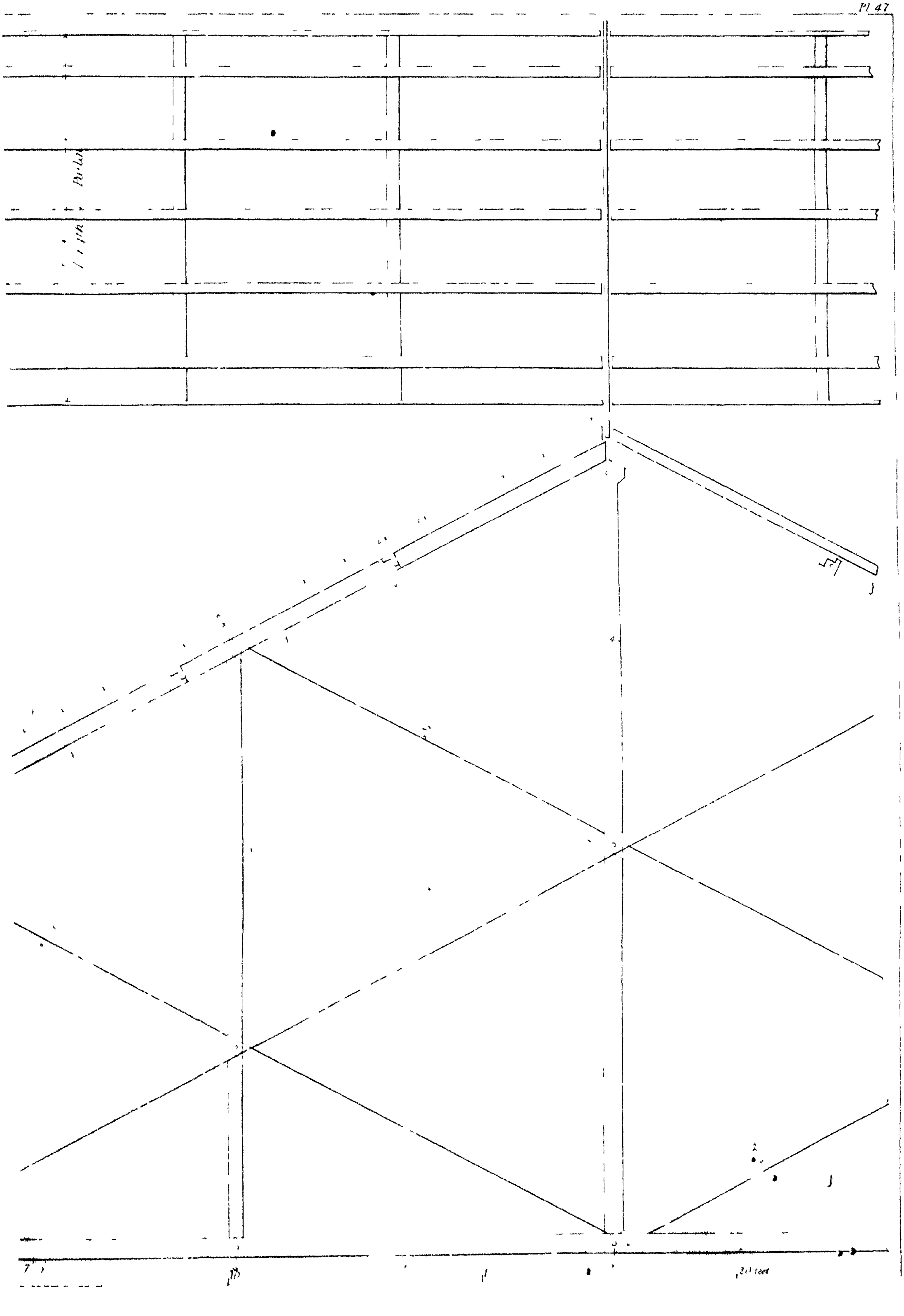

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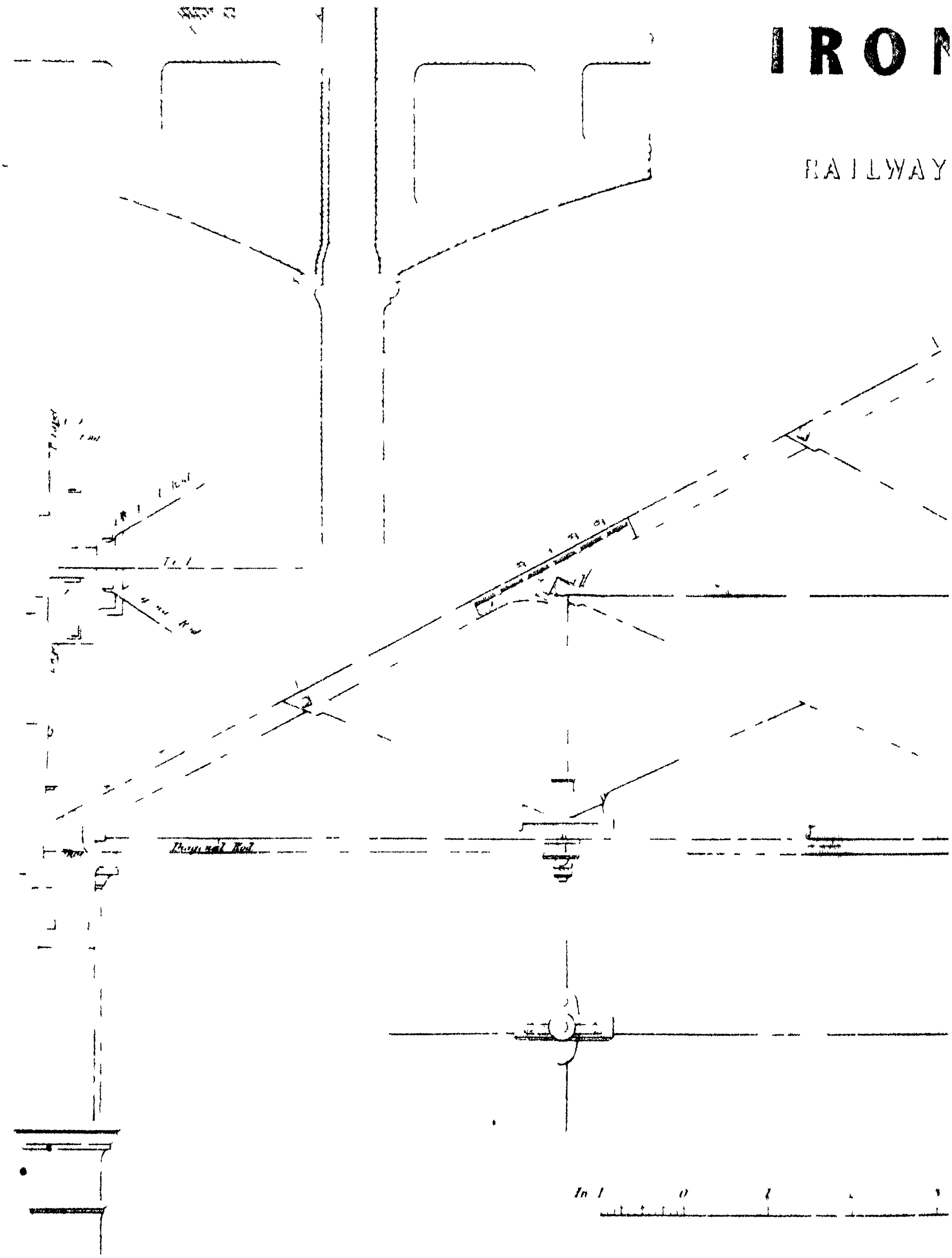
Section showing the manner of fixing the Arch casting upon the columns



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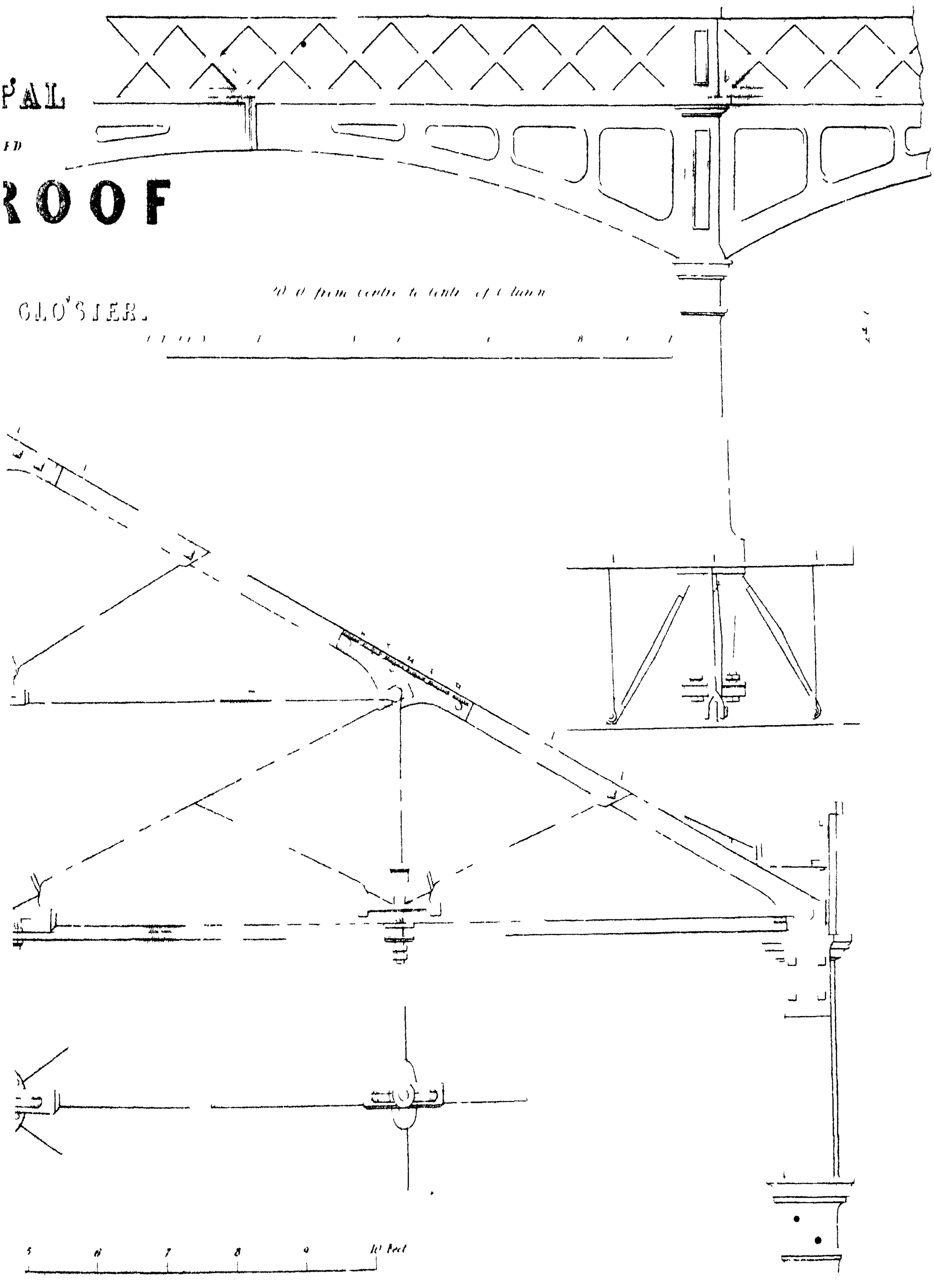

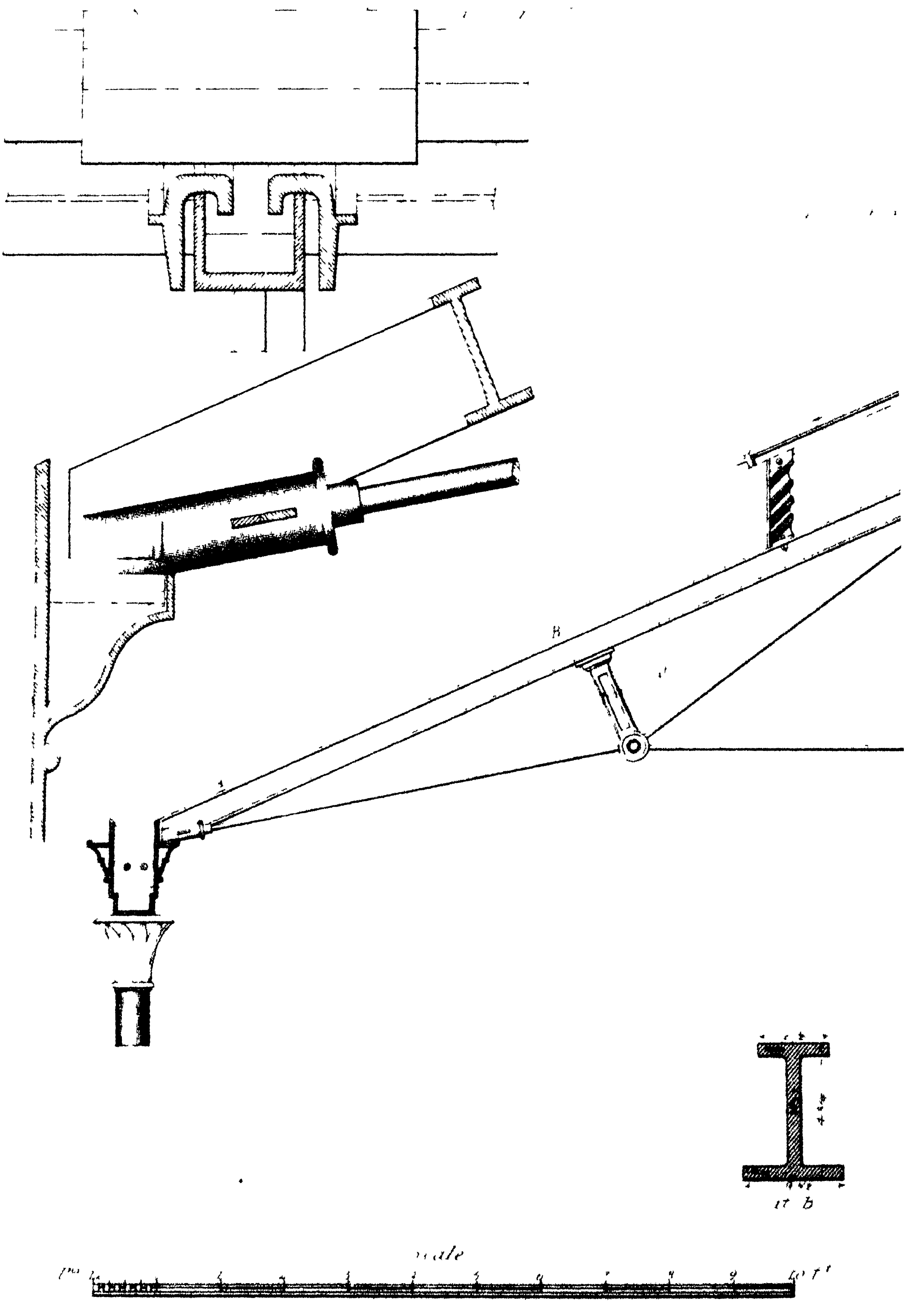
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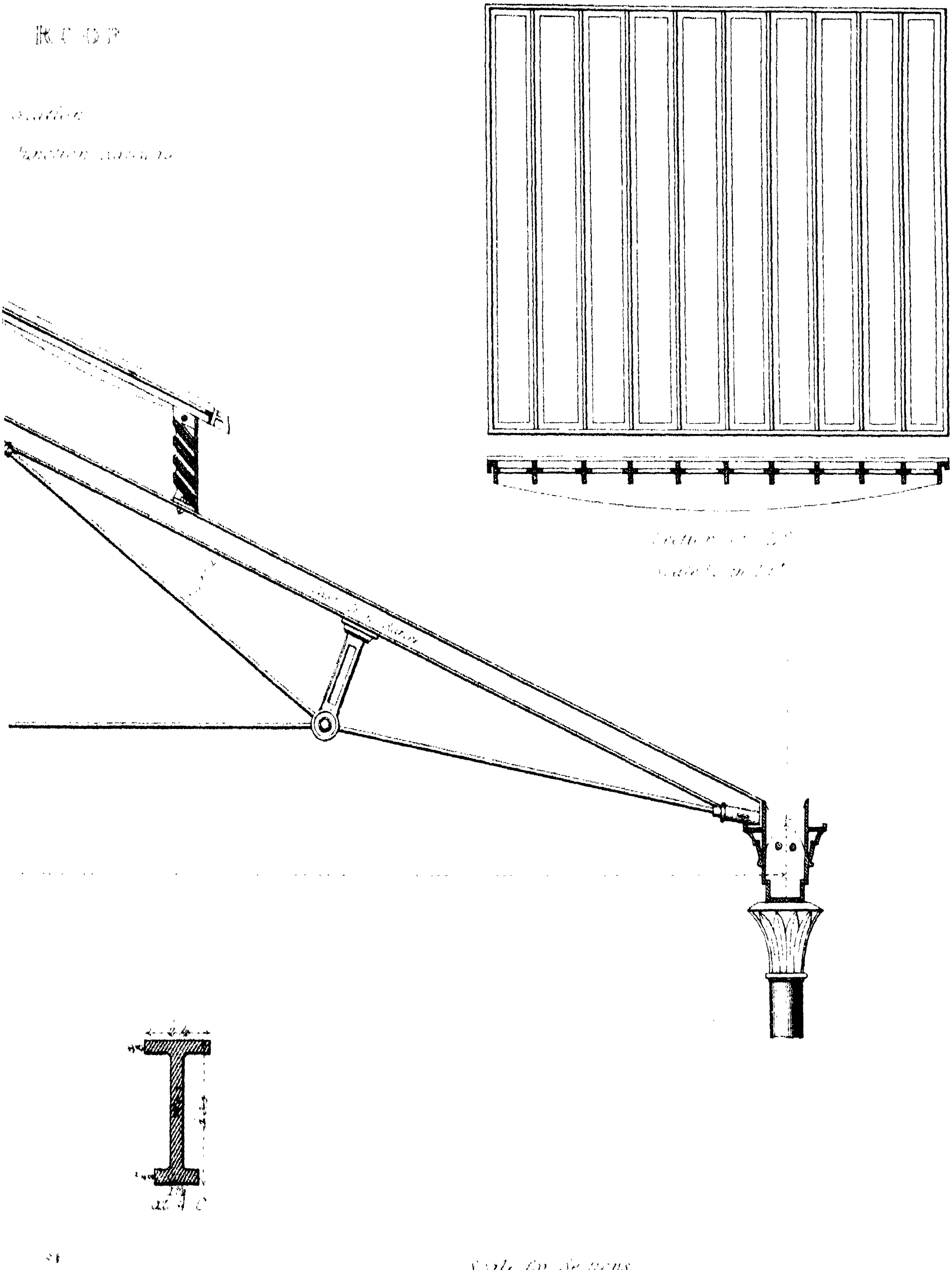
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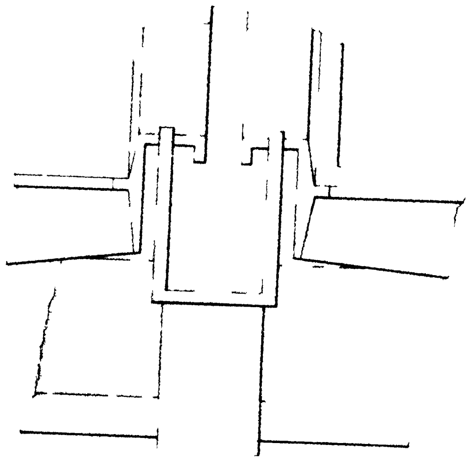

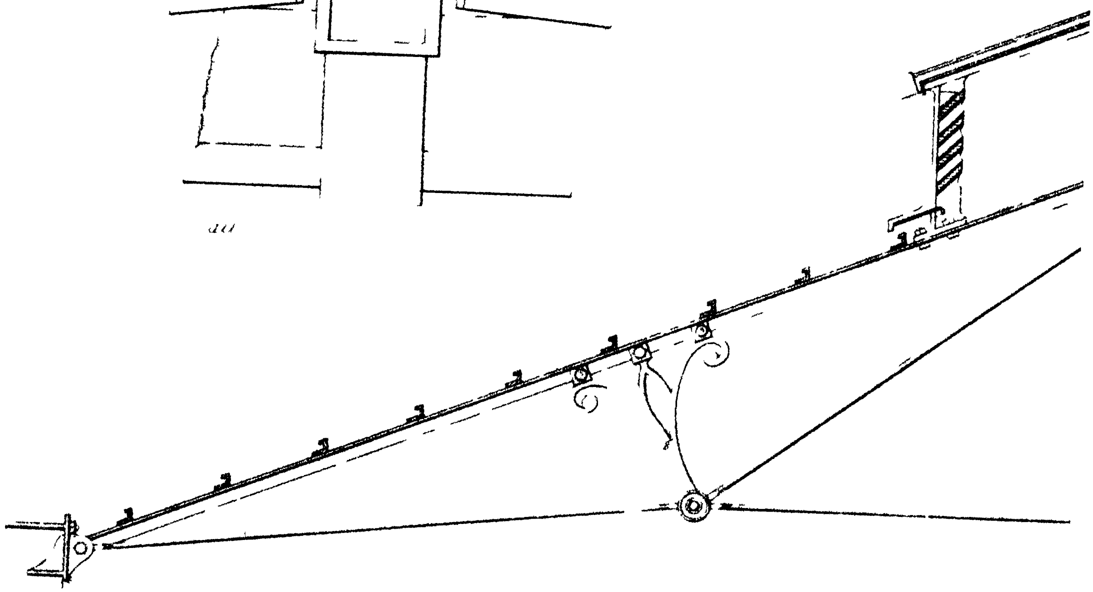

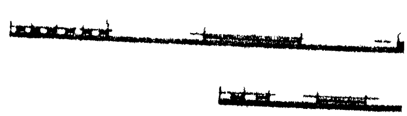

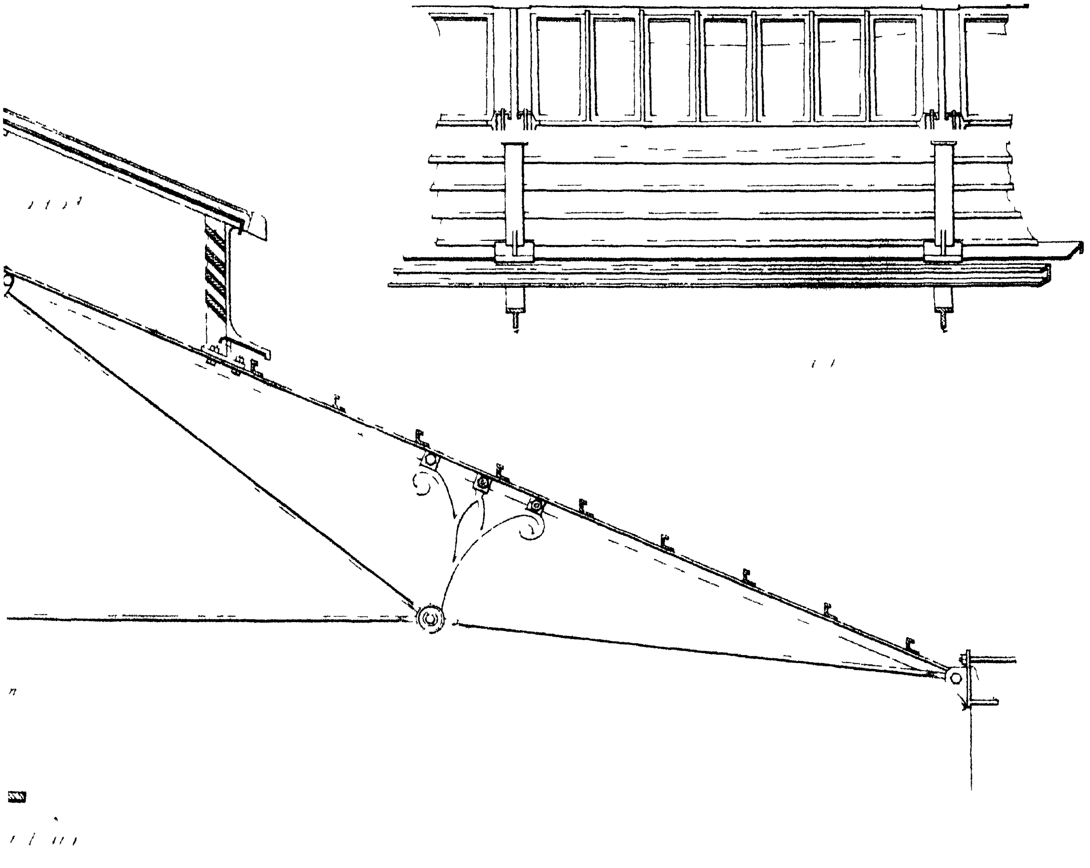

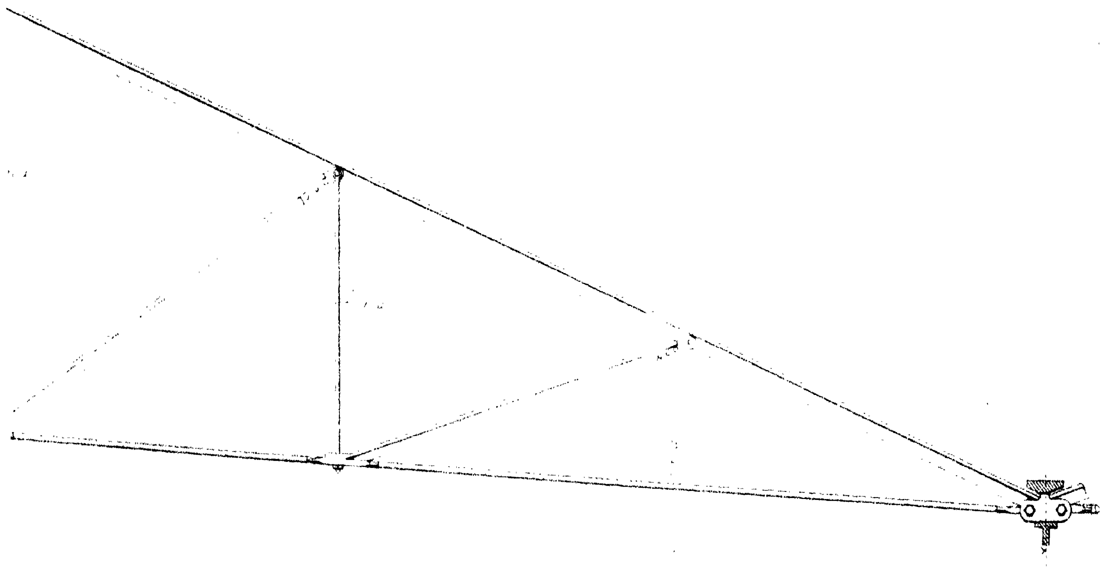

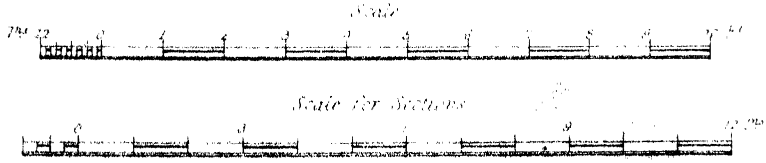

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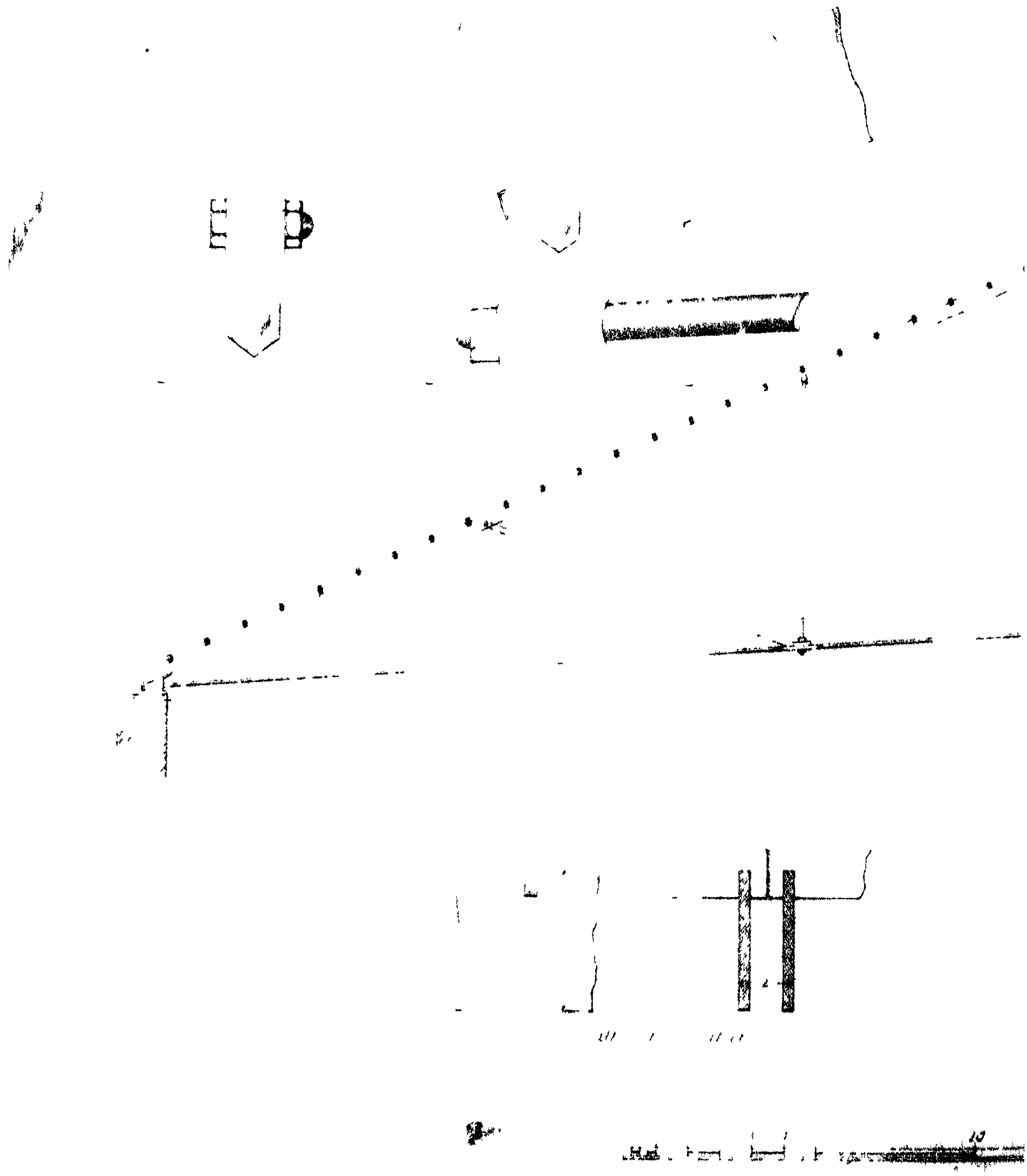
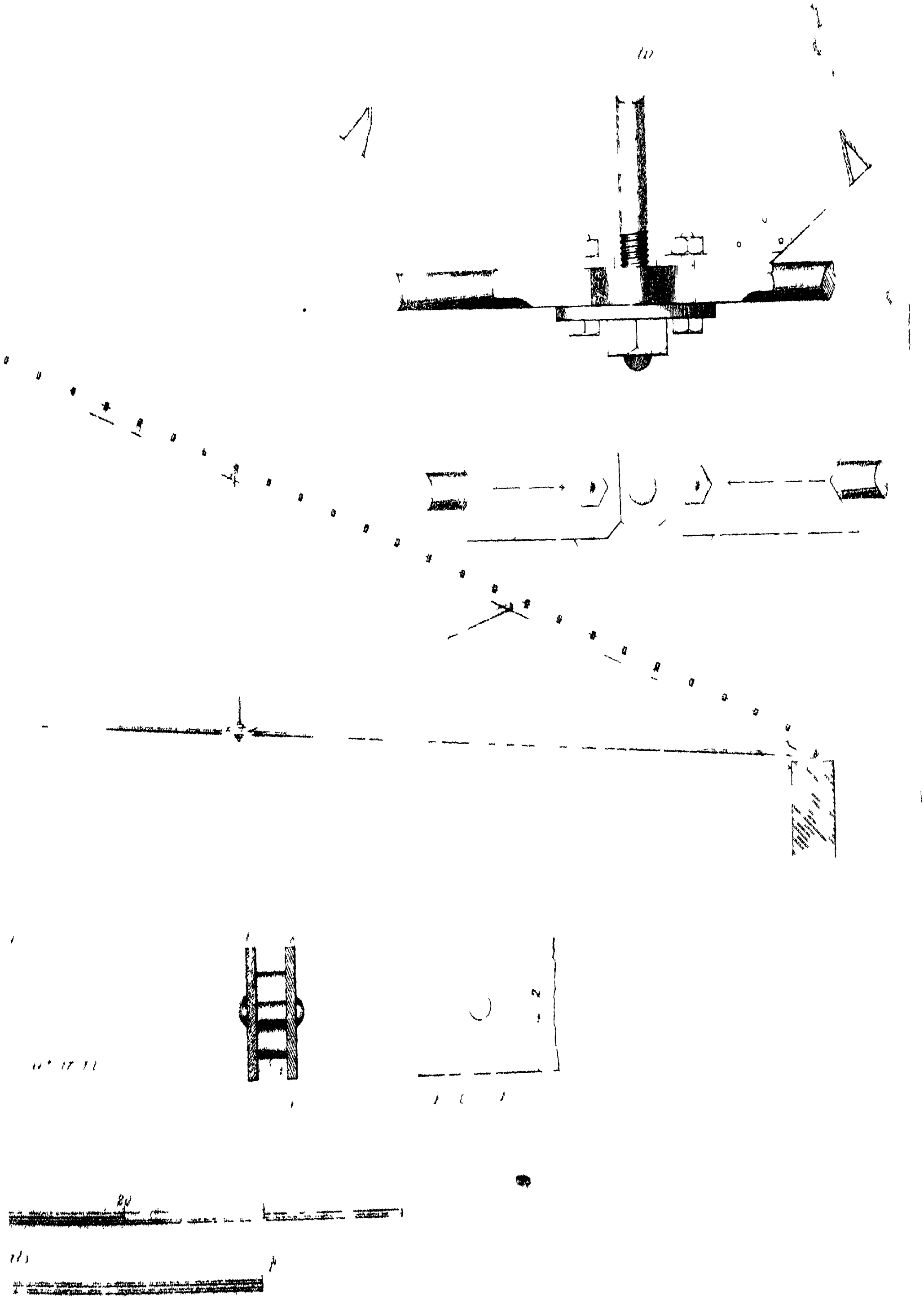




Subsequently, a roof has been erected at the Cowlairs station, Glasgow, on the line of the Edinburgh and Glasgow Railway, with rafters of this description; but the details and dimensions of the roof have been much modified to suit particular circumstances. It consists of eight bays of 33 feet span each, and one bay of 22 feet, making a total clear width of 286 feet, and extending for a length of 101 feet. The principals are 4 feet 9 inches apart from centre to centre; the rafters of bar iron, 3 inches by $\frac{5}{16}$ths of an inch. The general arrangement resembles that of the engine-house roof at Manchester, already described, each double rafter being trussed with wrought iron rods and cast iron struts, connected at their lower ends by a horizontal tie rod of iron. Part of the roof supports louvres with skylights, &c., of similar construction to those described.

XV.—*On the Use of Fascines in forming Foundations to Buildings.*

(COMMUNICATION FROM COLONEL LEWIS, ROYAL ENGINEERS, TO CAPTAIN DENISON.)

SIR,

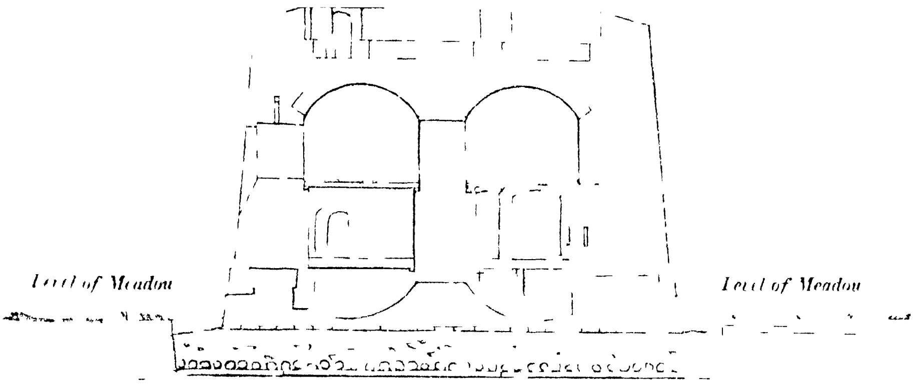
I was on duty in 1812 in the Eastern Districts, superintending some of the works for the defence of the coast, then building under the general direction of Sir Alexander Bryce: when an additional three-gun tower was ordered to be commenced in the height of Hollesley Bay, on the coast of Suffolk.

As the encroachment of the sea left no space between high-water mark and the embankment or sea wall which protected the low grounds, it was necessary to place the tower in the meadows. When the sward was removed, preparatory to the laying of the foundation, the ground was found so soft, that a 10-foot rod was easily thrust down the whole length of the rod with the hand.

Under this difficulty, I suggested to Sir Alexander Bryce the use of fascines, having had some experience in their application, which suggestion he was pleased to sanction.

Accordingly, I adopted the following method: I had the fascines made on the spot with some care: they were 12 inches in diameter, and 14 or 15 feet in length. When the soil was excavated 3 feet deep, and in breadth a few feet beyond the diameter of the tower (60 feet), the fascines were laid horizontally in two rows, one over the other; the first row nearly buried itself in the soil, the second was placed at right angles to the first row, and remained clear and above the soil; shingle from the neighbouring beach was wheeled upon the fascines to the level of the meadows nearly; when the tower was commenced in the usual manner of building them along the coast, as explained in the annexed diagram.

Section of a 3-gun Tower built upon a layer of Fascines at Hollesley Bay, Coast of Suffolk.



Construction.

Foundation, of a double row of fascines of 12′ diameter; then, about 3 feet of shingle or pebbles

Tower.—3-inch elm plank

Masonry with inverted arches

Walls of brick with granite coping

Scale 24 feet to an inch

During the progress of the tower no settlement took place, and it now stands as an example of the advantages of the plan proposed.

I conceive that in the use of fascines, every care should be taken to render them compact; for brush-wood loosely placed, or fagots imperfectly made, will not answer. The failure of brush-wood in foundations was proved in constructing one of the Essex towers, as has been explained in Major-General Pasley's work on Practical Fortification.

I should add, that in 1810, at the siege of St. Maura, one of the Ionian Islands, fascines were used as a foundation to mortar platforms at my suggestion to the Commanding Royal Engineer, now Major-General Thackeray. The sleepers or joists were laid upon the fascines, and then planked in the usual way. This idea was suggested in the use of junk at the siege of Gibraltar for mortar platforms; the fascines answered as a substitute for junk, for the mortar platforms kept their level perfectly.

My first experience in the use of fascines in foundations occurred in 1800, when employed under Sir Thomas Page, at Chatham, in forming a hard way, as it was called, on the muddy banks of the Medway River, as a military communication from Chatham to Upnor.

These fascines having been placed in the mud forty years, wholly or partially buried, will give some information of importance, as to the durability of the materials employed in making fascines, and used in this way.

It has occurred to me likewise, that fascines, placed as under the tower at Hollesley Bay, would save considerable expense in planking and piling, and also as a bed for rail or tram roads over bogs and marshes.

I am, Sir, &c., &c.,

(Signed) G. G. Lewis.

Captain Denison, Royal Engineers.

Detail of some Experiments carried on in Her Majesty's Dock-yard, Woolwich, for the purpose of ascertaining the Resistance of Brick-work under various conditions.

An arch of brick in cement, the span of which was 6 feet in the clear, the rise in the centre 6 inches, the bricks being laid on edge so that the thickness of the arch throughout was $4\frac{1}{2}$ inches, was loaded on its extrados, which was made level with brick in cement, with iron ballast. The load was distributed over the whole area between the abutments, which, as the arch was 2 feet in width, amounted to $6 \times 2 = 12$ feet. Weights were added from day to day equally over the surface, until the total load amounted to 20 tons, or at the rate of 1 , ton per foot. The arch with this weight became twisted on the soffit. The spandril rose just over the abutment, but the arch did not fall; and as the weights were then piled up to a great height, it was thought advisable to remove them.

A new plan of constructing a fire-proof floor of brick in cement, between iron girders, was submitted to me by Mr. Fox, who is about to carry the plan into execution at Liverpool. The difference between this plan and that commonly adopted of turning an arch from girder to girder, consists in the arrangement of the bricks.

In Mr. Fox's plan these are placed on end, and the joints are all vertical. In the plan about to be carried into effect at Liverpool the girders are 10 feet apart. For a space of $4\frac{1}{2}$ feet in the centre of this interval the floor is 9 inches or 1 brick thick, formed of bricks on end; the upper surface of which forms the floor, the under surface the ceiling of the lower story. For a distance of $1\frac{1}{2}$ feet on each side of this central space the thickness is $1\frac{1}{2}$ bricks or 14 inches; the remainder of the space is 1′ 6″ or 2 bricks deep; the whole presenting an uniform upper surface for the floor. The iron girders which support this are connected together by wrought iron rods about 4 ¦ th apart from centre to centre, to resist any lateral thrust which might take place; and the first course or two of bricks on each side rest upon the lower flanges of these girders.

Mr. Fox sent to me the following statement of experiments made upon floors constructed upon this plan.

No. 1, girders 10 feet apart, arch 18 inches wide, and constructed as above described. It was loaded on the centre with 10 tons of pig iron, the base of this stack occupying a space about 3 feet in length. The arch deflected $\frac{5}{16}$ths of an inch with this load, but resumed its original position when the load was taken off.

No. 2 was similar to No. 1 in length and breadth, but was thinner, the centre part being only $4\frac{1}{2}$ inches deep, and the depth at the girder only 14 inches The arch was loaded with 15 tons of pig iron equally distributed, or with 1 ton per superficial foot; and after standing nearly three days, crushed and fell in.

Being struck with these results, I determined to make the experiment myself, omitting the iron tension rods, in order to get the actual power of the brick beam. I accordingly had one built 10 feet in length between two solid abutments of granite. At the abutments the depth was 18 inches, and this continued for six courses or about 18 inches; then the depth diminished to 1½ bricks, or 14 inches, for a length of eight courses, or nearly 2 feet; the remaining thirteen courses were 1 brick or 9 inches in depth; the joints at the abutment and those of all the bricks were vertical. The beam was 1′ 2″ wide at top; it was loaded two days after it was built with

	1¼ tons of iron ballast
On the 3rd day .	1½ ,, ,,
,, 4th ,, . . .	1 ,, ,,
,, 5th ,, .	2 ,, ,,
,, 6th ,,	4 ,,
Total	10 tons

On the fifth day a brick on edge was placed against the abutment under the springing of the beam, which diminished the bearing to 9·6 tons. With this load of 10 tons, or 17 cwt. per superficial foot, the brick-work gradually gave way, completely destroying the beam.

An arch of similar construction, but 1′ 6″ wide instead of 1′ 2″, was built in good mortar, and after remaining from the beginning of May to the 4th of July, was loaded in the same manner: in this case the load under which the arch gave way was 10¼ tons, or 14 cwt. per superficial foot.

A corbel of brick-work was let into a wall consisting of two courses of brick in cement, the total projection being 4½ inches. A plate was laid upon this corbel, and then a flooring of planks, supported at the other end upon blocks from the ground. The length of the corbel was 3 feet 6 inches, and the load placed upon the planks was 8½ tons, with which load the corbel broke short off.

The corbel in this case may be said to have given way under a load of 4¼ tons, or about 1 ton 4 cwt. per foot run. The utmost load, then, that a brick corbel composed of two courses of brick can be expected to bear with safety would be about one-half of this, or 12 cwt.; but this would be equal to any weight which would be placed upon a common floor.

W. D.

END OF VOL. VI.

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