with Ralph Tweddell's compliments

ON THE

HYDRAULIC MACHINERY

IN THE IRON SHIPBUILDING DEPARTMENT

OF THE

NAVAL DOCKYARD AT TOULON.

BY

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BY AUTHORITY OF THE COUNCIL.

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ON THE HYDRAULIC MACHINERY IN THE IRON SHIPBUILDING DEPARTMENT OF THE NAVAL DOCKYARD AT TOULON.

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In the course of the year 1874, the French Government decided to provide the port of Toulon with the means of building ships of iron and steel of the largest size, with the utmost degree of economy and despatch. For this purpose it was indispensable that the existing shops, which had been built and furnished with machinery in 1867, should be greatly extended. These shops had till then been sufficient for the construction of the ironwork for the extremities of the ships previously adopted for the French navy, in which the whole of the bottom, as well as the central portion of the sides throughout the extent covered with armour-plates, was still constructed of wood.

Having been commissioned to prepare plans for the new workshops, the author in the first place proceeded to England, in order to visit the royal dockyards and the leading private shipbuilding yards, with a view to profit by the experience acquired on the other side of the Channel in works of naval construction. His main object was to study the general arrangement of the most celebrated establishments, whilst at the same time he directed his attention to the most recent improvements in the tools employed there, as well as to the means used for facilitating or improving the work and for reducing the cost of manufacture.

Before leaving for England, the author had obtained valuable information with respect to the application of hydraulic pressure to machine tools intended almost exclusively for exerting a very considerable force through a very short stroke and for a very short time: such as machines for riveting, punching, and shearing, for

bending and straightening angle-irons and channel irons, and for bending, flanging, stamping, and corrugating iron plates, either hot or cold.

With the assistance of Mr. Ralph H. Tweddell of London, the author has been enabled to lay down works, the first he believes of their kind, where the plant consists exclusively of tools worked by hydraulic power, and where consequently there is absolutely no shafting. The Council of the Institution of Mechanical Engineers having expressed a desire that this novel arrangement of tools and machinery should be described, the author has much pleasure in responding to this desire, and, by permission of the Minister of Marine, in submitting the following observations.

As before stated, a workshop was already in existence at Toulon for the construction of the ironwork for the ships of the navy. This workshop, started in 1867, is shown at A in the general plan, Fig. 1, Plate 48. It was furnished with a heating furnace for plates and angle-irons, with cast-iron tables on which the angle-irons were bent, and with tools for planing, slotting, countersinking, drilling, punching, and shearing plates and angle-irons; in a word, with all the machinery necessary for preparing the materials for being put together on the slips. With the smith's shop, which then occupied, and still occupies, the portion D of a shed erected against the wall of the dockyard, the workshop referred to constituted the entire establishment for the construction of the ironwork of ships. This shop is 262 ft. 6 in. long by 131 ft. wide, and is divided longitudinally into four bays of 32 ft. 9 in. each, for which the roofs are supported on columns placed at intervals of 43 ft. 9 in. between centres.

It was proposed by the author to retain the existing workshop, and to occupy it exclusively with the tools then in stock, as well as with the new tools of the ordinary kind with continuous motion, which were needed to meet the additional requirements; and to build two new workshops, shown at B and C on the plan. The first of these B was to hold the furnaces, the cast-iron tables for bending angle-irons, and the drawing floors, together with the new hydraulic machines for punching, shearing, bending or stamping plates and angle-irons:

constituting in fact the new plate and angle-iron shop. The second shop C was designed to replace the old smith's shop D, which was insufficient in size and accommodation, its width being barely 36 ft. These proposals were approved by the Minister of Marine, and the construction of the new plate-iron shop was commenced immediately, at the same time that the first instalment of Mr. Tweddell's hydraulic tools was ordered from Mr. Henry Chapman.

The foregoing description, which is all that the limits of the paper allow, will suffice to give an idea of the general economy of the establishment, and the remainder of the paper will be devoted almost exclusively to the plate and angle-iron shop.

The plate and angle-iron shop is 377 ft. in length, and 164 ft. wide, divided into two bays of 82 ft. each by a row of columns 34 ft. 5 in. apart between centres. On the side next to the sea, the middle portion of the length is occupied by three reheating furnaces. Two of these are 59 ft. long by 5 ft. 3 in. wide, inside measure; and are more especially intended for angle-iron and channel-iron work. The third furnace is 52 ft. 6 in. in length by 6 ft. 7 in. wide, and is more especially intended for plate work. These furnaces are heated by gas on the system of Mr. Gorman of Glasgow; and are fitted at each end with the appurtenances necessary for working plates and channel-irons hot, that is to say, sand-boxes for use in moulding the plates, cast-iron plates for bending angle-irons and channel-irons, together with very large wooden floors or platforms, large enough to receive the full-size drawings of the frames for the largest ironclads.

The greater portion of the hydraulic machinery collected in the same shop occupies the side opposite to the furnaces. This machinery, as proposed and approved, comprises the following tools, the positions of which are indicated on the general plan, Plate 48.

E and F are two double machines for punching and shearing plates: one of them is shown in Figs. 2 and 3, Plate 49. Of these, the machine E is capable of dealing with the thickest plates which have as yet been brought into the shop, namely $1\frac{1}{4}$ in. thick and under. The other machine F deals with plates 1 in. thick and under. GG are two single machines for punching and shearing plates $\frac{5}{8}$ in. thick and under. H and I are two quadruple machines for

punching and shearing angle-irons; one of them is shown in Figs. 4 and 5, Plate 50. The machine H deals on one side with angle-irons $6\frac{1}{4} \times 6\frac{1}{4} \times \frac{5}{8}$ in. and under, and on the other side with angle-irons $5\frac{1}{2} \times 5\frac{1}{2} \times \frac{9}{16}$ in. and under. The other machine I deals with angle-irons $5\frac{1}{8} \times 5\frac{1}{8} \times \frac{1}{2}$ in. and under, and with those $4\frac{3}{8} \times 4\frac{3}{8} \times \frac{7}{16}$ in. and under.

J is a large vertical press with two pistons, of a length sufficient to take in plates 20 ft. long, available for bending garboard plates by means of rollers similar to those which are employed for the same purpose in machines worked by hand; and available also for doubling, bending, shaping, flanging, stamping, or corrugating iron plates, whether hot or cold, by the employment of suitable swages or dies. K is a large horizontal 100-ton press, for cold-bending channel-irons of the largest scantlings that have hitherto been employed in the French dockyards; these are double-T or channelled bars $13\frac{3}{4}$ in. $\times$ $6\frac{7}{8}$ in. $\times$ $\frac{25}{32}$ in. L is a similar press, of only 50 tons pressure, for bending channel-irons of medium sections, and also angle-irons of the largest sections. M M M are three 10-ton horizontal presses for bending, straightening, and bevelling angle-irons $6\frac{7}{8} \times 6\frac{7}{8} \times \frac{11}{16}$ in. and under. N N N are three similar presses, of only 5 tons pressure, for bending, straightening, and bevelling angle-irons $5\frac{1}{2} \times 5\frac{1}{2} \times \frac{9}{16}$ in. and under: one of these presses is shown in Figs. 6 and 7, Plate 51.

O O are two hydraulic cranes capable of lifting 3 tons, of the type usually employed at steel works, for taking the iron plates from the railway wagons to the furnaces, and thence, when heated, to the large garboard-bending machine. P P are two small three-cylinder hydraulic capstans, on Brotherhood's system, for introducing plates, angle-irons, and channel-irons into the furnaces, withdrawing them, placing them on the bending plates, and bending them there; as well as for moving all the railway wagons within the shop.

Such is the complete list of the tools and machinery intended for the plate department, as approved by the minister. Of these, several have already been at work for about a year.

To afford a complete notion of the importance of this collection of hydraulic machinery, it may be mentioned that it comprises in addition, outside the plate-iron shop, the following tools:—

Q, a fixed hydraulic riveting machine of Mr. Tweddell's ordinary type, of 40 tons pressure, with an effective gap of 6½ ft. This machine, placed at one end of the fitting-shop, is provided with a differential accumulator, and with special pumps driven by a belt from the shafting.

R is a large vertical press of 1000 tons, formerly employed for bending and straightening armour-plates, but not powerful enough for acting on the thicker plates in use at the present day. It is serviceable for all the various work requiring pressures greater than that of the other machines; for instance, for shearing very heavy angle-irons, for opening out wide apertures in the iron plates used in the new constructions, and for bending channel-irons of exceptionally large sections. This press, under the three pistons of which the pressure can be raised to 300 atmospheres, stands between the fitting-shop and the plate-shop; special pumps for its service are situated in the first of these shops and are driven from the shafting.

S and T are two of Tweddell's portable riveting machines. One, of the type B, is capable of closing rivets of ⅝ in. diameter at 17 in. from the edge of the plate, and ¾ in. rivets at 8 in. from the edge. The other, of the type C, is capable of closing ¾ in. rivets at 27 in. from the edge, or 1¼ in. rivets at 13 in. from the edge. These two machines, which are intended to be used on the shipbuilding slips, have been until now employed in the plate-shop while the water communications for working them are being completed, as well as the supports, carriages, and travelling-cranes by which they are to be worked.

With the exception of the fixed riveting machine Q and the large vertical press R of 1000 tons, all the hydraulic machines take their supply of water from cast-iron mains laid underground and fed by means of force-pumps, which are driven by a double-cylinder steam-engine of a maximum power of about 50 actual horse-power. Two accumulators, 14 in. diameter and with a stroke of 19½ ft., are employed to regulate the pressure of the water in the pipes; and they constitute a reserve of water sufficient at any moment to satisfy all

the demands that could be made at one time. The steam-engines, pumps, and accumulators are erected at one end U of the shed which contains the forges at present in use, and are entirely apart from the operations of the workshops.

There is at present only one set of pumps and steam-engines; but a second set has just been ordered, as a reserve in case of accident to the first. It has further been considered advisable to provide space for a third accumulator, as a reserve in cases where the first two may be insufficient. Such an eventuality is however very remote; the present stock of tools might be doubled or even trebled without involving an increase in the present supply of water under pressure; and probably there will be no need of a larger supply until the number of hydraulic machines, such as cranes, crabs, and capstans, is increased, as will very probably become needful.

The pressure of water in the pipes amounts to 1500 lb. per sq. in. These pipes, the course of which is indicated on the plan, Fig. 1, Plate 48, are of cast-iron, 2½ in. inside diameter; and they have been tested to double the regular working pressure, or 3000 lb. per sq. in. They are fitted with a number of branch pipes placed at intervals, not only for the supply of the tools at present in use, but also for the supply of any new tools that may hereafter be added. The pipes form a complete circuit, starting from the base of the accumulators and returning to them. The water under pressure is thus supplied to each machine by two different routes; this is a useful arrangement, for, in case of accidents or repairs, any particular portion of the pipes may be cut off from the circulation and isolated, by means of stop-valves, without interruption to the flow of water in the other portions of the pipes. The pipes within the workshop are thus divided by stop-valves into six nearly equal parts. Lastly, besides the escape valves or safety-valves which are placed at the foot of the accumulators and are eased by these when they reach the top of their stroke, there are two similar valves within the shop, intended to come into operation in cases where, through the simultaneous action of several machines of great power, the pressure may rise exceptionally high above the normal limit.

The water to be placed under pressure is conducted to the suction-valves of the pumps by cast-iron pipes leading direct from a plate-iron cistern, which holds nearly 4,400 gall., and is placed on the roof of the engine-house at a height of about 26 ft. above the suction-valves. The water thus arrives at the pumps under pressure—a condition which ensures the satisfactory performance of the pumps. In the same brick conduits which hold the pressure-pipes, and beneath these, are placed other cast-iron pipes of 3 in. diameter, proved to 175 lb. per sq. in., which receive all the discharged water from the machines, and return it to the reservoir over the engine-house. The same water is thus always employed, with the exception of the slight losses, which are made up with fresh water by means of one of the small donkey engines which are employed for feeding the boilers. That the pressure-water may be always as clean as possible—a point obviously of importance for the durability of the leather packings—the feed-tank for the pumps is divided by a partition into two distinct compartments; into one of these is delivered the water from the return-pipes, as well as that from the feed-pumps; while the other is solely supplied from the first by overfalls in the upper part of the partition. From this second compartment the water for the pressure-pumps is taken through strainers placed at a height of from 12 to 16 in. above the bottom. By this arrangement any foreign matter is enabled to settle in either the first or the second compartment, and there is very little probability that it should be drawn into the pumps.

As already stated, the large vertical press of 1000 tons and the fixed riveting machine are the only two tools which do not draw their supply of pressure-water from the main pipes. For the vertical press, which has been in operation for more than ten years, this exception is justified by the fact that the maximum pressure of 1000 tons is only attained with a pressure of about 4270 lb. per sq. in., for which its proportions were calculated; whereas with the normal pressure in the pipes of 1500 lb. per sq. in., only 350 tons gross pressure could be obtained, which is much below what can be utilised by this machine.

With the riveting machine the reason for the isolation is very different. It was placed in entire independence of the main pressure-

pipes, in order that it might be under the most favourable conditions for performing the work of riveting—conditions which differ entirely from those under which the operations of the other hydraulic machines are to be conducted. That this difference of conditions may be rightly understood, it is necessary to examine closely the nature of the work done in riveting on the one hand, and on the other hand the work done in punching, shearing, and bending.

When the die comes into contact with the hot rivet and drives it before it, the resistance during the first few instants of the stroke is comparatively feeble; but as the die advances, the resistance increases, not simply because the material of the rivet loses its malleability in cooling, but still more because, in closing the rivet, it is necessary not only to drive back the shank of the rivet upon itself, but also to squeeze it into the irregular cavities of the plates which are to be united, moulding it into all their interstices, and at the same time compressing in front of it the material of the plates themselves, which resists this intrusion of the rivet. In a properly constructed riveting machine therefore, the die ought to come up to the hot rivet without pressure, and then to exert on it an increasing pressure, equal at every instant to the force required, which is chiefly expended in following up the compression of the rivet. Finally, when the process is nearly completed and the cavities of the plates have been filled up, a pressure of still greater amount is necessary in order to force the material of the rivet into the smallest fissures of the plates.

The work of the punching, shearing, and bending machines, and generally of all the other machines which operate by pressure, is entirely different. It is not necessary in any of these machines to increase the pressure at the end of the stroke. On the contrary, the pressure should be maintained as nearly constant as possible during the whole of the operation, which does not demand any greater force at the end than at the beginning. For the work of punching, in fact, the order should be reversed, and advantage might be gained by considerably reducing the pressure during the last portion of the stroke, since it is by the first effort of the punch that the rupture of the plate is determined over a small cylindrical or conical surface, corresponding to the form of the punch and die, and since, after this rupture is once produced, much less force will evidently suffice for driving the burr out of the hole.

It is in recognition of the difference just pointed out that the riveting machine has been left unconnected with the pressure-pipes by which all the other machines are supplied, and has been provided with a special accumulator, called by Mr. Tweddell a "differential accumulator," of which the distinctive feature consists in employing a ram of extremely small area, so that the consumption of water necessary for closing a rivet in its place entails a considerable height of fall of the weights by which the apparatus is loaded, and thus these weights arrive at the end of the fall with a considerable velocity. This velocity is suddenly destroyed by the bringing up of the die upon the rivet, resulting in a blow precisely the same as that of a hydraulic ram, whereby the final pressure exerted by the die upon the rivet is materially increased, and that severe compression is produced which is necessary for making perfect riveted work. Moreover, whatever may be the actual relation between the force required and the length and transverse section of the rivets, it is evident that there must be a certain proportion between these elements, and that a greater pressure must be required for closing rivets of larger dimensions. Further it is evidently of great importance that the rivets should not be compressed beyond the needful limit, in order that they may not be placed in a state of tension when they cool down. By the employment of a special accumulator the great advantage is secured that the load on the accumulator, and consequently the pressure at the die, can be readily proportioned to the dimensions of the rivets.

For all the other machines which act by pressure, there would not only be no advantage in working them with special accumulators of small area, but on the contrary the larger the proportion of the useful area of the accumulator ram to that of the machine ram, the greater is the degree of regularity with which the machine does its work, preserving a uniform velocity during the different phases of the work to be done. It is in every respect preferable therefore that all the machines of this kind, collected in the same place, should be supplied from one system of pressure-pipes, connected with

accumulators having a total sectional area so large that their loads may never have to fall through more than a comparatively small height, and may never acquire too great a velocity. Under these conditions the system of water-pipes has been laid out in the workshops at Toulon.

The general arrangements of the hydraulic machinery having been described, some account will now be given of the manner in which the work of the different machines is performed, having regard to (1) the practical facilities for the execution of the work, (2) the excellence of the work itself, and (3) the economy which is effected by the employment of the hydraulic tools.

(1.) With regard to the practical facilities for the execution of the work, there is an evident advantage in hydraulic machinery over all machines which are driven by means of shafting. The latter machines, once started, repeat their stroke at regular and equal intervals, determined by the proportions of the gearing. A stroke once commenced must be completed, the attendant not having the power to arrest the machine. Take, for instance, a punching machine driven by shafting, in which the punch derives its movement from an eccentric in the ordinary manner. The attendant, it is true, can at pleasure engage or disengage the punch; but to do this he must take advantage of the ascending stroke, and having done so, a certain time elapses before the eccentric comes round and brings the punch down upon the plate. This is time lost, and it has its importance when repeated a very great number of times in the course of a day's work. Besides, after the down-stroke is once commenced, it must be completed; and if, after the punch is engaged, the attendant should find that the plate has been wrongly placed or has shifted its position, it is no longer in his power to stop the punch, and the hole is wrongly punched. With the hydraulic punching machine, on the contrary, the attendant exercises perfect control over the motion; and he can at any moment stop the punch whether it be rising or falling, so as either to reverse its movement or to continue in the same direction. Again, if the machine be at rest, it can be started instantly by a movement of the starting lever. This power of stopping the punch at any point of its stroke, even when it may have already come into contact with the plate, or made its mark on the surface, affords the means of absolutely preventing the production of false holes, since it becomes so easy to avoid their occurrence. The perfect and absolute control which the attendant thus exercises over the machine results in execution at once more expeditious and of better quality.

(2.) With regard to the excellence of the work itself, it is easily understood that, for the operations of punching, shearing, and bending, there is no difference between hydraulic machines and the ordinary machines driven by shafting, which are likely to be replaced by them. With equal range and power of the machines, the excellence of the work depends simply upon the quality of the materials under treatment, and on the form of the tools employed. It seems needless therefore to say more on this point with regard to machines for performing any of the above operations.

In the case of riveting and stamping machines on the contrary, there is a very great difference between those worked direct by steam and those worked by hydraulic pressure. This difference is altogether in favour of the hydraulic machines; and it arises from the fact that the steam machines act like steam-hammers—with a blow of greater or less force, the only effect of which is to strain the material operated on as well as the tool itself; whereas the latter machines perform the same work quietly and progressively, without shock, and without undue strain, either on the material or on the tool itself.

The author has been able on many occasions to examine great numbers of rivets, cut down through the middle after having been put in place by machines of different kinds. He has also made numerous experiments of the same kind at Toulon, to contrast the performance of the new hydraulic riveting machine with that of a Garforth steam-riveter which has been at work for several years in the same shop. The superiority of the work executed with the hydraulic machines has invariably been proved beyond dispute. But the special value of these machines is best exemplified in the closing of rivets of considerable length, such as those which are employed in the construction of iron bridges, where as many as six, eight, or ten thicknesses of plates are riveted together; or in closing the large rivets employed in riveting up the shells of cylindrical boilers of large dimensions; or finally in the closing of rivets in irregularly matched holes. In such cases the more gradual and at the same time more powerful and better sustained pressure, which can be applied by means of the hydraulic machine, is of the greatest importance. Even in such extreme cases, the substance of the rivets is compressed in such a manner as entirely to fill all the irregular cavities formed by the combination of holes in plates of differing thicknesses; whilst the plates themselves, however numerous, are always perfectly closed up.

(3.) With regard to the question of economy, though it is almost impossible to give absolutely precise data, there need be no doubt as to the important economical advantages to be derived from the substitution of hydraulic machinery for machines driven by shafting. As to the first cost, setting the outlay upon the accumulator and pumps against the cost of shafting and its fittings, including belts and steam-power, it appears certain that the outlay in the latter case must be the greater. But even supposing the respective outlays to be equal, there remain the tools themselves, reduced on the one hand to forms of extreme simplicity, namely hydraulic cylinders fixed on the simplest possible framing, as illustrated by the accompanying drawings: while on the other hand there are a number of complicated details—shafts, flywheels, toothed-gearing, eccentrics, &c. On the one hand the machines are constructed almost entirely of large castings, or of pieces fitted together in a very simple manner, with a very limited number of forgings and brass pieces; on the other hand there are a great number of pieces requiring careful finishing and fitting, with comparatively complicated and therefore more costly framing. On the one hand foundations are almost entirely dispensed with, being rendered unnecessary in consequence of the absence of all the vibrations incident to sudden blows and rapid movements; on the other hand there is the necessity for foundations more or less solid and deep, to resist the continual vibrations caused by the movements of heavy pieces set in motion at high speeds.

The conclusion to be drawn from the foregoing comparison cannot be doubtful; and although the author is not in a position to prove it exhaustively—inasmuch as this would require the preparation of complete designs and estimates for two similar workshops fitted with machinery of the two different classes respectively—yet the benefits which may legitimately be expected by Mr. Tweddell from his system ought certainly to be very considerable, even if they were limited to the comparative cost of machinery on the two systems.

In the foregoing comparison it has been assumed that the ordinary machinery is driven by a single steam-engine, through a system of shafting. On this supposition the argument was the more conclusive, inasmuch as it is generally admitted that a system of tools, all of which derive their motive power from a single source, costs less than a system of independent tools, driven each separately by a small special steam-engine, and having nothing but the main steam-pipe in common. The intermediate system, according to which some of the largest tools only are driven by special engines, is evidently the most costly of all; since it involves the double provision of a principal engine with shafting, and also of special separate engines with a common steam-pipe to supply them all.

It has also been assumed that the boiler power is the same, whatever the system employed for the transmission and distribution of the driving power. But it will now be shown that this is by no means the case, and that much less boiler power is required for the employment of water as the motive agent. By the employment of an accumulator, or reservoir of water under pressure, available for all the tools in the workshop, a force may be exerted at any given moment, much greater than that which can be exerted in the same time by the engine producing the power. As all the tools in the workshop may be at work simultaneously, it is indispensable that, if the power is supplied through shafting, the boilers should be of sufficient power to generate at any time the whole of the steam required to drive, not only all the individual tools, but also the whole of the shafting; or, if each tool is driven by its own special engine, the boilers must be capable of making good the losses by leakage, and by condensation in the pipes and the steam-cylinders. With hydraulic machinery on the contrary the required boiler-power and engine-power may be considerably less than the gross power required for working all the tools at once; and so much the less as the available quantity of water under pressure in the accumulator is the greater.

Suppose for example that, in order to maintain the load of the accumulator at a constant height while all the tools are in full work at once, a force of 100 horse-power is required for working the pumps; and suppose also that each of the tools is actively at work for 2 hours out of a day of 10 hours, which is a very exaggerated estimate, since it implies that each machine would make 720 strokes of 10 seconds each, or 1440 strokes of 5 seconds each. On these suppositions, pumps working uniformly for 10 hours, and driven by a force of $100 \times \frac{2}{10} = 20$ horse-power, would suffice to deliver into the accumulator a quantity of water equal to that which might be required during the day for all the tools. Further, if the pumps were kept at work continuously night and day, the power required for the day's work of the tools would be reduced to $100 \times \frac{2}{24}$, or less than 10 horse-power: on the assumption of course that the accumulator was of so large capacity as never to empty itself entirely, even in the longest periods during which all the tools might have to be in full action simultaneously. Pushing the argument to an extreme, in order to illustrate more fully the advantages of the accumulation of motive power, an accumulator may be conceived capacious enough to hold a week's or even a month's supply of water under pressure. And though the proportions necessary for accomplishing such an abnormal scheme would not be feasible with artificial accumulators charged by mechanical power, the case of a natural supply from a high-level basin is a very possible one: if the capacity of such a reservoir were sufficiently extensive, the supply stored in it from the winter's rains or melted snow might suffice for the whole year round.

It must not be assumed that the foregoing calculations for a reduction of horse-power by augmenting the capacity of the accumulator are exaggerated. To dispel any such idea, it will be sufficient to glance at the appended Table, in which a general summary is given of the working conditions of the hydraulic machinery originally proposed by the author for the plate and angle-iron shop at Toulon Dockyard. By means of this Table he was enabled to determine the power of the pumps, the engines, and the boilers, as well as the dimensions of the accumulators. The figures are now open to some modifications, partly on account of several important additions which have been made to the original scheme of machinery; partly by reason of various alterations made at the time of construction of the different machines in the diameters and strokes of their rams; and partly because the engine-power has been increased with a view to meet future requirements. These modifications however would not affect the force of the interesting conclusions which may be deduced from the Table.

A few words of explanation may be added with respect to the determination of the figures given in columns 5 and 8 of the Table, namely the stroke and pressure necessary in each instance for the performance of the maximum duty assigned to the machine. The strokes have been fixed empirically, taking as a standard the actual strokes of ordinary machines driven by shafting, and working under good conditions. The pressures in the punching and the shearing machines have been calculated by multiplying the superficial area in square inches of the maximum section to be punched or sheared, by the force necessary to punch or shear a section of one square inch: a force which is theoretically equal to the direct tensile resistance of an equal section, but is in reality a little less, in the proportion of about 30 to 36, because, before yielding to shearing stress, the material is always more or less compressed, and the section to be sheared is by so much reduced. The pressures reckoned for the flanging and bending machines have been deduced from the experimental data furnished by the ordinary tools employed for the same operations, and from the results given by the ordinary formula for the transverse resistance of pieces to bending. It may be added that the pressures thus estimated beforehand have been found to be perfectly proportioned for the work to be done in all the machines that have as yet been put to work.

In regard to the other columns in the Table, it is assumed in the first place that each machine has always to perform its maximum duty, although such a condition is exceptional. It is also assumed that there are very considerable losses of work: whether by leakages of water, which have been taken at one-tenth of the total volume of water drawn from the accumulators: or by the frictional resistances of the leather packings and the mechanism, and of the water in the pipes, which have been taken together at one-third of the total work done by the prime-mover. It has been assumed finally that all the machines in the workshop are in a state of continuous activity, which will certainly never be realised, some of the machines being supposed to work up to 1200 strokes per day of 10 hours. Taken together, these extreme assumptions lead to 643,375,350 ft.-lbs. (column 13) as the total maximum work to be supplied by the engine per day of ten hours: equivalent to 33 horse-power, supposing that the engine works regularly and uniformly for the whole of that time.

The maximum amount of work which can be expended by the whole of the machines together at any given time is found in column 10 of the Table, which shows that the work corresponding to one stroke of the rams of all the machines, performing simultaneously the hardest work they are capable of, amounts to 2,327,760 ft.-lbs. This work may be supposed to be performed in 10 seconds, which is nearly the average period of the movements of all the machines; it corresponds to 232,776 ft.-lbs. per second, or 423 horse-power. One machine alone, the garboard-bending press, is capable of expending 455,679 ft.-lbs. for one stroke, or about 45,568 ft.-lbs. per second, equivalent to 83 horse-power.

From these data it will be clearly seen what an enormous disproportion may exist, for a collection of hydraulic machines like those in question, between the power of the prime mover and the sum of the powers which can be exerted by the several machines at any given moment. It is obvious that, if these machines were driven either by means of shafting or by small special engines, the power of the single prime mover, or the united power of the special engines, as the case might be, must be equal to the sum of the maximum powers capable of being exerted simultaneously by the different machines: that is to say, to a power of nearly 430 horse-power in the example under consideration; assuming only that the magnitude of the losses of work during the periods of effective action of the machines remains the same, whatever may be the system of transmission employed.

It remains to ascertain whether the total reserve of work stored up in the accumulators would be sufficient to supply the maximum united demand for power as calculated above, amounting to 2,327,760 ft.-lbs. The total load of the two accumulators, amounting to 460,351 lbs., supplies 460,351 ft.-lbs. of work per foot of fall. It is necessary therefore that the load should fall through $\frac{2,327,760}{460,351} =$ 5·05 ft., to supply the quantity of work requisite for driving all the machines under the supposed condition of simultaneous performance. But the total fall of the accumulators is equal to 19·7 ft., amounting to nearly four times (exactly 3·89 times) the fall of 5·05 ft. necessary for the maximum performance assumed. If therefore the accumulators be taken at the top of their stroke, they would be capable of performing the maximum work four times consecutively; expending in a few seconds the very large quantity of work $2,327,760 \times 3{\cdot}89 =$ 9,054,986 ft.-lbs., before the relatively small pumping-engine of 33 horse-power would become sensibly insufficient. Furthermore the accumulators could be pumped up again to the top of their stroke in less than $8\frac{1}{2}$ minutes, supposing that the machines after their abnormal performance were to remain at rest during that time. If on the contrary it be supposed that the machines, instead of making four strokes consecutively, remain at rest after each stroke, the pumps having then to raise the accumulators through only 5·05 ft. would accomplish this in only 2 minutes 10 seconds. The evidence of such calculations appears conclusive in favour of the hydraulic machine-tools, and nothing more need be added in that line of argument.

Evidence in favour of the economy in cost of maintenance and of working of the hydraulic machines is also brought out by a

comparison of the two kinds of machines. It has been shown that with hydraulic machinery, by means of an accumulator of sufficient size, the power of the engine, and therefore also the power of the boiler, can be considerably reduced, say in the ratio of 4 to 1 when the pumps are kept working during the whole of the day's work of 10 hours. Now even if it be true theoretically that a 20 horse-power boiler working for 10 hours ought to produce exactly the same quantity of steam, and therefore to consume the same quantity of fuel, as a boiler of 100 horse-power working for 2 hours only, such as would be necessary for working all the machines by means of shafting, yet nothing is farther from the truth in actual practice. In reality, although the 100 horse-power boiler would only have to work intermittently during very short periods of time, it must nevertheless be kept constantly under steam, with the fires alight and in condition to be forced, in readiness to furnish the whole supply of steam that can be required at any given moment. Hence there is a continual consumption of fuel, more or less, even while absolutely no work is being done. Even in respect therefore of cost of working, it is more profitable that so desultory a mode of supplying steam should be replaced by a prime-mover of less power, but kept regularly at work in as uniform a manner as possible, and producing the same total quantity of work per day.

Another economical advantage of hydraulic machines consists in this, that they absolutely do not consume any work at all during the intervals between active employment. With ordinary machinery, whether driven by shafting or by small special engines, it is otherwise. Shafting must be constantly in motion, though it be only for the purpose of driving the most insignificant tool in the shop; and it absorbs, by its mass, its friction, its vibration, its heating, in a word by all its unavoidable imperfections, a very considerable proportion of the power of the steam generated in the boiler. In the case of a collection of tools driven by special small engines, there is the loss of heat by the cooling of those which are at rest, and of the branch steam-pipes belonging to them, which is quite as considerable as the loss with shafting. When, after an interval of rest, one of the tools so driven is to be started, the cylinder-cocks must be opened, and all the water which escapes from these before dry steam shows itself represents the quantity of work absorbed by condensation during the period of rest. Even then the tool is not immediately ready for work, and it is necessary to wait until the speed has been got up sufficiently for performing the work to be done.

A hydraulic machine on the contrary is always ready, and it continues ready for working at any moment without any consumption of power. By moving the lever of a valve, the machine acts immediately at full power. Whilst at rest, provided that there are no leakages at the joints of the pipes or at the packings—and any such leakages are always very easily detected and stopped—such a machine consumes absolutely nothing, not even for lubrication or for maintenance, since all its parts without exception are absolutely at rest, and are not subject to any friction or wear. Suppose again that several of the machines are stopped at the same time, the load of the ascending accumulator soon acts on the shut-off steam-valve, gradually closing it and thus reducing the speed of the engines, until when the accumulator is full they come to rest.

To sum up, the most important source of economy in working, to be effected by the employment of hydraulic machines, consists in this, that they expend absolutely nothing when not at work; and the importance of this economy is due to the relatively long intervals of rest, which for each machine amount to by far the greater part of the working day, even when the machine is constantly employed. For instance, take one of the punching machines referred to in the table as capable of punching 1200 holes per day. This is certainly a maximum performance, which will very rarely be attained, as it supposes an average of 120 holes per hour or 2 holes per minute. Moreover the duration of each stroke cannot be taken at more than 5 seconds; so that the total time in movement would amount to about 6000 seconds for the working day, that is to say 1 hour 40 minutes out of 10 hours, or less than one-fifth of the total working day. On the contrary, in order to be always ready for work, ordinary machines driven by shafting must be constantly in motion, thus incurring a certain expenditure of power. This obviously makes a great point in favour of the hydraulic machines, in addition to the advantage

arising from the principle of the accumulator, namely that the whole power required for the day's work can be supplied by a relatively small prime-mover working as regularly as possible.

In comparison with the great economy arising from the two sources just noticed, that which may result from the more or less satisfactory manner in which the power is conveyed and transformed into useful work, at the precise moment at which the work is done, is but secondary; and, even if the hydraulic machines were inferior in this respect to ordinary machines, this inferiority would be largely compensated by the economical advantages before-named.

It is to be regretted that hitherto no experiments have been made precise and complete enough to determine exactly the comparative economical conditions of the performance of two sets of machine-tools, of the same capacity, one of them driven by shafting, and the other by hydraulic power; that is to say, to determine exactly in each case the total quantity of motive power supplied by the boiler, and the sum of the useful work done in a day. Although such experiments have not yet been made, it may be admitted, for example, that hydraulic machines which have to act through a stroke of considerable length, and consequently while the water is in motion within the pipes, are subject to greater losses during the periods of work—by friction and eddies in the pipes—than machines driven by shafting. This is the case in regard to cranes, crabs, and capstans, for instance; and still more so if water be employed for driving continuous tools, such as lathes, planing machines, drilling machines, &c. It can be shown, on the contrary that, to machines exerting a considerable pressure during a very short stroke, the same objection can scarcely be applied; and that they consequently possess in this respect very important economical advantages, even when compared with hydraulic machines of another kind.

Reverting, for instance, to the punching machine, suppose that it is employed to punch a plate of the maximum thickness suited to its power; the starting valve is opened, the ram descends, and descends at a very moderate velocity, sensibly uniform, until the punch touches the plate. From the fact of the uniformity of the velocity during what may be distinguished as the useless portion of the stroke, it may be inferred that the moving force is just balanced by the resistances, although these resistances consist thus far of nothing more than the friction of the leather packings, and the friction and eddies of the water in the pipes and cylinder. It follows that the whole of the moving force is, under the circumstances, absorbed by these resistances; and that it would be impossible for the machine to perform any useful work whatever at the same velocity. But from the moment that the punch touches the plate, its forward movement, if not entirely arrested, is at least considerably reduced in velocity; consequently the friction of the water and the packings is likewise considerably reduced,—even to nothing if the motion cease entirely, as may happen when the plate is too thick for the punch to pass through it. In such a case, equilibrium of pressure between the interior of the accumulator and the interior of the cylinder is established without any loss. When all motion ceases, there is no longer any friction, or any loss of work, and in reality the whole of the moving power becomes available for the execution of the useful work. In other words, the limit of the useful power of the machine is really and truly that measured by the product of the effective sectional area of the ram carrying the punch, multiplied by the pressure per unit of surface of the water stored in the accumulators. No doubt, after having been brought perhaps absolutely to a state of rest for a very short space of time on the surface of the plate, the punch is set in motion again with a certain velocity to pass through the plate; but this velocity necessarily continues so low that the resistances of friction absorb but an insignificant fraction of the motive power: so that practically the power may be considered entirely available for performing useful work.

It thus appears that it is a characteristic peculiar to hydraulic machines worked by very high pressures and with very short strokes, —and a highly valuable characteristic,—that they do not involve any appreciable loss of power during the periods of performing the useful work which they have to do. This characteristic is not to be found in any other class of machinery: not even in hydraulic

machinery, such as lifts, cranes, crabs, and other machines, in which the useful work is being done whilst the water is traversing the pipes at a relatively great speed, and where consequently only such fraction of the motive power is available for useful work as is not absorbed by the friction of the packings and of the water in the pipes. The employment of water under pressure is therefore most satisfactory and most rational when it is effected in machine-tools of the kind under consideration; and it might well be matter of surprise that this application was not the first to be adopted, were it not well known by experience that the simplest ideas are sometimes very difficult to discover and to realise in a truly practical form.

In the machines now under notice, and in these only, the losses of power are reduced absolutely to nothing during the periods of repose; and practically to nothing also during the periods of useful action. It is only during the intervening periods—during the useless portion of the downstroke and during the whole of the upstroke—that losses of power of any importance take place. But even these periods of time, the total length of which is always very short, can be reduced to the absolute minimum that is necessary by means of the ingenious arrangement of tappet motion applied by Mr. Tweddell to all his hydraulic machine-tools.

This very simple appliance is shown at VV in Figs. 2 to 7, Plates 49 to 51. It consists of a vertical screwed rod, the upper end of which is pinned to the starting-lever, and the lower end passes through an eye in the extremity of a horizontal arm carried by the ram of the machine; on the screw are fixed two nuts, one above and one below the arm. When the ram ascends, the arm rising strikes the upper nut on the screw, and acts on the starting-lever with a force much greater than the attendant is capable of exerting; by this movement the exhaust-valve is closed, thereby arresting the upstroke of the ram, even against the will of the attendant. When on the contrary the arm descends with the ram, it strikes the lower nut on the screw, the starting-valve is closed, and the descending stroke of the ram is arrested. It is obvious that the length of stroke, either upwards or downwards, may be regulated at will by means of the two nuts on the screwed rod, so as to limit the stroke of the machine to the length which is strictly sufficient for the execution of the work to be done.

By means of the adjustable appliance just described, the only periods of time during which the losses of moving power are of any moment are reduced within very narrow limits; and the remarkable result may be attained of having a set of hydraulic machine-tools working practically without any other loss of power than that which is incurred by the working of the prime mover and the force-pumps which are driven by it.

It may be thought that it has been solely by a series of theoretical inductions that the author has been led to appreciate the last advantage which has just been pointed out in favour of hydraulic machine-tools of very high pressure and very short stroke, namely the entire absence of loss of power at the moment when the maximum useful work is to be performed. It was not so in fact, for neither Mr. Tweddell nor the author had even suspected the existence of this element of superiority until it was revealed to the author by experiment alone, and more particularly by an examination of the indicator diagrams which he was enabled to take from the cylinders of the hydraulic machines while they were in operation. These curves are particularly interesting, and the author may be permitted to conclude with a few words upon this subject.

A Richards indicator was used for taking the diagrams, several of which are shown in Plates 52 to 55. It was modified so as to measure pressures amounting to 2250 lb. and 3000 lb. per sq. in. by means of the ordinary springs. The modification was effected by replacing the steam-cylinder of the instrument by a new cylinder of much smaller sectional area, with a small hydraulic piston packed with doe-skin; the ratio of the section of the new cylinder to that of the old one being known, it was easy to calculate the scale of pressures corresponding to each of the springs belonging to the indicator.

The specimen diagrams shown in Plates 52 to 55 were taken from the hydraulic cylinders of machine-tools of six different types, namely:—

A riveting machine, Plate 52, Figs. 9 to 15.
A punching machine, Plate 53, Figs. 16 to 21.
An angle-iron shearing machine, Plate 53, Figs. 22 to 32.
A plate shearing machine, Plate 54, Figs. 33 to 38.
An angle-iron bending machine, Plate 54, Figs. 39 to 44.
A machine for flanging plates whilst hot, Plate 55, Figs. 45 to 50.

The diagrams taken from the Riveting machine, Plate 52, all possess, as may be seen, the same general form. After the horizontal part, which corresponds to the period during which the machine has no useful work to perform, the pressure gradually rises, at an almost uniform rate, until the closing of the rivet is completed. This period is nevertheless divisible into two distinct phases, the second being distinguished from the first by a more rapid augmentation of pressure. But, though this character is visible on several of the curves taken from the riveting machine, it cannot be said that it is quite a constant feature; and it is still therefore somewhat doubtful whether there exist in reality two different phases of work, during the first of which the stem of the rivet would be simply driven in, little by little, upon itself, while during the second the head would be formed, and the material of the rivet would be forced into the cavities, more or less irregular, of the plates to be united.

The same curves furthermore show clearly that, after the period which corresponds to the closing of the rivet, the pressure continues to increase, but much more rapidly than before, till it arrives at a maximum which corresponds not merely to the statical pressure due to the load on the accumulator and the area of the ram of the machine, but to the dynamic effect produced by the sudden arrest of the load on the accumulator. By virtue of this sudden stoppage, the actual force exerted by the die at the end of the stroke may amount, as is seen in the diagrams, to as much as one and a half times the force due to the statical pressure simply. When the accumulator is loaded with its twelve weights, Fig. 9, the pressure in the cylinder of the machine may thus mount up to 2560 lb. per sq. in., whilst the statical pressure corresponding to the load on the accumulator does not exceed 1590 lb. per sq. in.

The last part of the diagram, corresponding to the period during which the pressure rises most rapidly to the maximum produced by the ram-like blow just referred to, does not represent any further work done in the closing of the rivet, but only the resistance opposed to the motion of the die by the plates, which absolutely arrest its movement. This then is not a period of useful work; and if the edges of the die be sharp, it may even leave its imprint upon the plate around the rivet-head, thereby reducing its thickness and diminishing by so much its power of resistance. It is therefore very desirable to suppress this period corresponding to the last part of the diagram. This object may be accomplished by reducing in each case the number of weights on the accumulator, so that the maximum force exerted by the machine may be only what is strictly necessary for completely compressing the rivet, without the subsequent exertion of compressive force which is sustained only by the plates.

The general character of the indicator diagrams taken from the Punching machine, Plate 53, Figs. 16 to 21, is quite different from that of the diagrams taken from the riveting machine. When the punch comes in contact with the plate, its motion is nearly stopped, and the pressure rises until it reaches the amount necessary to shear the plate around the punch; this done, the pressure falls again almost as rapidly as it rose, the punch having then only to push the burr out of the hole.

For the punching machine, as for all the machines which are driven by the water from the general main, the maximum indicated pressure does not correspond to the constant pressure of the accumulators, but only to what is strictly necessary for performing the actual work required from the machine. As the total work expended is always measured by the volume of water consumed under pressure, that is, by the product of the area of the ram of the machine multiplied by the length of its stroke, it is easy to see that the ratio

of the useful work done to the total work expended may be very small, and proportionally smaller as the useful work required from the machine is below the maximum work of which it is capable. But this fault is not peculiar to hydraulic machines, and it is largely compensated in these machines by the smallness of the total quantity of moving power which they require during a whole day, even with the greatest activity. Be that as it may, far from being greater than the statical pressure corresponding to the dimensions of the ram and the load on the accumulator, as in the case of the riveting machine, the maximum pressure indicated by the diagrams taken from most of the other machines remains always less than this statical pressure. It approaches the statical pressure more and more as the work required from the machine approaches the maximum work of which it is capable; but it only attains to that pressure when the machine is absolutely brought to a state of rest, that is to say, when the work demanded from the machine is above its capacity.

The diagrams from the Angle-Iron Shearing machines, Plate 53, Figs. 22 to 32, are very similar to those from the punching machine. The similarity is explained by the arrangement of the blades of the shearing machine, in which the two edges of the moving blade are nearly parallel to the corresponding edges of the fixed blade, so that the angle-iron is sheared simultaneously through its whole section at once. If the edges of the fixed blade made a greater angle with the edges of the moving blade, as in the plate-shearing machines, the diagrams would have assumed another form, indicating a constant pressure during a certain time. The inclined arrangement of the blades, as generally adopted in French practice for the plate-shearing machines, has the disadvantage of considerably deforming the part of the angle-iron which sustains the force of the blade. It admits, it is true, of a reduction in the maximum force exerted by the tool in shearing an angle-iron of given section; but this advantage—which is not without its value for machines driven by shafting, which may thus be made lighter—is of much less importance for hydraulic machines, in which it is nearly a matter of indifference whether the total work to be done, which is always the same, is performed with a stroke nearly nil and a ram of large diameter, or on the contrary with a longer stroke and smaller ram.

The diagrams from the Plate Shearing machine, Plate 54, Figs. 33 to 38, in which the cutting blade has a certain degree of inclination to the fixed blade, are of another character. Without referring to the part which corresponds to the useless portion of the stroke, these curves contain at least two other very distinct parts. Of these, the first corresponds to the period of work during which the pressure exerted by the blade continues to increase in proportion as the section attacked becomes larger and larger. The second part, indicating a constant pressure, represents the period during which the section attacked continues constant. This part of the curve is the last part in the case in which the plate is so wide that it is not sheared right across at one stroke. If on the contrary the plate is narrow enough to be sheared right across at one stroke, the diagram is terminated by a third part, Fig. 33, in which the pressure gradually diminishes as the section attacked becomes less and less.

The diagrams from the Angle-Iron Bending machines, Plate 54, Figs. 39 to 44, belong to the same general type as those from the plate shearing machine. They indicate, like the last, a period during which the pressure gradually increases, corresponding to the period during which the limit of elasticity has not been reached. When this limit is passed, the pressure necessary for increasing the curvature of the angle-iron continues nearly constant: the irregularities shown in the diagrams arise simply from the momentary fluctuations of pressure produced by the sudden shiftings of the angle-iron, which there is much difficulty in keeping absolutely steady between the blocks bearing against it.

Lastly, the diagrams taken from the Plate Flanging machine, Plate 55, are particularly interesting in this respect, that they show what a small quantity of power is required for this kind of work. These diagrams were taken during the flanging of steel plates $\frac{1}{3}$ inch thick, intended to be divided down the middle into two equal parts, and designed for making tight the joints of the longitudinal bulkheads of the new ships, around the cross beams of double T section by which they are traversed. The form of the pieces under consideration is that of an irregular rectangle, as shown in Figs. 51 and 52, Plate 55, 12 in. by 14 in., with a $3\frac{1}{8}$ in. flange all round the sides. The flange is at right angles to the plate, and is recessed at the corners, so as to fit exactly upon the double T irons, within which these pieces are to be lodged. The work has not been done under the most favourable conditions possible, since the plates, after having been heated, had to be carried some distance from the furnace to the machine, and their temperature fell in consequence to that of a dull red heat before they could be placed in the machine. Notwithstanding these unfavourable conditions, it is apparent from the diagrams that the pressure required for flanging such plates at a single operation is not more than a third or a fourth of the total pressure which can be exerted by the ram of the machine. It follows that the same work could easily have been done in a machine of a third or a fourth of the power; say by a press of 40 or 50 tons—the ram of the machine that was actually employed being capable of exerting a pressure of 160 tons.

The diagrams from the plate flanging machine further show that at the end of the period of useful work, when the angle of the flange has been formed, and it is only required to sink the piece more and more until it arrives at the bottom of the matrix, the pressure exerted by the die or stamp diminishes considerably, and in a very gradual manner. These diagrams also show that, when once the useful work is completed, the machine, like the riveting machine, is brought to a dead stand, and that the pressure in the cylinder then rises very rapidly to the maximum which corresponds to the dimensions and pressure of the accumulator. In this case also, as in that of the riveting machine, it would be well to reduce the power of the machine to that which is strictly necessary for the accomplishment of the work to be done.

TABLE.—GENERAL WORKING CONDITIONS OF THE HYDRAULIC MACHINES PROPOSED FOR THE NEW WORKSHOP FOR BUILDING IRON SHIPS, AT TOULON NAVAL DOCKYARD.

Name of Machine.	2. Order Number of each Machine.	3. Effective Diameter of Ram.	4. Effective Area of Ram.	5. Maximum Stroke of Ram.	6. Maximum Volume of Water per stroke of ram. Taken by Machine.	7. Maximum Volume of Water per stroke of ram. Expended from Accumulator.	8. Effective Pressure transmitted by Ram.	9. Maximum Work per stroke of ram. Done by Machine.	10. Maximum Work per stroke of ram. Expended by Prime Mover.	11. Maximum per Day of 10 Hours. Strokes of Ram.	12. Maximum per Day of 10 Hours. Water Expended.	13. Maximum per Day of 10 Hours. Work Expended.
		Inches.	Sq. ins.	Inches.	Cubic inches.	Cubic inches.	Tons.	Foot-lbs.	Foot-lbs.	Strokes.	Cub. feet.	Foot-lbs.
Plate Punching Machine (Plate 49).	1	9·93	77·50	3·15	244·10	268·51	49·21	28,932	43,398	1,200	188·33	52,077,600
	2	14·05	155·00	3·94	610·25	677·38	98·42	72,330	108,495	600	235·45	65,097,000
Plate Shearing Machine (Plate 49).	1	9·93	77·50	6·30	488·20	543·12	49·21	57,864	86,796	500	156·94	43,398,000
	2	14·05	155·00	7·87	1,220·50	1,354·75	98·42	144,660	216,990	250	196·21	54,247,500
Angle-iron Shearing Machine (Plate 50).	1	9·93	77·50	5·51	427·17	476·00	49·21	50,631	75,947	500	137·34	37,973,250
	2	12·17	116·25	6·69	775·02	866·56	73·81	92,221	138,331	400	200·14	55,332,450
	3	14·05	155·00	7·87	1,220·50	1,354·75	98·42	144,660	216,990	300	235·45	65,097,000
	4	17·21	232·50	9·45	2,169·90	2,441·00	147·63	260,388	390,582	200	282·53	78,116,400
Angle-iron Punching Machine (Plate 50).	1	7·02	38·75	2·36	91·54	103·74	24·60	10,849	16,274	1,200	70·63	19,529,100
	2	7·02	38·75	2·36	91·54	103·74	24·60	10,849	16,274	1,200	70·63	19,529,100
	3	8·88	62·00	2·76	170·87	189·18	39·37	20,252	30,379	1,000	109·86	30,378,600
	4	9·93	77·50	3·15	244·10	268·51	49·21	28,932	43,398	800	125·58	34,718,400
Plate Flanging Machine	1	15·39	186·00	13·78	2,563·05	2,849·87	118·10	303,786	455,679	50	82·39	22,783,950
Channel-iron Bending Machine (Plate 51).	1	14·05	155·00	11·81	1,830·75	2,032·13	98·42	216,990	325,485	100	117·71	32,548,500
	2	9·93	77·50	11·81	915·38	1,019·12	49·21	108,495	162,742	200	117·71	32,548,500
					13,089·87	14,548·36		1,551,839	2,327,760	8,500	2326·90	643,375,350

Observations.

(7.) The volume of water expended per stroke of ram has been calculated in each instance on the assumption that the loss of water is equal to one-ninth of the volume described by the ram; that is, to one-tenth of the total volume expended from the accumulator per stroke of ram of machine.

(8.) Pressure of Water in the pipes, 1500 lb. per sq. in.

(10.) The maximum work expended per stroke of ram has been calculated on the assumption that the losses of work are equal to half the useful work done by the machine; that is, to one-third of the total work expended by the prime mover.

(11.) The figures in this column are taken on the supposition that the work of the shop is extraordinarily active: a condition which will but very rarely be attained.

Leading Particulars of the Accumulators.

Number of accumulators	2
Diameter of rams	13·98 inches.
Stroke of rams	19·69 feet.
Area of each ram	153·42 sq. ins.
Total load on each accumulator	102·8 tons.
Total work in each accumulator, full	4,530,230 ft.-lbs.
Total work in both accumulators, full	9,060,460 ft.-lbs.
Height of fall of the two accumulators for one stroke of all the machines simultaneously	5·05 feet.

The two accumulators, when filled, are sufficient for nearly 4 similar discharges (exactly 3·89), even if the pumps are not at work.

GENERAL SUMMARY FOR ONE DAY OF 10 HOURS.

Maximum Volume of Water expended, or Duty of force-pumps—

Per hour	232·59 cub. ft.	
Per minute	3·88 „	
Per second	0·065 „	
Duty of the pumps ordered...	0·106 „	per second.
	6·36 „	per minute.

Maximum Work expended per min., or Power of prime mover—

In foot-pounds	1,072,292 ft.-lbs.
In horse-power	32·49 H.P.
Power of the engine ordered	50 H.P.

Composition of the Total Work expended during the day—

	Ft.-lbs.		Per cent.
Work in the water utilised	428,916,900	or	66·667
Work in the water lost	47,654,812		7·407
Work in the total volume of water expended	476,571,712		74·074
Sundry other losses	166,803,638		25·926
Total Work expended by prime mover	643,375,350	or	100·000

In conclusion, the author may add that, although he has already taken a large number of indicator diagrams from these hydraulic machines, he has not yet had time to investigate them with all the attention they deserve, or even to have them calculated out so completely as to be enabled to deduce from them all the information they appear to him capable of affording. These diagrams however appear to him to be of so much interest that he hopes to be excused for having submitted some examples of them to the notice of the members, notwithstanding their present very imperfect condition.

The President said that M. Berrier-Fontaine had found it impossible to be present, being just now in Scotland; but Mr. Tweddell was fortunately able to take his place, and it might be convenient if, before the discussion took place, he would explain the indicator diagrams which were exhibited, and point out anything that he thought most deserved attention.

Mr. R. H. Tweddell regretted extremely that the author of the paper was unable to be present to explain further the results of his very interesting investigations; but he would endeavour to the best of his ability, in his absence, to describe the diagrams more fully than it was possible to do in the space of a paper, although he had himself not had an opportunity of looking into the special diagrams taken by the author, until informed a short time ago that M. Berrier-Fontaine could not be present.

With regard to the indicator diagrams generally, although they were taken from the hydraulic cylinders in the same manner as engine diagrams from the cylinder of a steam engine, they did not of course give the same information as to the consumption of water which the latter did in reference to steam. They were, more correctly speaking, simply diagrams of resistances; because the various curves, as they ascended or descended, represented the amount of resistance against the tool on the end of the hydraulic plunger. The diagrams might be divided into two parts, the first representing the nearly constant resistance of the machine itself, while the curve in the latter portion showed exactly the resistance offered by the useful work being done, in addition to the resistance of the machine itself. The bottom line in each case was the atmospheric line.

In the diagrams, Plate 52, Figs. 9 to 15, taken from the Riveting machines, it was seen that there was a horizontal dotted line showing the statical pressure in the accumulator, due to the load, and the continuation of the resistance curve above that line represented the temporary dynamical increase of pressure due to the momentum attained by this load in its fall. This highest portion of the diagram, representing in Fig. 10 for instance a rise of pressure from 1400 to 2100 lb. per sq. in., had been referred to in the paper as being not a period of useful work; but in his opinion this temporary increase of pressure at the end of the stroke possessed great value for the purpose of riveting, although not for any of the other applications of hydraulic pressure described in the paper. At the last part of the stroke, in making the rivet, the accumulator had fallen perhaps 2 ft. while the riveting-die had travelled perhaps but $2\frac{1}{2}$ in.; and the momentum acquired by the falling weight caused the pressure to rise, as shown in Fig. 10, from 1400 to 2100 lb. per sq. in.: the plates were thus tightly closed and kept together at the same time that the rivet was being finally compressed, the two operations being simultaneous, and the sharp but temporary pressure thus applied to the plates prevented any spreading out of the rivet between them. This was one of the chief practical advantages obtained in work riveted by hydraulic machines. The same effect was not obtained in other machines, where the material of the rivet was often found to have become pushed in between the plates, in consequence of their not having been closed together tightly enough to prevent the rivet from spreading and forming a washer between the plates at the moment of completing the rivet.

The PRESIDENT wished to refer to the author's statement (see p. 370) as to the plate round the rivet-head being marked by the tool and also made thinner, under this heavy final blow: he could understand the first, but not the second statement.

Mr. TWEDDELL said that M. Berrier-Fontaine's meaning might be illustrated by the sketch, Plate 52, Fig. 8, where the closing of the plates and clinching of the rivet were shown as completed, and the sharp edges of the dies, under the final blow of the accumulator, were represented as actually cutting into the plates at the points A, B, C, D, and thus reducing their effective section. The author's view of the action of the accumulator might be illustrated from any one of the diagrams, say Fig. 11; in this the first part of the curve, EF, represented according to him the period of setting up of the rivet; the steeper part, FG, the period of clinching of the rivet and closing of the plates; and the final part, GH, represented useless work done on the plates by compression or cutting, as just explained. As he had

already mentioned, he did not himself share in that view, but held that the part GH should be included with FG as representing the clinching process; nor did he approve of using dies with the sharp edges shown in the sketch. However that might be, any injury thus done to the plates would of course occur equally with any form of riveting machine which was too strong for its work; but with the differential accumulator it could be at once removed by using a smaller pressure, or in other words, by taking some of the weights off the accumulator. The differential accumulator had still the advantage that, on account of the final blow given by its momentum, a riveting-machine for a given class of work could be made smaller than with an ordinary accumulator, of larger area and shorter stroke.

The PRESIDENT asked by what means the travel of the end of the plunger in these hydraulic machines was communicated to the indicator by which the diagrams exhibited had been taken.

Mr. TWEDDELL replied that a Richards indicator was placed at the side of the hydraulic cylinder; and the travel of the machine being in all cases comparatively small, the rectilinear movement of the machine was easily transferred into the rotary motion of the indicator.

The diagrams taken from the Punching machine (Figs. 16 to 21, Plate 53) showed in a marked manner the work done in punching a plate. He might mention that the low-pressure part of the stroke was not necessarily all performed in actual work: the whole length of travel had been given to the machine while the diagrams were being taken; but in actual work the travel would really start only at the point where it was wanted, with just enough clearance to clear the plate. After contact it was seen that the pressure rose rapidly until the rupture of the metal took place, and then as rapidly fell.

The diagrams in Figs. 22 to 32, Plate 53, were taken from the Angle-Iron Shearing machines; they approached very nearly the character of the punching-machine diagrams, owing to the fact that the shape of the knives for shearing the angle-iron was as nearly as possible identical with the shape of the angle-iron itself, so as to attack the whole section at once, and prevent the deformation which would otherwise take place at the angle of the knife and the angle-iron. The result was that all the first part of the diagram represented useless travel, just as in the punching machine, and then the whole work was done suddenly as soon as the cutters came in contact with the angle-iron. In the latter portion of the diagram there were seen to be parts of the curve which rose up suddenly after the main resistance had begun to fall off; these could only be accounted for by the supposition that by some movement of the angle-iron, before it got clear away from the cutting tool, it met the knife again, and there was a sudden increase of pressure. There were also some irregular parts in the curves, which he thought were due to the oscillations of the indicator itself; at least he could not explain them in any other way.

The second horizontal line above the atmospheric line represented the draw-back pressure—a constant pressure acting against the forward travel in all these machines, so that the moment the exhaust valves were opened the tool went back automatically. Before making a regular attack on the work to be done, M. Berrier-Fontaine ran the machine in and out through the full length of its stroke, during which time the pressure never rose above the amount represented by the low horizontal line at the beginning of each diagram, showing that the power was all absorbed in the work done in friction of the machine at the high speed at which the tool ran out.

In the diagrams from the Plate Shearing machine, Figs. 33 to 38, Plate 54, as contrasted with those from the punching and angle-iron shearing machines, the first part showed as before the low pressure which existed until the knife reached the plate, but it would be seen that the pressure then rose gradually, instead of abruptly as in the preceding diagrams; that was due to the cutting edge of the knife being inclined to the plate, so that it met it at first only at one point; then, when the whole length of the cutting edge had come in contact with the plate, the curve went up to the full height in the diagram, and there was a steady pressure as long as the knife remained embedded in the plate; lastly, after it was through the plate, the pressure suddenly fell, and the work was done. There was seen to be a fall in the latter part of the diagram, Fig. 34, which

showed that at this point there was a soft place in the iron. Fig. 35 showed a more uniform condition of plate, the top line continuing horizontal. There were also some of the diagrams which showed where the knife was bad, the curve showing a rise where the knife had cut badly, as in Fig. 36. That afforded a means (which M. Fontaine was not slow to appreciate) of checking the quality of the iron and steel used in the dockyard. The condition and best forms of the knives and cutters could also be thus tested.

The diagrams in Figs. 39 to 44, Plate 54, were from the machines for Bending and Straightening L or T or H iron bars, and simply showed the resistance offered by the bars to being bent or straightened. In some instances (Figs. 39 to 41) it was seen that the ram had travelled out through the full length of its stroke, and had done all that amount of bending on the bars. In other cases (Figs. 42 to 44) it would be observed that the bars successfully resisted being bent, and consequently the ram was brought up short.

The PRESIDENT presumed that where the pressure rose at once, as seen in Figs. 42 to 44, the bars were put cold into the bending machine, so that the whole pressure would come on them immediately as they resisted bending.

Mr. TWEDDELL replied that the bars were all cold, and the pressure accordingly came on them immediately the ram touched them. The low part of the diagram at the commencement was simply a friction diagram, showing the friction of the machine.

The only other diagrams were those of the Flanging machine (Plate 55). A great number of dished-out plates had to be made of the shape shown in Figs. 51 and 52, and they were dished out under one of the shearing machines. These machines would appear to many to have an excessively long stroke for shearing only, but they had purposely been made so, in order to enable them to be used for other purposes than shearing and punching only. One of them indeed had never done any punching or shearing yet; the shears had been taken off, and stamping swages substituted. The gradual rise of the curve showed how the ram, as it travelled down, gradually met the plate until it was dished out. Then the curve rose further when the head of the ram was just passing through the hole in the die; and finally the curve reached the pressure in the accumulator, namely 1500 lb. per sq. in.

The PRESIDENT asked what was the colour of the plate when it was put into the flanging machine.

Mr. TWEDDELL replied that in the case he was referring to the plates were about cherry red. They had to be carried some considerable distance from the heating furnace to the flanging machine. In flanging large plates for boiler ends, and work of that description, it was surprising to find how little power was required. At the same time he must say that M. Fontaine had adopted a more scientific method of estimating the power which would probably be required to flange different classes of work than had been done by himself or others in designing flanging machines.

Dr. JOHN ANDERSON considered the paper was a very interesting and suggestive one, showing the particular direction which the application of hydraulic machinery was now taking. The President had, on the previous day, made use of the term "mechanical analysis," and he thought that expression would remain. It was very interesting to see how precise their knowledge had become; and more especially on the present occasion was it interesting to have such a subject discussed by French and English engineers, and all the more so since they were within a few hundred yards of the spot where this question of hydraulic pressure was first started about 230 years ago by the celebrated Pascal. Then their own great countryman, Bramah, took the subject up, and others followed—a house in Glasgow, and then Sir William Armstrong. It appeared to him that hydraulic pressure would shortly be applied to all purposes where intense pressure with comparatively short range of motion was required. He would suggest to the young engineers present that the subject had not been exhausted by Mr. Tweddell, and that there were still many things to which hydraulic pressure could be applied.

Mr. D. GREIG was quite of opinion that the subject of hydraulic forging was only in its infancy, and that where intermittent motion was required hydraulic pressure was by far the most economical; but he wished to ask Mr. Tweddell if he would explain any plan of constructing a cylinder so that, without getting any extraordinarily large dimensions, it might be possible to obtain a pressure of say 2000 lb. per sq. in.

Mr. E. B. ELLINGTON said he had been exceedingly interested in the paper just read, and in the explanation given by Mr. Tweddell of the indicator diagrams exhibited. A distinct advance had been made in the direction of specific knowledge of the working of these hydraulic machines; he had however not seen the diagrams before, and they required a good deal more attention than could be given to them without careful examination at leisure.

He could however answer the question that had been asked by Mr. Greig as to the construction of hydraulic cylinders for working up to a pressure of 2000 lb. per sq. in.: at present they were simply made of cast-iron of good quality, and of ample thickness, and in that respect there was nothing special in their construction. There was no doubt however that by the substitution of steel the weight of such cylinders could be materially reduced; but at present there had been no difficulty in obtaining the required strength in cast iron.

He was exceedingly pleased to hear Dr. Anderson say that the field for the application of hydraulic machinery had not been entirely covered, and might mention one or two applications on which he was himself engaged. One was the application of hydraulic power on board ship, which hitherto had been extremely limited; and another was its application to mining purposes. Something might be done, he believed, in the way of hydraulic hoisting in mines, superseding the ordinary winding engine at present in use. There would be some advantage in the use of hydraulic power in that direction; and he hoped to be successful in the course of a little time in introducing an apparatus of that kind.

Mr. J. A. G. Ross observed that the author had called attention to the necessity of having a separate supply of pressure-water for working the fixed riveting machine and the large vertical press of 1000 tons. With regard to these it appeared to him that a separate supply would unnecessarily complicate the system, because it would then be necessary to have an entirely independent system of pipes for supplying each riveting machine and each heavy press; whereas the result of modern practice among hydraulic engineers had been to reduce the system as much as possible to one pressure throughout. He remembered a case in which Sir William Armstrong's firm had been requested to arrange for the supply of higher pressures than those which had previously been used in their practice; and the result in that case, after long years of experience, had been that those higher pressures were reduced to 700 lb. per sq. in.; at which pressure some of the most powerful machines of the present day were being worked. He might instance the hydraulic cylinder at the Tyne Bridge, which lifted a weight of about 1200 tons. He did not see any reason for having a separate supply of water at a higher pressure for the 1000-ton press mentioned in the paper, inasmuch as, with the general pressure of 1500 lb. per sq. in. employed in the Toulon dockyard, the required increase of diameter for obtaining a total pressure of 1000 tons would be but small. An increase of 14 inches, in the diameter of a press large enough to give 350 tons total pressure, would give the 1000 tons required. In case such an increased diameter was an objection, as occupying too much room, an extra cylinder could be put on the top of the first to assist it, and the two cylinders could be worked at a pressure of 700 lb. per sq. in. The placing of special machinery, such as pumps and accumulators required to obtain separate pressures, in boiler yards was he thought objectionable, inasmuch as it deterred people from the application of hydraulic power.

With regard to the riveting machines, it had been stated in the paper that the dynamical pressure obtained by the fall of the accumulator was one and a half times greater than the dead pressure to which the accumulator was loaded. Here again he could see no

reason for varying the method of working with the ordinary pressure, inasmuch as the dynamical pressure indicated by the highest portion of the diagram (Fig. 9, Plate 52) would represent the quantity of water used in that case, while the dotted line, indicating the statical pressure, represented the quantity used on the ordinary system, and the difference was considerable. As it had been stated in the paper that the amount of work required to be done was very small, when extended over a whole day, he thought the recommendation with regard to the application of a blow from the accumulator was very doubtful, as it limited the times and manner of working. He had occasionally observed that, unless the accumulator was pretty high up, it did not produce the blow at all, or the blow came at the wrong time. If the valve was opened quickly, the blow came too soon; and if there was little work to be done, with a long fall of the accumulator, the blow was too severe. If it was a matter of economy, the best plan was to use low pressure to begin with, and to follow that up by the ordinary hydraulic pressure as soon as the die touched the rivet. He remembered a hydraulic riveting machine made in that way twenty years ago in Sir William Armstrong's works, and it was working still, and, as far as he knew, required very little repair. The method of working was to have a water tank placed high up in the smith's shop, and the low pressure obtained from the tank brought the die forward until it touched the rivet; then, by moving the handle a little further forward, the pressure valve was opened, and the ordinary accumulator pressure brought into action.

The President observed that a similar system of two cylinders with different pressures was adopted for cotton presses.

Mr. Ross said that was so; or three presses might be used, one in the middle and one on each side, and in that way three or four powers could be obtained.

With regard to the differential accumulator, he could see no good in it; and it did not seem to him to be consistent with the simplicity that was always to be aimed at in mechanics. A simple ram he considered would accomplish the same object at a much less cost, and there would be much less loss by friction. In an ordinary accumulator, working at about 700 lb. per sq. in., the difference of pressure between rising and falling due to friction was as much as 20 or 30 lb. per sq. in.; and assuming that the friction rose in proportion to the pressure, which to a certain extent it did, then for a pressure of 1000 lb. per sq. in. there would be a difference of pressure of 30 to 45 lb. per sq. in. between rising and falling; and this again, in the case of the differential accumulator, would be increased by having the friction of two large differential cylinders instead of one small simple ram, which would altogether involve perhaps a difference of pressure of 100 or 200 lb. per sq. in. The first thing was to have the accumulator perfect, and to effect economy there as much as possible. Perhaps there might be some particular object in regard to the differential accumulator, but at present he could not see anything to recommend it.

Mr. J. Platt said he had had some experience in hydraulic work, and had given some attention to the matter of the compound riveting machine with two pressures—a low pressure to bring the rivet up to the work and a higher one to finish it; but it had been found that the additional complication of a machine of that kind was so great that the economy of water pressure realised was not worth the trouble it involved. The most simple machines that could be made were the most appreciated by the users; and the saving of power was not sufficient to warrant the additional expense and trouble of more complicated machines. The same thing would apply to closing the plates for riveting; many plans had been tried for closing the plates first before the rivet was formed. The idea seemed promising, but no practical advantage had been found in it. It was found from experience that a simple direct cylinder was the best, and that in respect to the power required it compared very favourably with any other system of riveting; the users were quite satisfied with it. The power expended was much less than with the direct steam machine, and he believed considerably less even than with the geared machine.

As to the amount of pressure to be employed, he had come to the conclusion that 1500 lb. per sq. in. was the best that could be adopted. With higher pressures there was more trouble with the joints and packings, and with a lower pressure the bulky character of the machine was objectionable; with 1500 lb. per sq. in. no difficulty had been found. With regard to the very powerful machines of 1000 and 2000 tons total pressure, they were certainly rather bulky with 1500 lb. pressure per sq. in.; but he did not think there was any real objection in that. The cylinders of course were very large; but they were much less expensive to make than those which would be required for very high pressures. He had noticed in the Exhibition a fine example of hydraulic forging from some of the Austrian works, which was well worth the notice of engineers.

The President observed that Mr. Platt had spoken of its not being necessary in hydraulic riveting to close the plates before applying the machine to the rivet. But when a large number of plates were put together, with a long rivet, had he not found that there had been a tendency to spread the rivet into the interstices between the plates?

Mr. Platt replied that he had not found that to be the case at all. It was claimed as a peculiarity of hydraulic pressure in riveting that it did not cause the rivet to "washer" between the plates. The plates did not require so much closing as in the case of steam riveting or any other riveting that he had seen; he had done all kinds of riveting, and in no case had he found the rivets "washer" between the plates under the hydraulic riveter.

Mr. J. Gimson thought too much had been made in the paper of the matter of economy, and that more had been claimed for hydraulic machinery in that respect than it would effect. Looking at the indicator diagrams exhibited, it appeared to him that there was an immense expenditure of power for the work done; the diagrams did not represent the expenditure of power, but only the effective work accomplished. By comparing the small area of the diagram itself with the complete rectangle comprised by the whole length and height of the diagram, it would be seen that in some cases not a tenth of the power expended was utilised. It appeared to him to be a serious objection to this hydraulic machinery that the water was used at full pressure, whether there was any work being done or not; thus there was a full expenditure of power throughout the whole stroke of the piston. Where that same work was effected by machinery driven by belts—with which a comparison had been drawn in the paper—only the actual power required for the work done was used, and that appeared to him to be an immense advantage in favour of shafting. It was not to be supposed that the friction of machines when driven by belts was any greater than that of the hydraulic machines. It had been admitted by the author that he had to allow some 50 per cent. of the net power, or 33 per cent. of the gross power, for the waste in forcing the water into the accumulators. That was a very heavy loss to start with, and it certainly seemed to him to outweigh the losses which the author deemed so heavy a matter in shafting. A great deal appeared to be claimed for the hydraulic machinery because it dispensed with shafting. But where did it dispense with shafting? In no ordinary works could the general work of the shop be conducted without other machines than those moved by hydraulic power. There were drills, rolls, and various other machines requiring to be driven by shafting, and yet which could not well, with a view to proper economy, be separated from the machinery that was worked by hydraulic pressure. In placing machines, regard should be had both to the prime mover and the work to be performed. In the present instance it appeared that the works in which the hydraulic machinery was situated were separated from the shops where the engines were at work, and that appeared to be a necessity of the case; had it not been so, he did not consider that shafting could have been dispensed with. With regard to the hydraulic machines themselves, which he had seen, he was quite prepared to believe that they were thoroughly effective; at the same time he thought they would be extremely extravagant in the amount of power used, which was the very opposite conclusion to that which the author had arrived at. In the punching

machine, for instance, the same power was used for punching $\frac{3}{4}$ in. holes as for $\frac{5}{8}$ in. holes. If therefore the work was to be done with economy, a great number of machines would be required for the different sizes of work to be performed.

Mr. J. C. WILSON observed that the author's remark in the paper (see p. 370) about the highest part of the indicator diagram from the riveting machine not being a period of useful work should be read with the context. In the preceding sentence, it had been stated that the last part of the diagram did not represent any work done in the closing of the rivet, but only the resistance opposed to the motion of the die by the plates, which absolutely arrested its movement. When therefore the author went on to say, "this then is not a period of useful work," he meant that it was not useful work *for the closing of the rivet.* It represented the work done in what would be called the clinching of the rivet. In hand-riveting, after the rivet had been knocked up with a hammer, the cup or die was put on it, the rivet was clinched, and the plates were closed as firmly as possible. That, he thought, was the work represented by the highest part of the diagram. When the rivet was closed up to the extent represented by the lower line on the diagram, the momentum of the accumulator gave a greater pressure on the riveting piston to drive up the plates and clinch the rivet; this took no more power from the engine, being simply the effect of the momentum of the falling accumulator.

He had lately adopted Mr. Tweddell's portable hydraulic riveter at the Avonside Engine Works, Bristol, and it had been found very effective. One portable machine had dispensed with six sets of riveters, representing about £30 a week in wages; so that the saving was very great. The machine was suspended from a crane of 30 ft. radius, and was worked by two labourers, by whom $\frac{3}{4}$ in. rivets were put in at the rate of 70 per hour in straight work. The great point to be attended to was to have the rivets made exactly of the proper length. If they were too long they made a rough head; if too short they did not make a sufficiently full one. But with a little care the work was far superior to hand-riveting. He was now altering a Garforth steam-riveting machine to the hydraulic system, and was employing an arrangement which he thought would be useful. Instead of carrying the riveting die direct on the end of the ram of the hydraulic cylinder, it was carried on the upper end of a vertical lever working on an adjustable fulcrum at the lower end; and the hydraulic cylinder was arranged to act upon an intermediate point in the length of the lever, and could thus be set at a variable distance from the fulcrum, according to the power required for closing the rivets in different kinds of work. One advantage of that arrangement was this, that there was nothing above the level of the die at the upper end of the lever, and the work could be got down very close to the die. On shifting the fulcrum nearer to or further from the hydraulic cylinder, the same machine could be used for $\frac{1}{2}$ in. to $\frac{7}{8}$ in. rivets, either of iron or of copper. The construction of this machine had been worked out by himself in accordance with the latest improvements of Mr. Tweddell, whom he had consulted in regard to it.

Mr. W. Menelaus thought that both in the paper and in the discussion a great deal too much had been made of economy in the moving power. According to his experience, economy in labour and good sound work were of far more importance than economy in the moving power.

Mr. Tweddell said he was quite sure that M. Berrier-Fontaine would appreciate the remark made by Dr. Anderson. He hoped, with the President, that in future the designing of machine tools would be carried out with a greater regard to combining theory with practice. The paper that had been read, and the manner in which the author had treated the subject, showed very clearly to all—even though there might be a difference of opinion as to the results obtained—that the author had not searched after facts in a superficial way, and had abstained from making vague general statements without anything to prove them. He could say for M. Berrier-Fontaine, in his absence, that he was not afraid of, but invited criticism. At first glance there did not appear much that was promising in respect to economy, so far as the diagrams showed anything. But

taking the results of the system as a whole, they not only fully confirmed the remark made by Mr. Menelaus, but in his opinion reduced the amount of coal consumed by the moving power, and in addition ensured good work done. In many kinds of hydraulic machines the quality of the work was no better of course than that done by others; but the old saying would be remembered, that "the proof of the pudding is in the eating." Certainly up to the present time the adoption of hydraulic machine-tools had fulfilled the hopes he had entertained of them for some years.

Mr. Ross had criticised the paper at some length, and his remarks were deserving of attention from his having been connected with so eminent a firm as that of Sir William Armstrong. His objections with regard to the employment of two different hydraulic pressures in one establishment were quite correct; but in reality the press referred to in the paper had simply been mentioned incidentally as one already in existence at the works, and it was proposed eventually to adapt it to the regular pressure of 1500 lb. per sq. in. employed throughout the rest of the dockyard at Toulon. No doubt it was better to have one uniform pressure, and that was what he had always maintained; only the uniform pressure he advocated was 1500 lb. per sq. in., whereas Mr. Ross preferred 750 lb. Both of these pressures were perfectly correct; but they were for entirely different purposes. He himself always employed 750 lb. per sq. in. in the case of hydraulic machinery for docks and railways; and in fact for all such machinery, constructed on Sir William Armstrong's principle, there was no question at present that that was the right pressure. Riveting machines also might be worked at 750 lb., if no higher pressure could be had; but when his own riveting machines were used in Sir William Armstrong's works, 1500 lb. pressure per sq. in. was employed to work them; which he thought was pretty conclusive that the highest authority in hydraulic machinery saw nothing objectionable in having two pressures in one shop. The pressure of 1500 lb. per sq. in. was employed, because the special machines which were required to be worked by that pressure were the portable hydraulic riveting machines; and to get portability, lightness was required, which was not consistent with the use of only 750 lb. pressure. In America 2000 lb. pressure was regularly used at the works of Messrs. Sellers, and machines were now being prepared for special circumstances in which a pressure of one ton per sq. in. would be used.

With reference to the consumption of power and the waste of water in hydraulic riveting machines, there had been direct-acting machines invented by Garforth, Cook, and others for hydraulic pressure as well as steam; and the waste was no greater in hydraulic riveting machines than in those worked by steam. It was immaterial whether water or steam were used, except as to the arrangements of detail, since the steam cylinder had eventually to be filled with steam if the maximum pressure was to be obtained at the end of the stroke.

With regard to the accumulator, he might point out that the hydraulic machinery at Toulon was worked by accumulators on the principles preferred by Mr. Ross. The only machine that was not so worked was a fixed riveting machine. The differential accumulator used for this machine was adopted for reasons already referred to, to ensure increased efficiency in the working; it had also advantages structurally speaking; for instance, the form of spindle used rendered any further guides unnecessary. The accumulator was also easily movable. That part of the diagrams which rose above the line of statical pressure did not represent any consumption of water, as supposed by Mr. Ross; it represented only the effect of the falling weight. The water consumption was represented by the dotted or statical line; and if the accumulator was allowed to come down slowly, the statical line representing the consumption of the water would be the top line of the diagrams, without any higher portion above.

In reference to the use of two cylinders, he had himself used them in some cases; and Mr. Greig had a press worked on the same principle. He never however used them, except in special cases, on account of the complication, the game not being worth the candle in practice, so far as any economy in the long run was concerned.

With regard to Mr. Gimson's remarks, as that gentleman had not shown any diagrams or given any exact figures in favour of shafting he could not go into the matter so fully as he should like; since on

the one side were actual figures and results, while on the other side were opinions and suppositions only. He was aware that the friction of shafting was small when it was all in good working order. At the same time it would be noticed that at Toulon dockyard all the power was required at a distance of 2000 ft. from the engines supplying the accumulator, and to convey the power to that distance by shafting would certainly involve a very considerable amount of friction. Of course certain machines were required to be driven by shafting, and it was not urged or suggested that hydraulic pressure was suitable in all cases. The hydraulic machines referred to in the paper were of a special class; and to attempt to use hydraulic pressure for rotary machines or lathes, or for machines with a constant demand upon them for perhaps very varying resistances, would not be desirable.

At the same time neither he nor the author could at all concur in the view that there was any undue waste of power with hydraulic tools. The parts of the diagrams corresponding only to frictional resistances appeared considerable because the machines were run, for the purposes of the experiments, through the whole length of their travel, and at a considerable speed; they would be quite insignificant in practice, when the travel would be scarcely more than the length required for actual work, and the speed very small. Against them must be set the important fact that, except when actually wanted, and therefore during three-fifths to four-fifths of the day, the machine was absolutely at rest. One advantage of these machines was that by diagrams of this character the exact distribution of the work could be ascertained, and it was known exactly where the power had gone; which was not possible with machines driven by shafting. Neither he nor the author had any doubt whatever that, if similar diagrams could be obtained from the latter class of machines, they would show losses and defects (even apart from the question of the power wasted while the machine was not doing work) much more serious than those which these diagrams had revealed in the case of hydraulic machines.

It was satisfactory to hear Mr. Wilson's account of the working of the hydraulic riveting machines at his works. The rate of 70 rivets per hour that he had alluded to was no doubt in connection with work on locomotive frames and of a difficult nature; but in bridge and girder work, and any work of that kind, which was not required to be steam-tight, it was not uncommon to put in 2000 rivets per day by the hydraulic riveter. In America as many as 6000 rivets had been put in by one man in a day of $9\frac{1}{2}$ hours with one of the portable hydraulic riveters. The arrangement that had been described by Mr. Wilson, as having been applied to a steam-riveting machine in his own works, was one which he (Mr. Tweddell) had recently designed to suit the special case, the object being to get varying power without having to take any of the weights off the accumulator; and the arrangement had been neatly applied by Mr. Wilson.

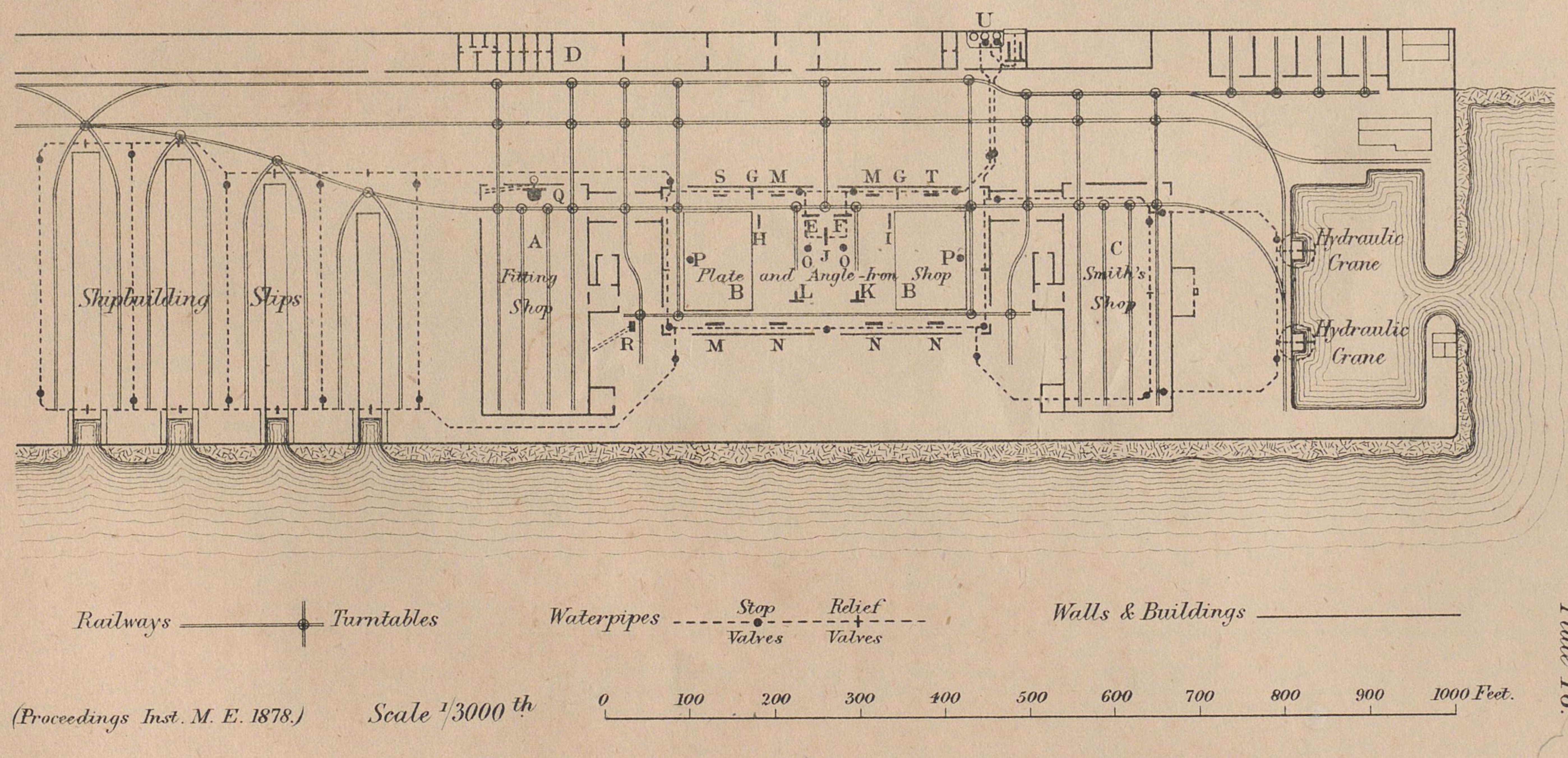
The PRESIDENT said he would now ask the members to accord the usual vote of thanks to M. Berrier-Fontaine for his interesting paper.

This was carried by acclamation.

The following paper was then read:—

TOULON HYDRAULIC MACHINERY. Plate 48.

Fig. 1. *General Plan of Iron Shipbuilding Department at Toulon Naval Dockyard.*



(Proceedings Inst. M. E. 1878.) Plate 48.

TOULON HYDRAULIC MACHINERY.

5 ft. gap Double Punching and Shearing Machine for Plates.

Fig. 2. *End Elevation*

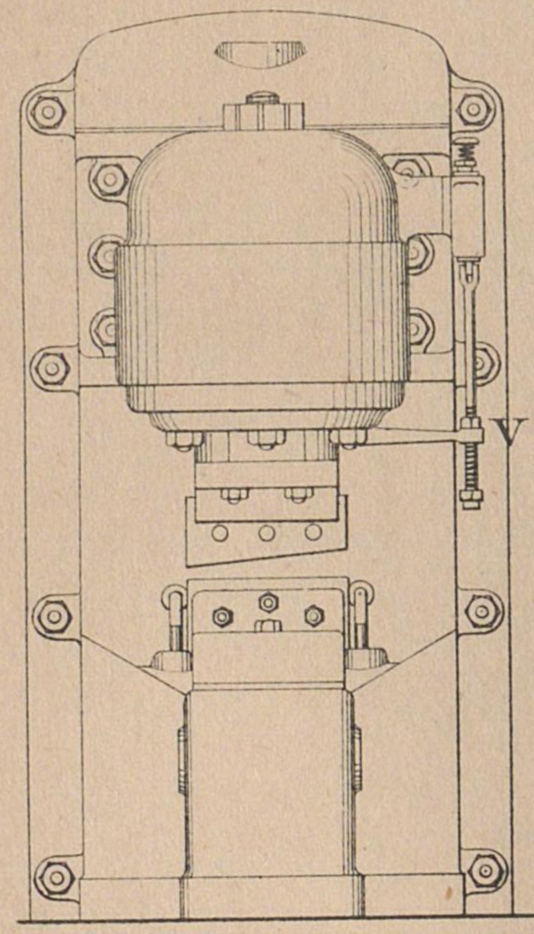
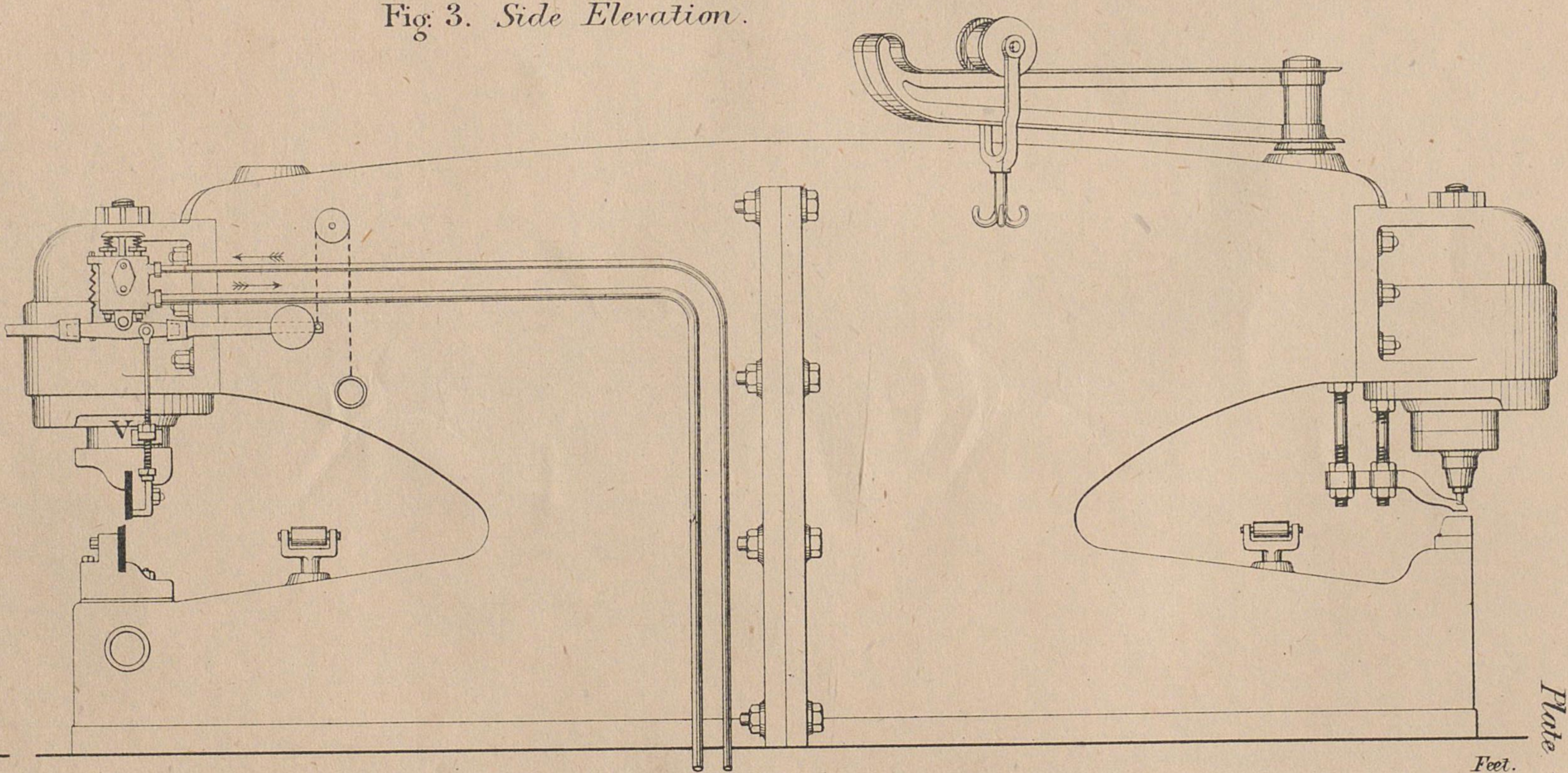


Fig. 3. *Side Elevation.*



Scale 1/40th Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 Feet.

(Proceedings Inst. M.E. 1878.)

Plate 49.

TOULON HYDRAULIC MACHINERY.

Quadruple Punching and Shearing Machine for Angle-Irons.

Fig. 4. *End Elevation.*

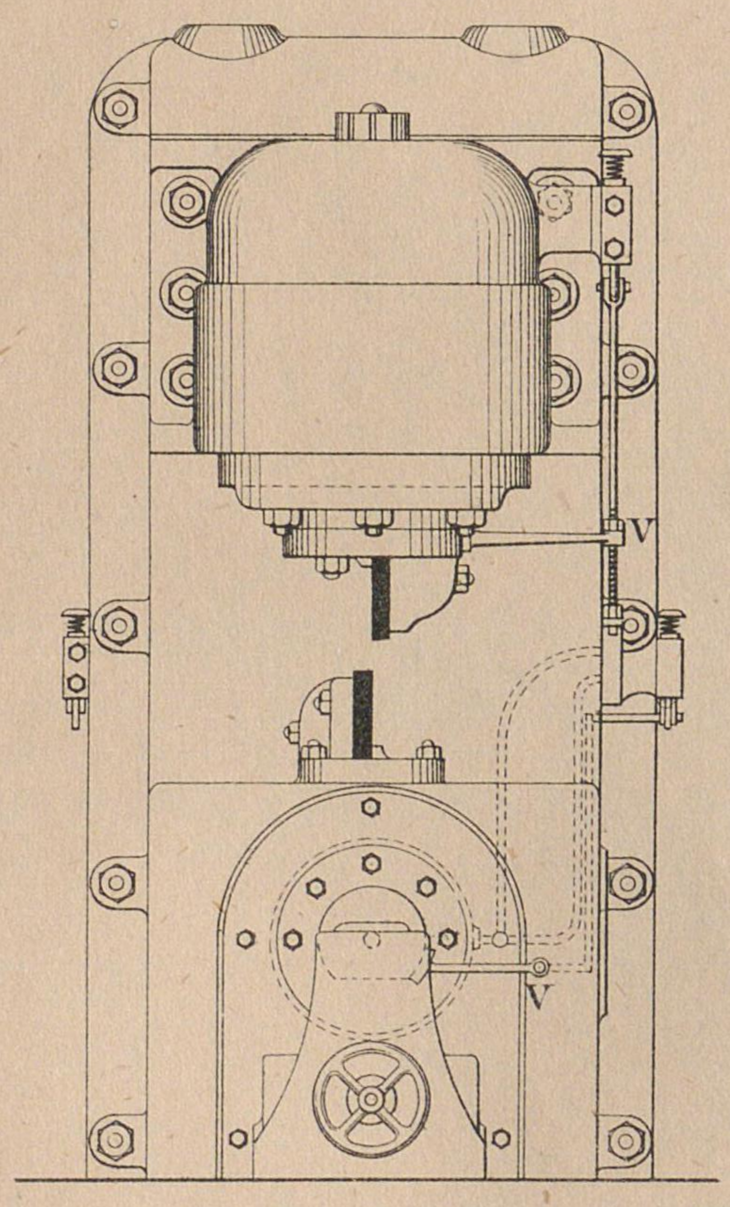
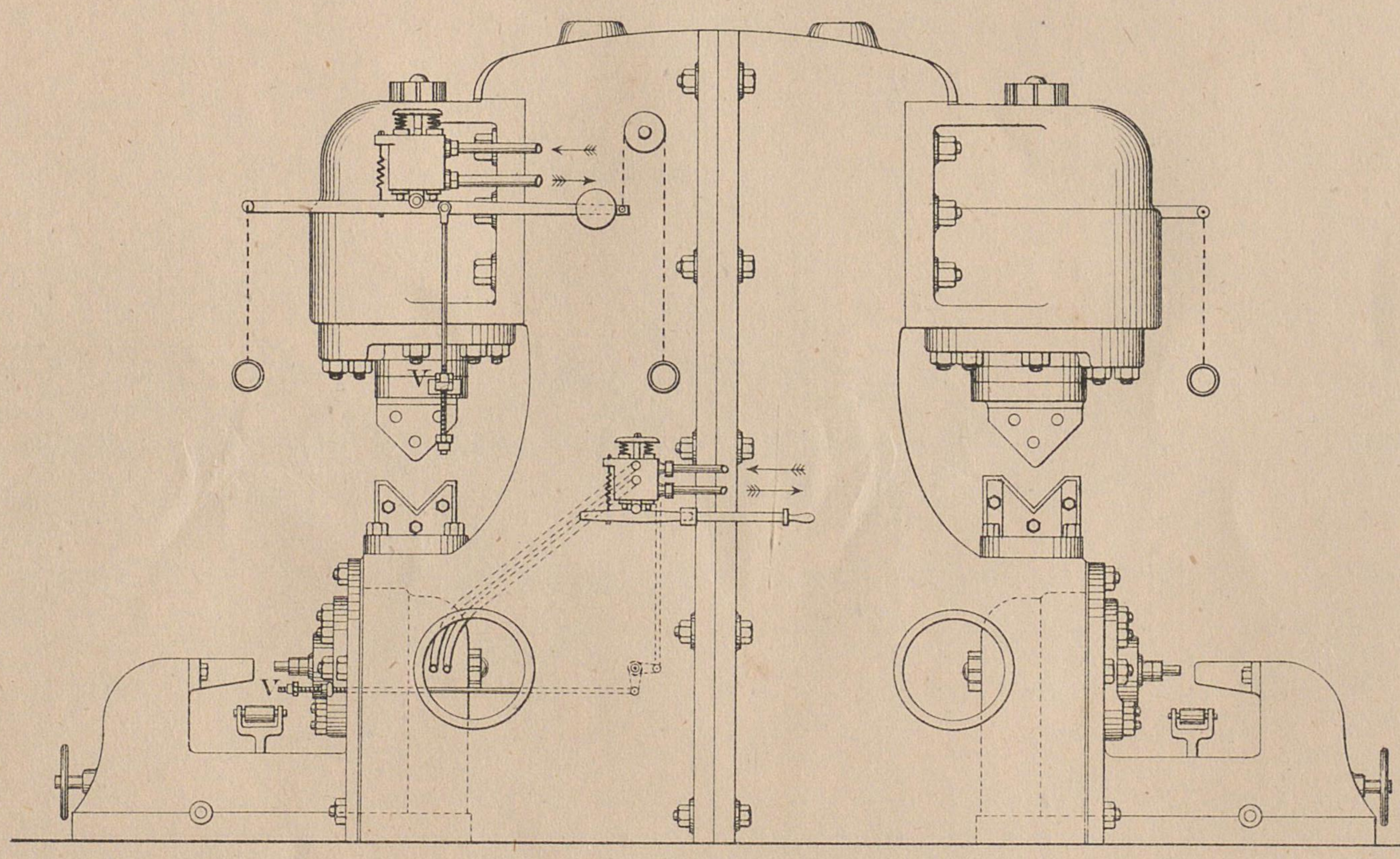


Fig. 5. *Side Elevation.*



Scale 1/40th. Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 Feet.

(Proceedings Inst. M. E. 1878.)

5 Ton Angle-Iron Bending Machine.

Fig. 6. *Plan.*

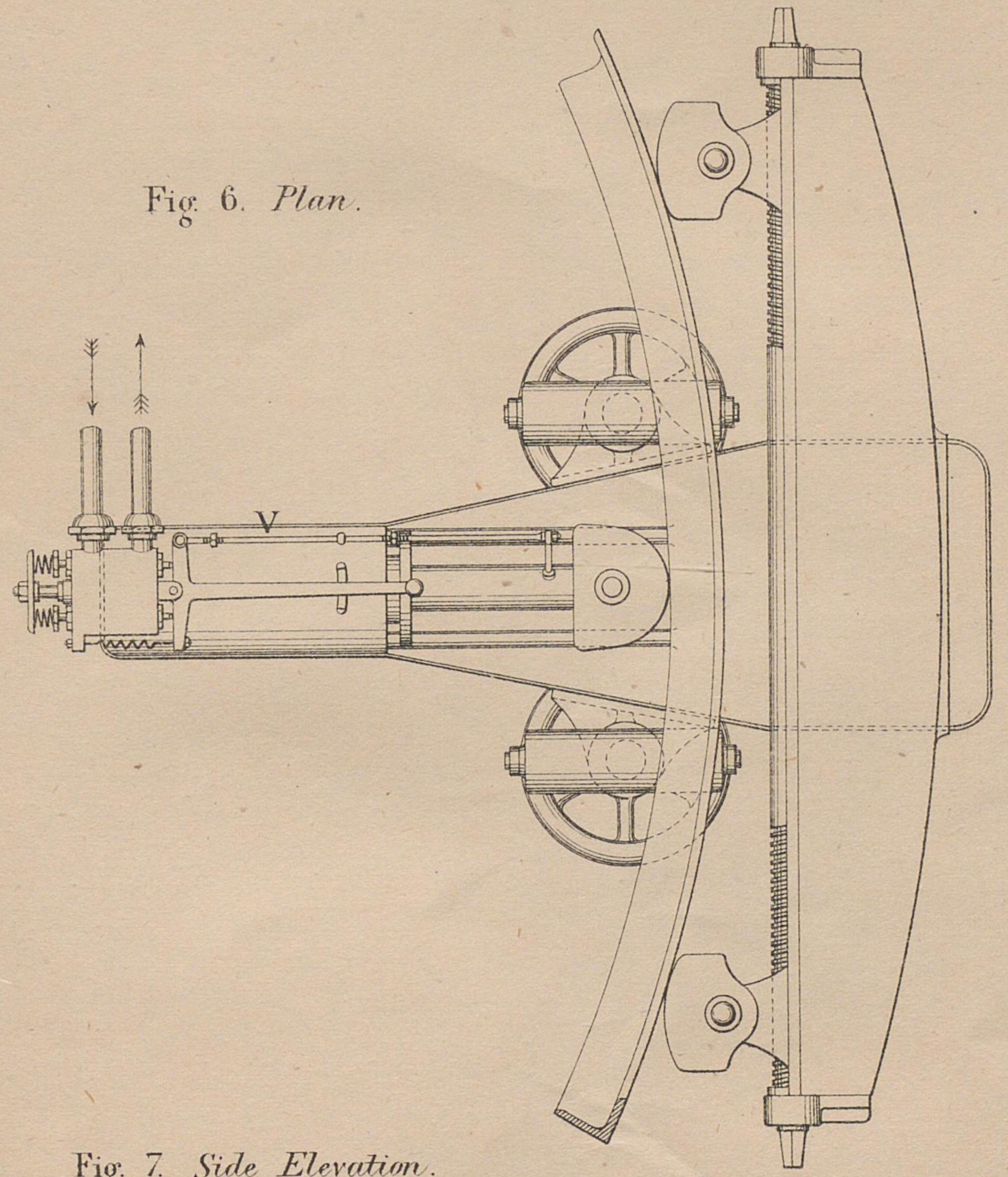
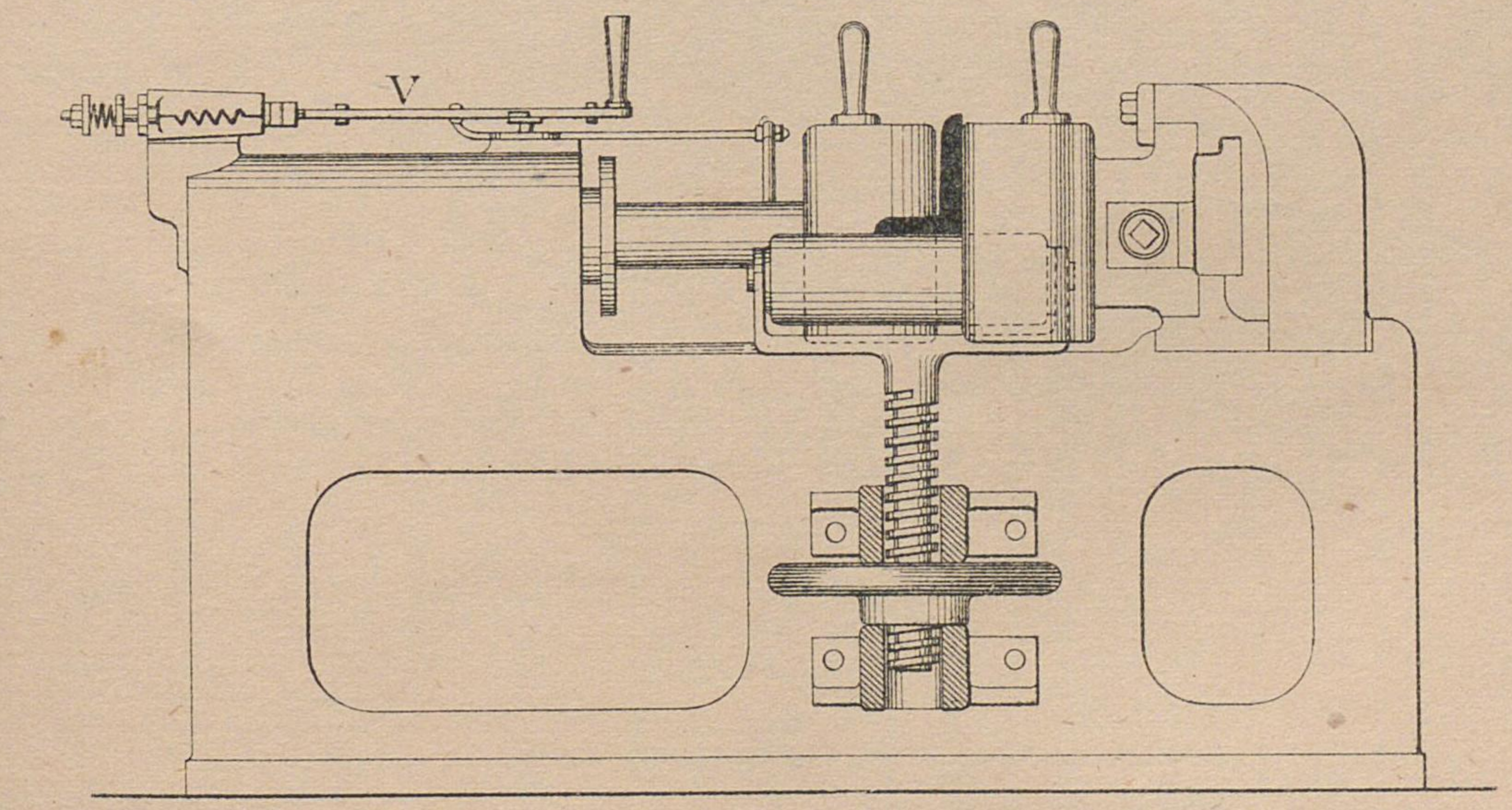
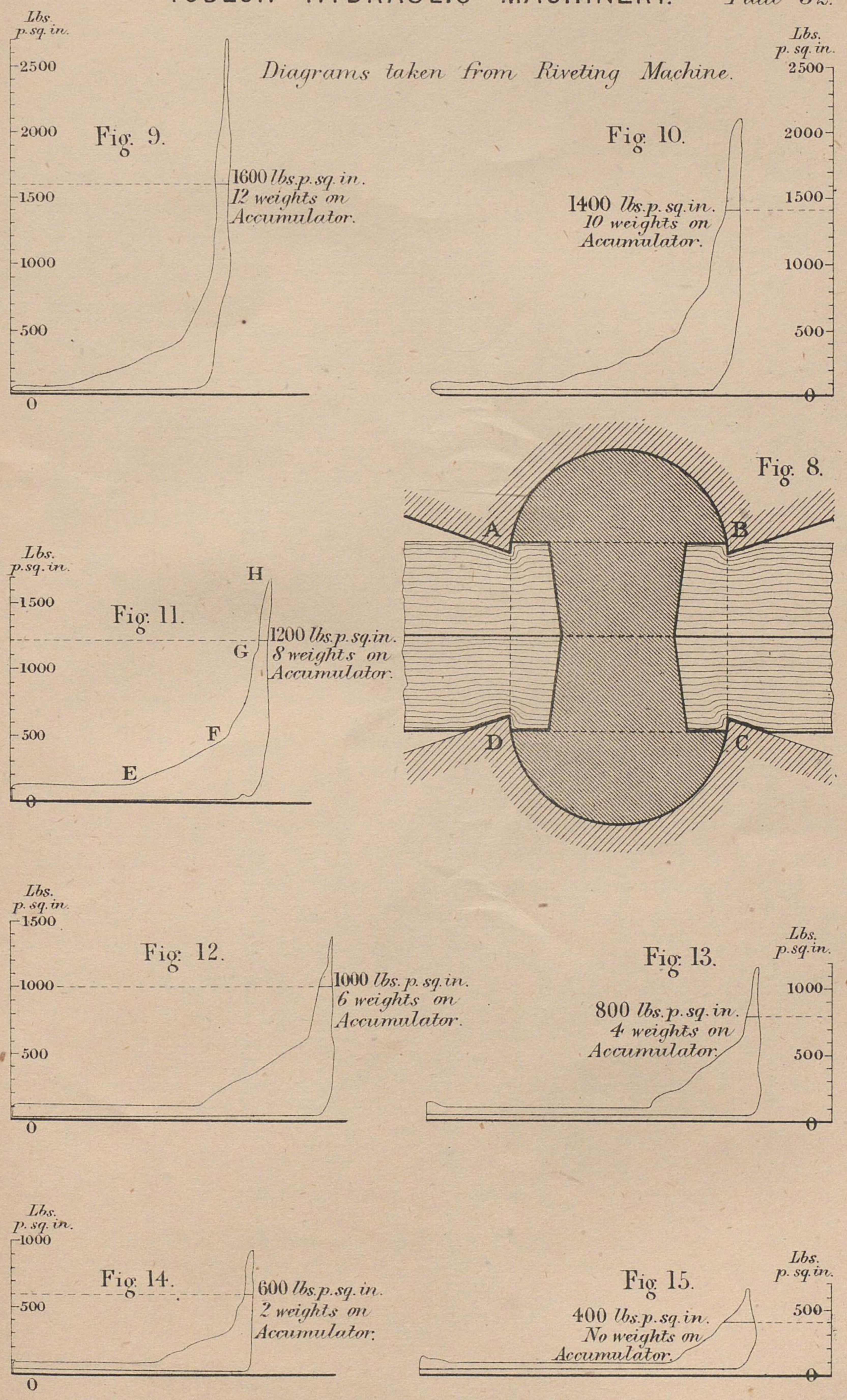


Fig. 7. *Side Elevation.*



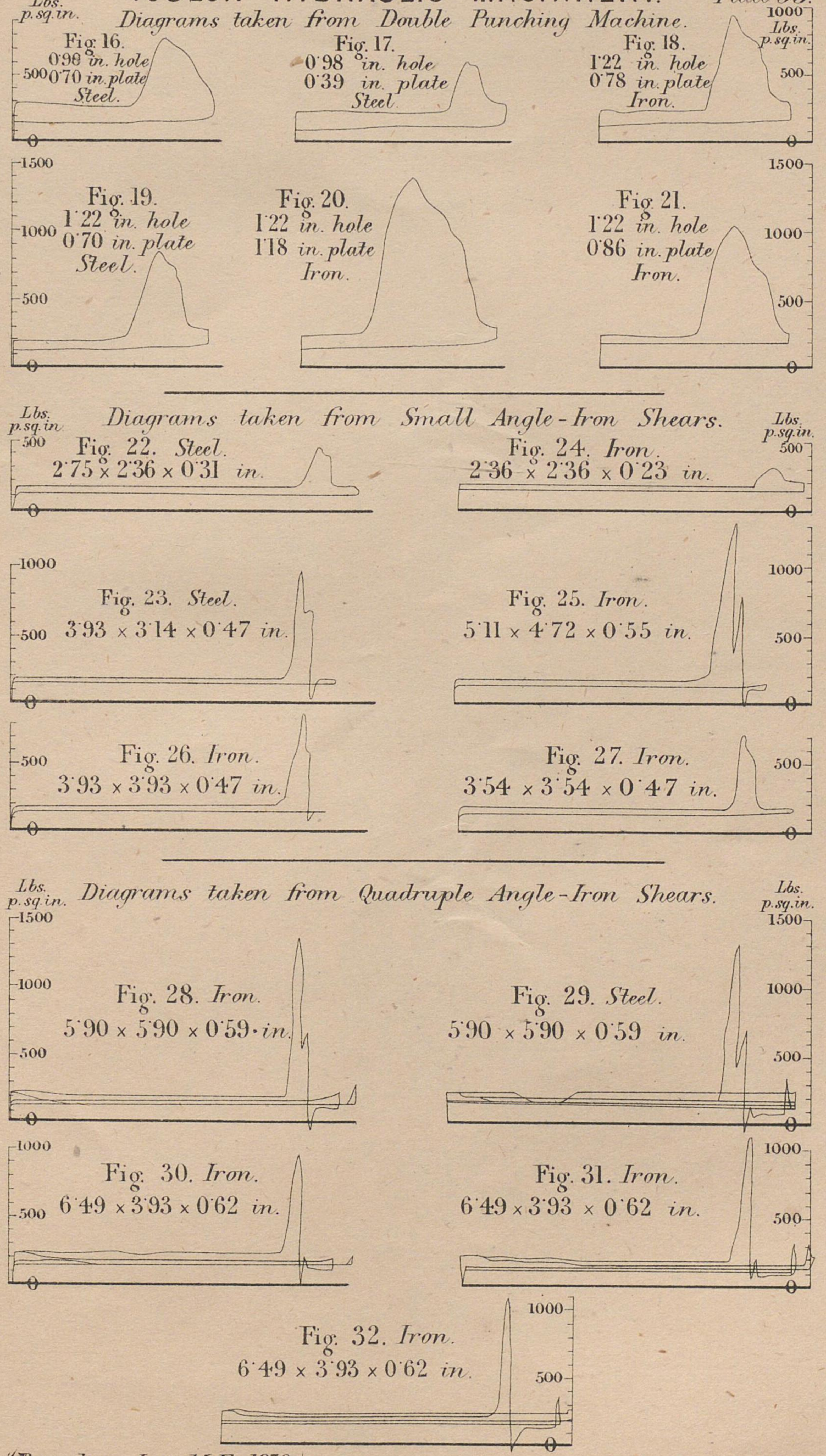
Ins. 12 9 6 3 0 1 2 3 4 5 Feet.

Scale 1/20th



(Proceedings Inst. M. E. 1878.)

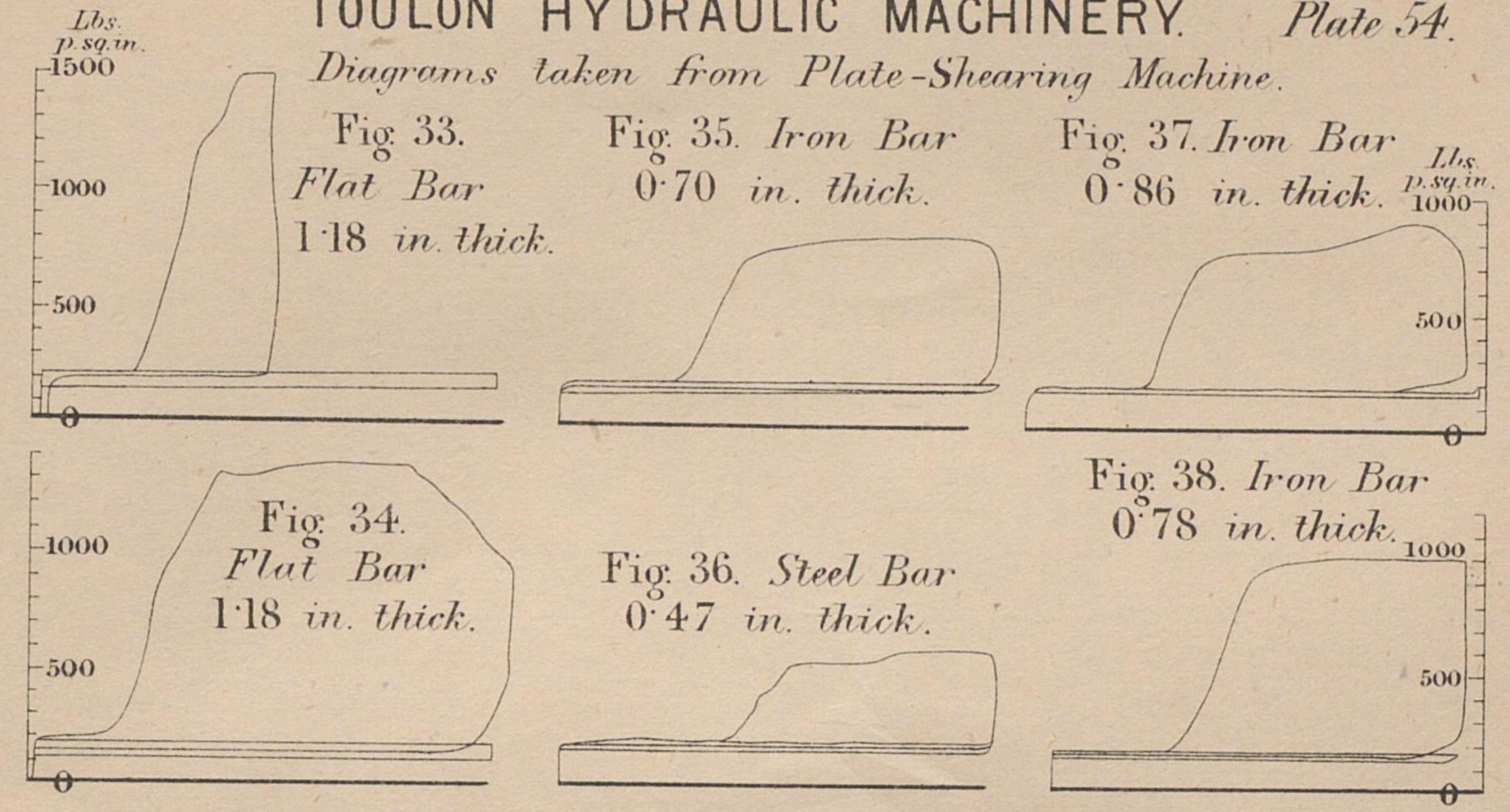
TOULON HYDRAULIC MACHINERY. *Plate 53.*



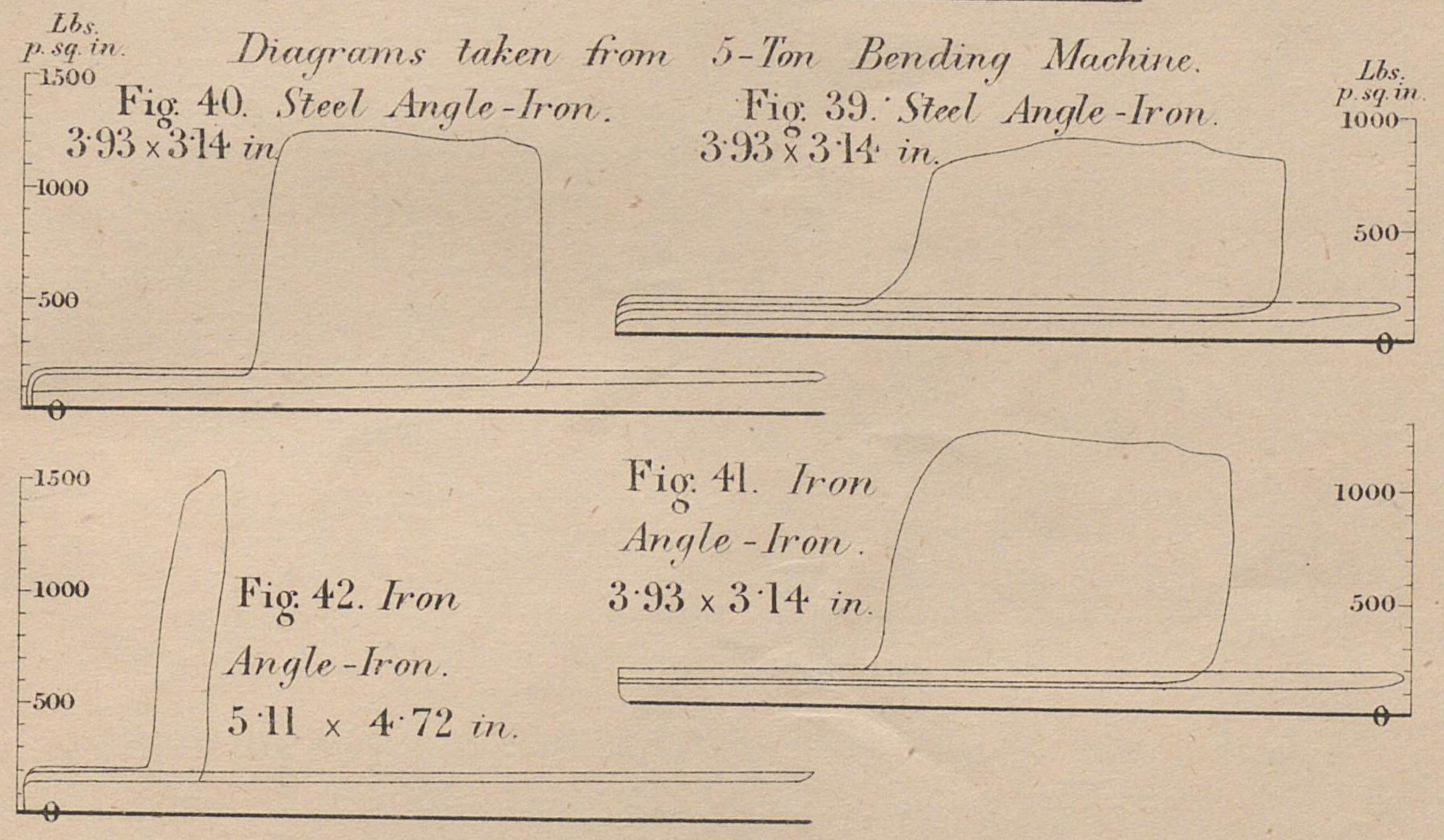
(Proceedings Inst. M.E. 1878.)

TOULON HYDRAULIC MACHINERY. *Plate 54.*

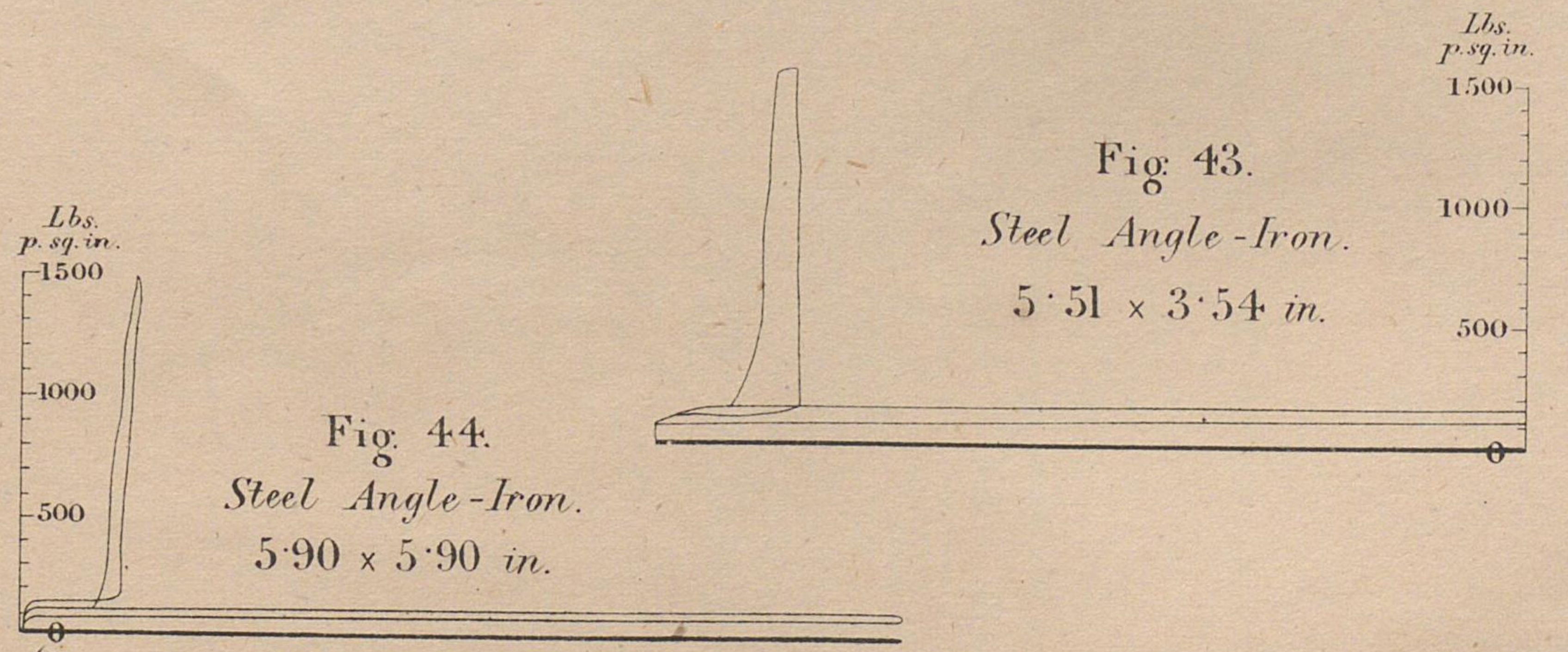
Diagrams taken from Plate-Shearing Machine.



Diagrams taken from 5-Ton Bending Machine.



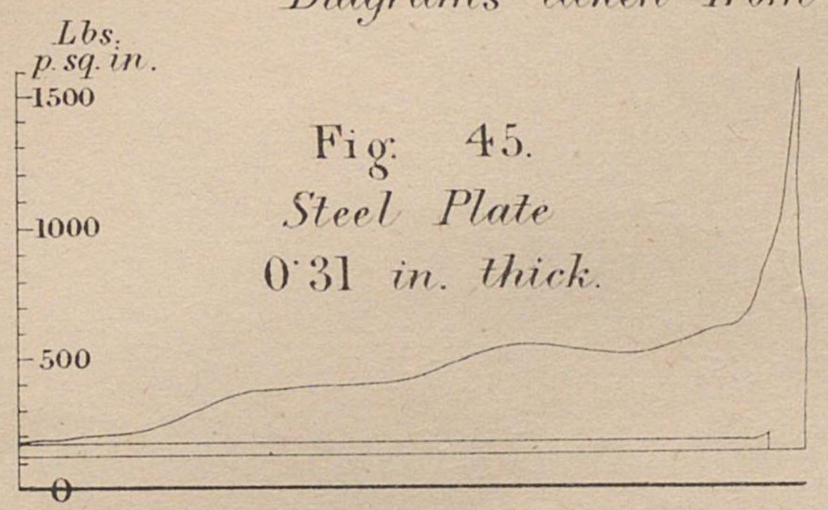
Diagrams taken from 10-Ton Bending Machine.

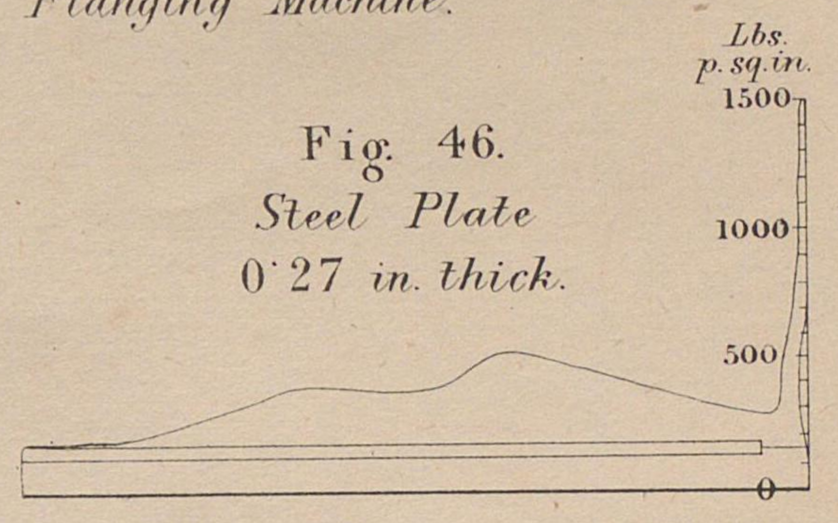


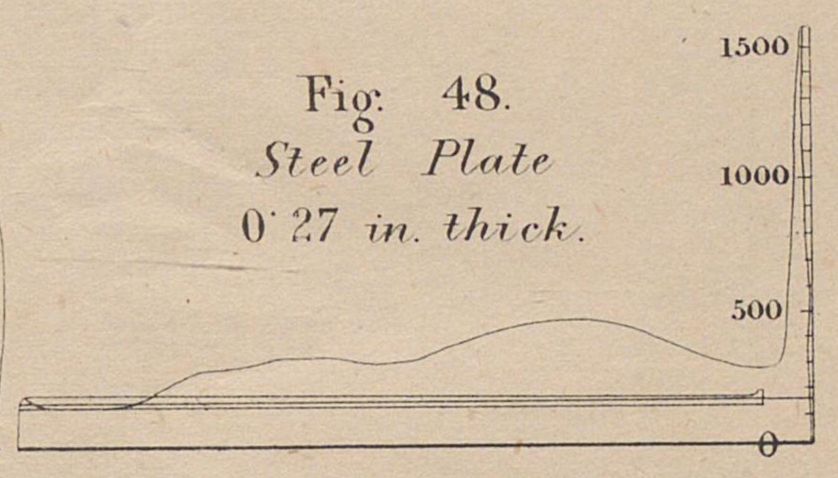
(Proceedings Inst. M. E. 1878.)

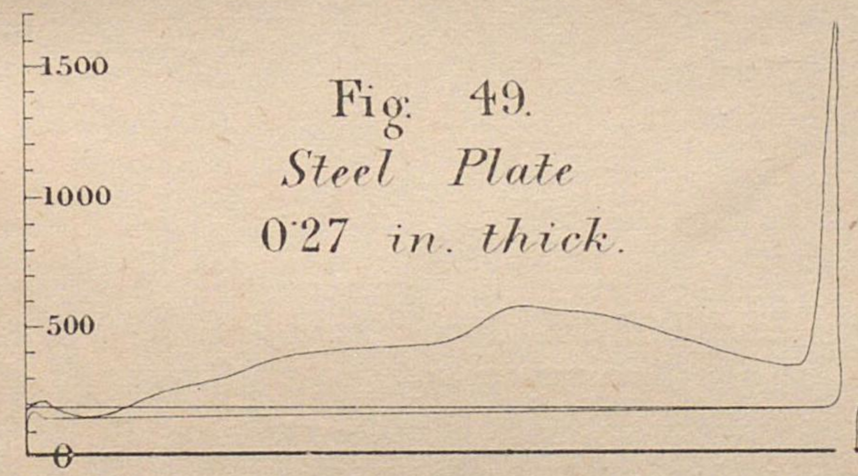
TOULON HYDRAULIC MACHINERY. *Plate 55.*

Diagrams taken from Flanging Machine.









Dished Steel Plates
for fitting to longitudinal bulkheads between cross beams.

Fig. 51.

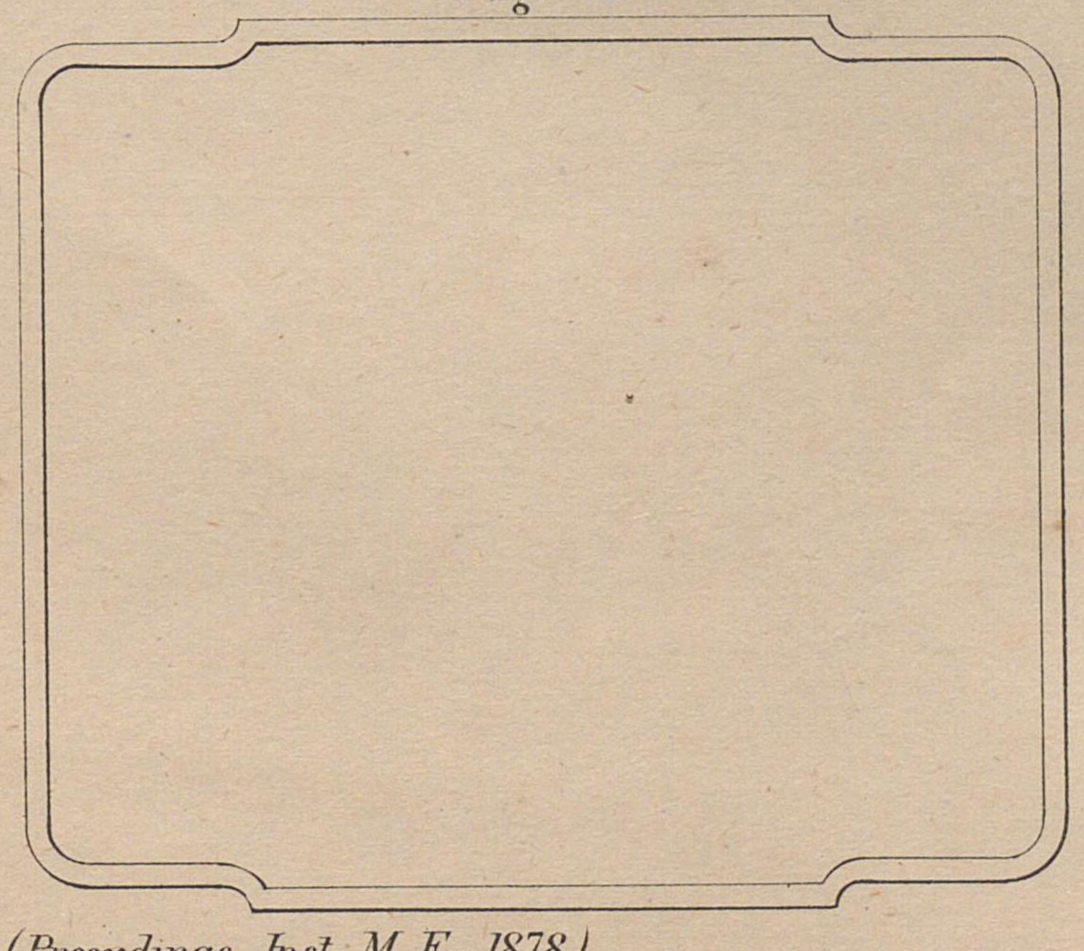
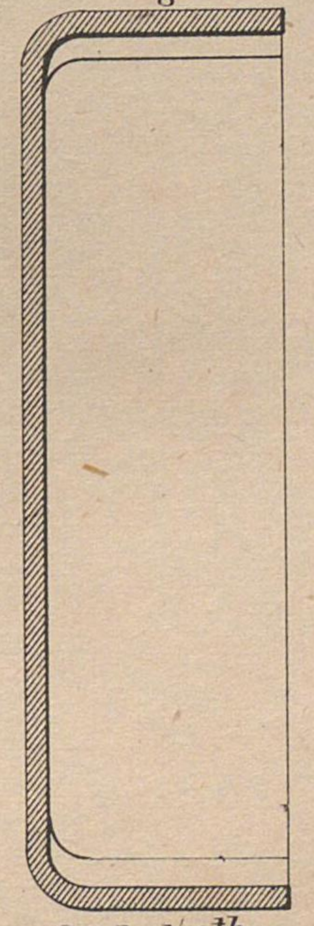


Fig. 52.



(Proceedings Inst. M. E. 1878.)

Scale 1/5th