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CABLE RAILWAY PROPULSION.

✓ BY

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S. S. B. Oct. 13 1884

TECHNICAL SOCIETY OF THE PACIFIC COAST.

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CABLE RAILWAY PROPULSION.

By W. W. HANSCOM, M. E., M. Tech. Soc.

Read June 6, 1884.

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MR. PRESIDENT AND GENTLEMEN—In presenting for your consideration a paper on Cable Railway Propulsion, I must premise my remarks by the statement that the subject is so comparatively new in its practical results, and so little has been done in the development of the system outside of San Francisco and Chicago, that we have but little of the experience of others which has been published upon which to rely for the collection of data. The subject matter of this paper will be mainly a collection of such facts and experiences as have come almost directly under my own observation, and such conclusions as I have arrived at are from the grouping together and endeavoring to find from these facts what constitutes some of the more important conditions connected with the construction and operation of cable railways.

The record which I have of the great number of persons who have directed their attention to this mode of propulsion of cars at once shows that the subject is not new, and that it has only waited until the particular time and conditions should arrive when it would be practically developed. This time arrived and the conditions were propitious, when the Clay Street Hill Cable Road was built, and from the time at which this experiment passed into the domain of practical and commercial success an increased interest has been manifested in the pecuniary results

to be attained, in comparison with the hauling of street cars by horses, and I need not enumerate the list of inventors whose patents have a bearing on this subject, and number several hundred, but pass directly to the features of the cable roads constructed and operated in our city.

In the construction of the Clay Street Hill Road, it was necessary to observe the strictest economy, as it was an experiment, or at least so considered by those interested, and consequently it was left to further experience to determine, in case of success, what should be the character and kind of material and workmanship to be adopted in the construction of additional cable roads.

In observing the condition of the street along which this road was to be constructed, it was found that it consisted almost entirely of grades, except at the crossings, which were level. These grades being in some places as steep as 1 in $6\frac{3}{10}$, and the steep grades made a sharp angle when leaving the level crossings, with curves of very small radius connecting the various changes from grade to level and from level to grade. The street was straight, so that there was only vertical and no lateral deflection. This was the serious matter, as in leaving a level crossing for a steep upward grade, the strain on the cable would bring it upward and through the slot of the tube made for the connecting bar between the car and the rope. Consequently it would require a sheave above the cable to keep it down at these points, so that while sheaves were used to support the cable when the weight and strain were downward, they were also required at certain points to counteract the upward strain, and whatever arrangement or apparatus might be used to correct the cable with the car, that part which clasped the cable must pass above the sheaves placed under the cable to support it and must also pass under the sheaves which were placed above the cable at points which were required to be kept down. These sheaves therefore must be at such distance apart, vertically, in reference to each other and the track (over which the wheels of the car which carried the gripping apparatus were to run) that when the car would be immediately over one of the sheaves which was under the cable, that the bottom parts which clasped the cable would be some little distance above the sheave, so that a slight

variation of the car or gripping apparatus in height would not bring the grip and sheave in contact. Also when the car is directly over a sheave which is above the cable to keep it down, the top of the part which clasps the cable must be a sufficient distance below the sheave that it will not touch in passing. In order that these requirements may be met, the vertical part of the gripping apparatus which passes upward through the slot of the tube and connects with the car, must be so located that it will pass to one side of the sheave above the cable, and this is arranged by projecting the part which clasps the cable sideways from the vertical part, which is shown by the drawing.

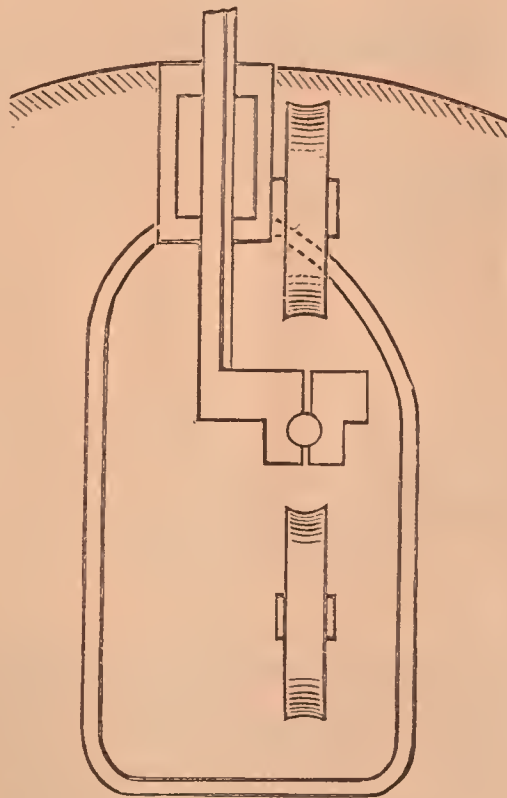


FIG. 1.

It will be seen that when the cable is held in the clasp, (or, as they are called, the jaws of the grip,) it is lifted above its normal position in the groove of the lower sheaves, and also that it is carried down away from the sheave, which is used to keep the cable down where sharp angles occur at upward change of grade.

This drawing shows the upward tendency of the cable in crossing a street and going up a grade; it being lifted from the lower or carrying sheave and brought up against the under side of the top or depression sheave.

This accedes to the conditions so far as a line is concerned, when there are no horizontal deflections occurring, and there are none on the Clay Street Hill Road.

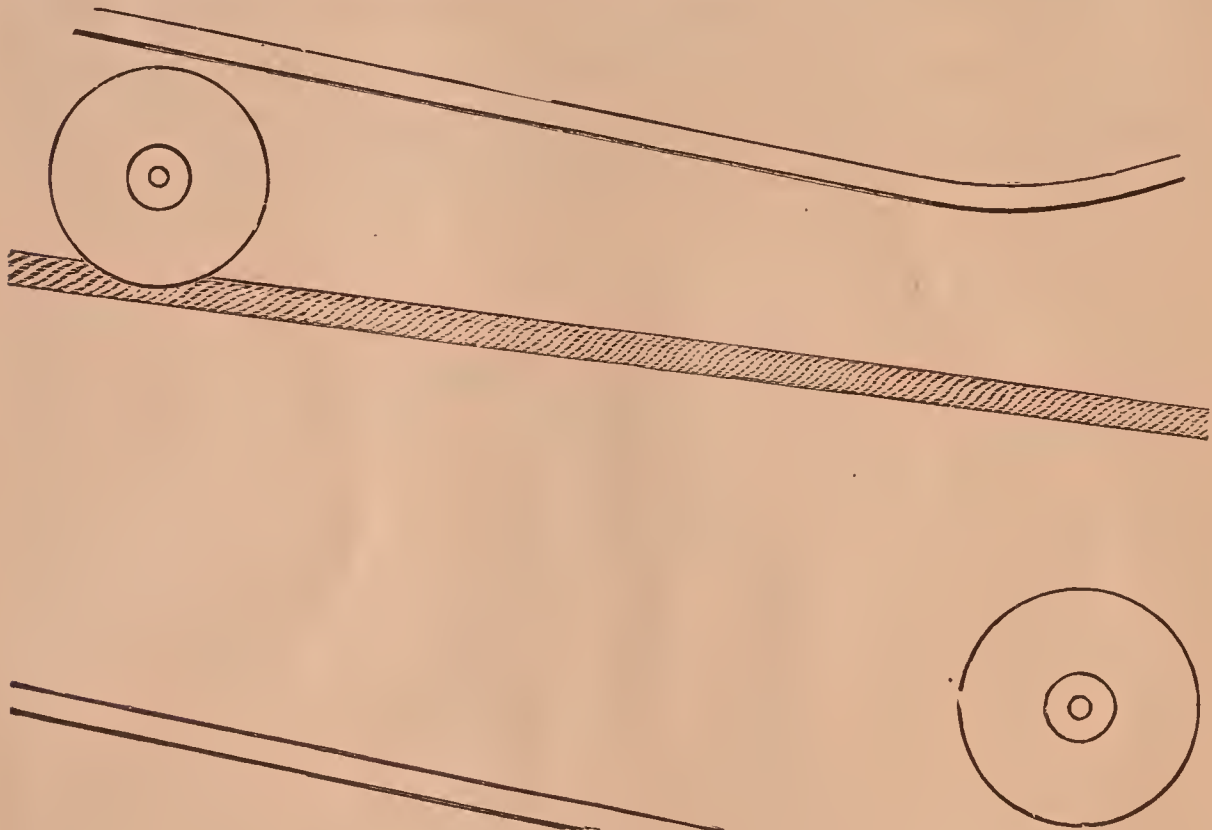


FIG. 2.

The form and size of the gripping arrangement being determined upon, such space between the lower and upper sheaves must be allowed that the grip will easily clear each, and some additional clearance space for variations which may occur in the height of the grip by the wear of the wheels, or variations in the level of the track in reference to the tube, added. Then the diameter of the sheaves being fixed, this fixes the depth of the tube, and the width will be fixed by the width of the grip and sheaves and necessary clearance.

In constructing the Clay Street Road, wood was used to a large extent. Cast iron frames were made to conform to the desired cross-section of the tube, and placed about three feet apart, they having ribs cast on them so that planks two inches thick

could be laid from one to another, and held in position by the ribs, thus forming a tube of wood with supporting ribs of cast iron.

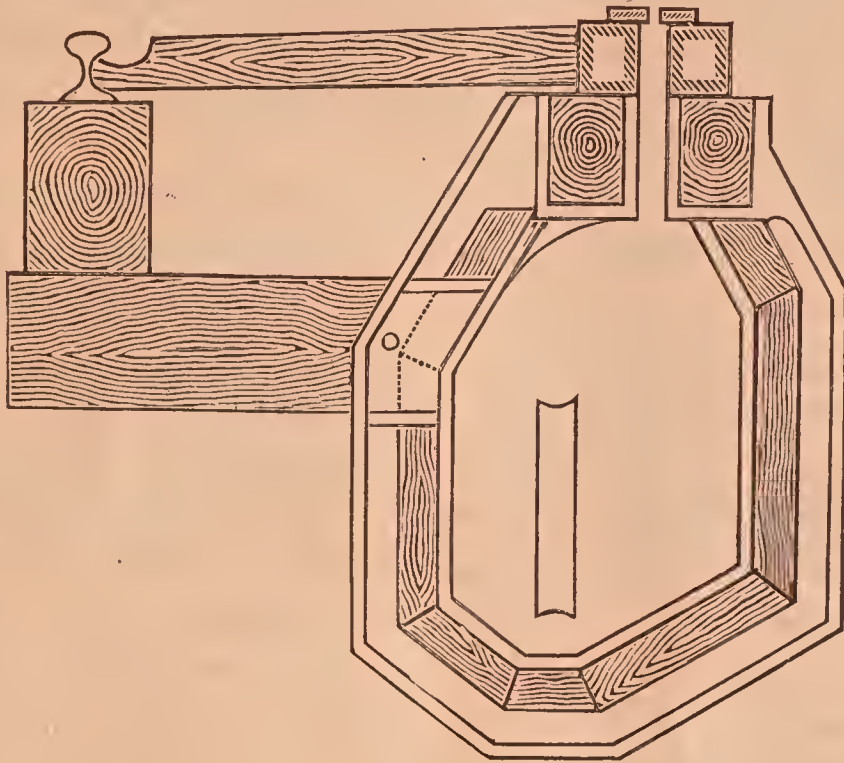


FIG. 3.

Ties extend laterally from these cast iron ribs, upon the outer ends of which are placed stringers which carry the rails. The castings, as shown, are open at the top, so that the vertical part of the grip may pass through, and close on each side of this opening, extending from one casting to another, are short carlines, which are bolted at each end to the casting, thus keeping them at the proper distance apart and maintaining them in proper position. On top of these, and extending over several of the castings, are laid wood scantlings, which form the slot, and to protect the top from wear are placed iron straps fastened to the scantlings by wood screws. The surface of the roadway between the slots and the rails on each side is formed of wood plank, as shown. This forms the general construction of the tube from one end of the road to the other, except at the point where the cable is made to enter the engine house to be connected with the driving machinery.

Along the straight portions of the tube the lower sheaves are about nine inches in diameter; those above the cable being about

seven inches, as it was considered necessary to keep the distance between the surface of the street and the upper, enlarged part of the tube as small as consistent with strength to support the traffic of vehicles on the street, and also that the distance between the cable and the part of the car from which projects downward the vertical bar or shank (which has the grip on its lower end) shall be the minimum.

At the ends of the road are placed large sheaves, around which the cable passes to return, there being four tracks and two tubes, and the diameter of these large sheaves, which are placed with the axes vertical, is equal to the distance between the centers of the two tubes or sets of tracks, which is about eight feet. Experience in the use of wire cables had shown that where the cable makes any great change of direction, as a right angle or more, and even much less, the diameter of a sheave over which the cable passes should be about 100 times the diameter of the cable. In this road the cable was a little less than one inch in diameter, and the sheave about ninety-six inches. In order that the cars might be transferred from one track to the other at the end of the route, two turn-tables are arranged, the diameter of each being a little less than the distance between the centers of the two sets of tracks, each turn-table having two rails across it, equidistant from the center. These two tables are geared together, so that by turning one through an angle of ninety degrees the two sets of tracks will be brought in line with each other, and a car which had previously been brought from one of the lines of rails on to the table, can be pushed on to the other table, and then, by reversing the movement of the tables, the tracks are brought in line with the main line, and the car can then be moved on the opposite track, and on its return journey.

In transferring ordinary cars from one track to another, the tables would be simple plates placed on central pivots, and supporting rolls around the circumference; but the car which carries the griping apparatus and is called the dummy, having the shank of the grip projecting downward and through the slot into the tube, would in this case have to be raised out of the tube to allow the dummy to go on the turn-table. This operation would not only require time but the expenditure of considerable labor. That these might be avoided, the table was constructed of two

parts, an upper and lower plate connected together by ribs or ties. The top plate has a slot across its diameter, and the space between the upper and bottom plate will allow the lower portion of the grip to pass through—the ties between the two plates being far enough apart for the grip to pass through without touching. Now, as shown before, by revolving the tables one-quarter way round, the slots, through the upper surface of the plates, are brought in line with each other, and the dummy can, with its grip, be pushed from one table to the other, and so on to the other line of rails.

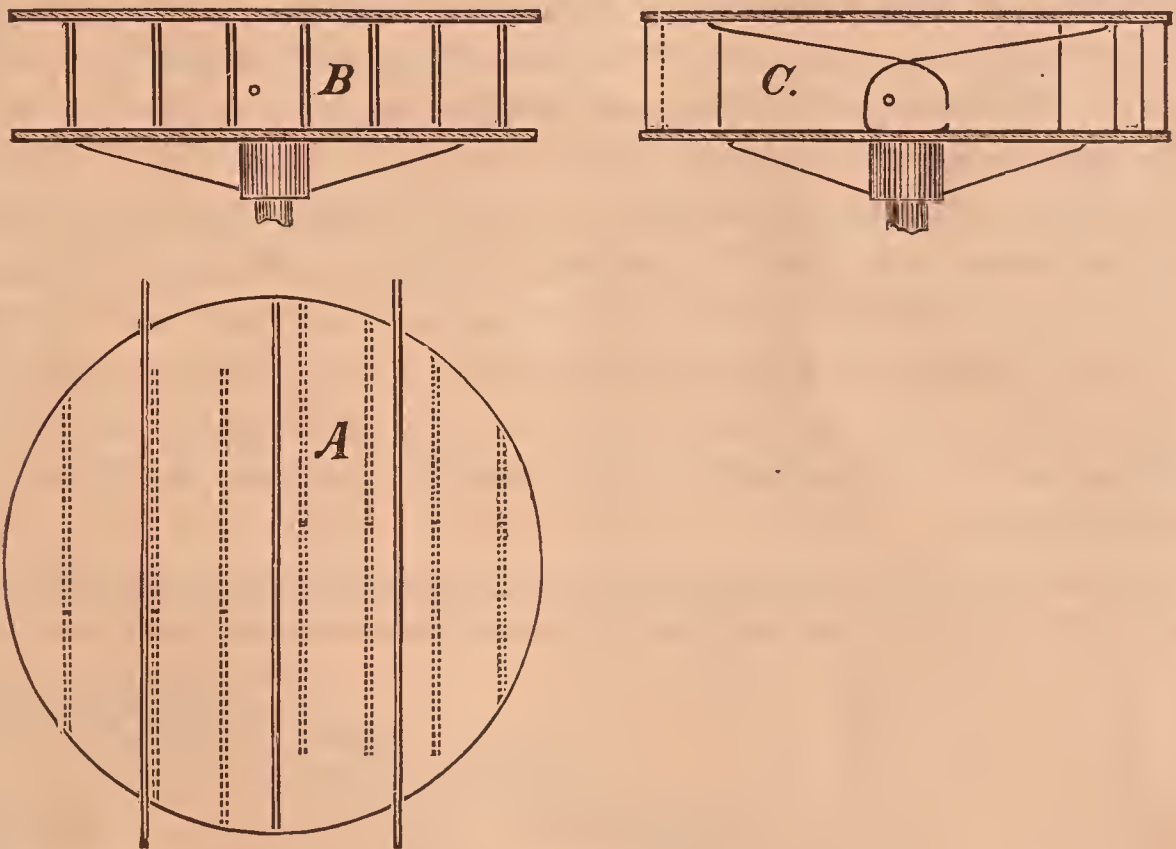


FIG. 4.

There is still one other requirement, and that is, that the cable shall also pass through the table, so that the dummy may be drawn on to the table and then dropped, and in order that this may be effected, the cable is carried through the table and some convenient distance beyond, before passing around the large sheave. Now the connection between the upper and lower plates of the turn-table must be so located that the table may be revolved through one-quarter of a circle without bringing this connection in contact with the cable, which is continually moving through.

A is a plan of the turn table.

B is a vertical section at a right angle to the slot which divides the top plate.

C is a vertical section in line with the slot through the top, and shows the manner in which the ties between the two plates are arranged so as to allow the cable to pass freely through when the table is turned so as to allow the car or dummy to pass from one table to the other.

As the large sheave at the end of the route lies in a horizontal position, or nearly so, a large pit or chamber is required, and the covering of this must be of sufficient strength to sustain any traffic which may pass over it, as it may be in the middle of the street; therefore, the thickness of this cover, and the fact that the axis or shaft of the sheave is vertical, it requires journal-bearings, both top and bottom, and this, added to the thickness of the cover, will carry the groove of the sheave some distance below the line of the cable in the tube, so that the cable at the point of leaving the tube to enter the chamber containing the large sheave will be deflected downward over a sheave somewhat larger than those supporting the cable in the tube, say 30 inches in diameter.

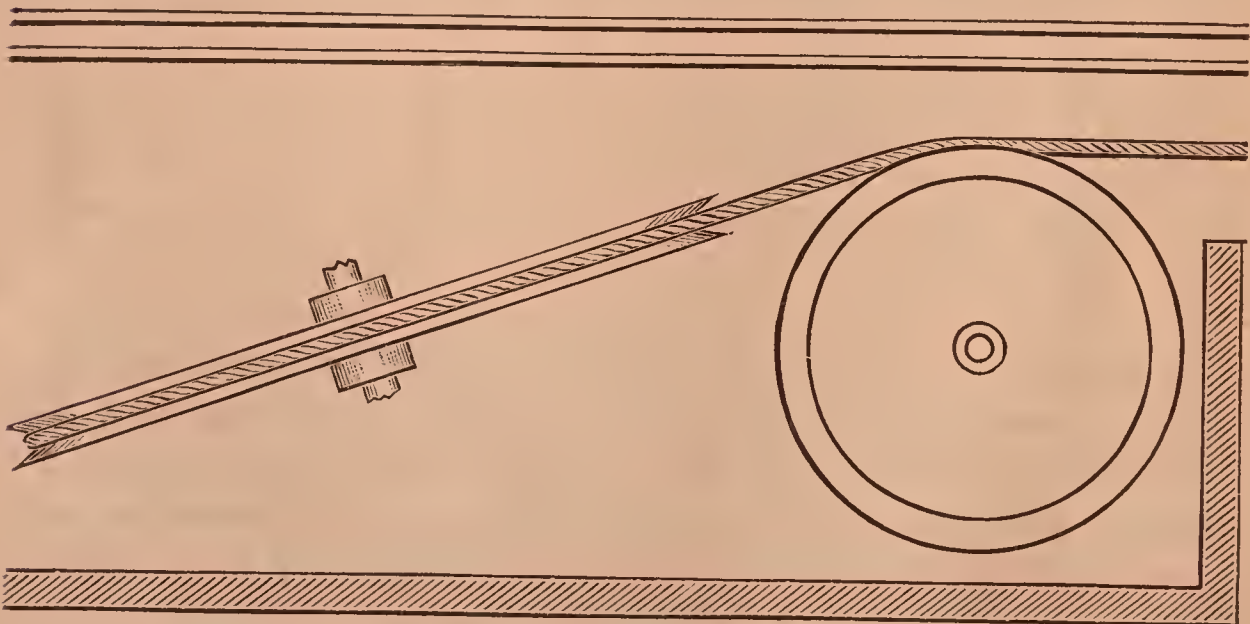


FIG. 5.

This large sheave is carried on a frame having wheels which run on a track prepared for it and of such a length that it may have a movement of 10 feet or more. A chain attached to the

end of this frame or carriage passes over a sheave at the rear end of the chamber and has a weight attached which maintains a tension on the cable passing around the large sheave, and will take up any stretch that may occur in the cable, and yet in case of excessive strain will yield and prevent rupture of the cable. A similar arrangement is at each end of the road.

At the point where the cable enters the engine-house the cable is deflected vertically over two sheaves eight feet in diameter, and thence at right angles to a horizontal direction, when they enter the engine-room, passing over a driving drum; thence over an idle sheave; thence over the driving drum again and backward to a sheave under the street, under which it passes and upward over a second sheave to the direction of and into the tube, when it continues on its route. These sheaves and driving drum are all eight feet in diameter. The driving drum is geared to the engine so that the cable has a speed of 528 feet per minute, or six miles per hour. There are 11,000 feet of cable employed in one piece, and it makes a total revolution over its route in about 21 minutes.

In changing the cars at the ends of the road the dummy is disconnected from the car and first transferred, then the car follows and is connected again to the dummy, and the train is ready to start so soon as the cable has been taken into the grip. This grip is so constructed that the cable is admitted between the jaws from the bottom side, and, as by opening the jaws the cable falls out, dropping away from the grip down into the carrying sheaves under the cable, it becomes necessary, in order to get the cable within the jaws again, either to raise the cable or to lower the jaws until they shall have brought the cable within them, and then raise the grip, bringing up the cable to such a height that the bottom of the grip will sufficiently clear the sheaves. This grip is so constructed, that by a hollow screw at the top passing through a nut, which is supported by a frame and encircled by a hand wheel, the turning of the nut will lower the hollow screw, and with it the gripping jaws, until they are low enough to take the cable, when the jaws are partially closed, so that while they will prevent the cable from dropping down it will still freely pass through and not draw the train un-

til sufficient pressure is put upon it, which is done by means of a screw drawing a wedge between a frame and a bar, thus forcing the jaws against the cable with any desired force, the power by this arrangement being as 480 to 1; in other words, one pound applied to the screw by the man operating the grip gives a pressure of 480 pounds on the cable, less the friction of the moving parts.

That the cable may be spared abrasion in moving through the jaws of the grip when the dummy is standing still and the cable passing along, four rolls, having their circumferences grooved to suit the rope, are so arranged that they are a little in advance of the jaws and support the cable before the jaws come in contact with it. A spring is placed behind these rolls, so that they may yield when the jaws are brought together to grip the cable.

The cars are of such size that they will seat 14 persons, and weigh, unloaded, 2,800 pounds each; the dummies weigh 2,850 pounds each, and have seats upon them for 16 passengers.

As this road was extended after having been in operation about five years, some changes were made in the construction of the tube and in the cast-iron frame, which was extended laterally, so that it now comes under and supports the rails, and has its base extending the same distance, the web being perforated in the centre to the shape of the tube, and also openings between the central, and each side-ribs or flanges being formed all around the openings and the outside of the frame. The tube in the extension is formed of concrete, and as it passes through the openings of the frame it forms a monolithic structure the length of the road to which this mode of construction is applied. The slot is formed by channel irons six inches deep, with two-inch angles top and bottom bolted to the casting, and wood carlines are placed from frame to frame only to support the wood plank which forms the street surface between the rails.

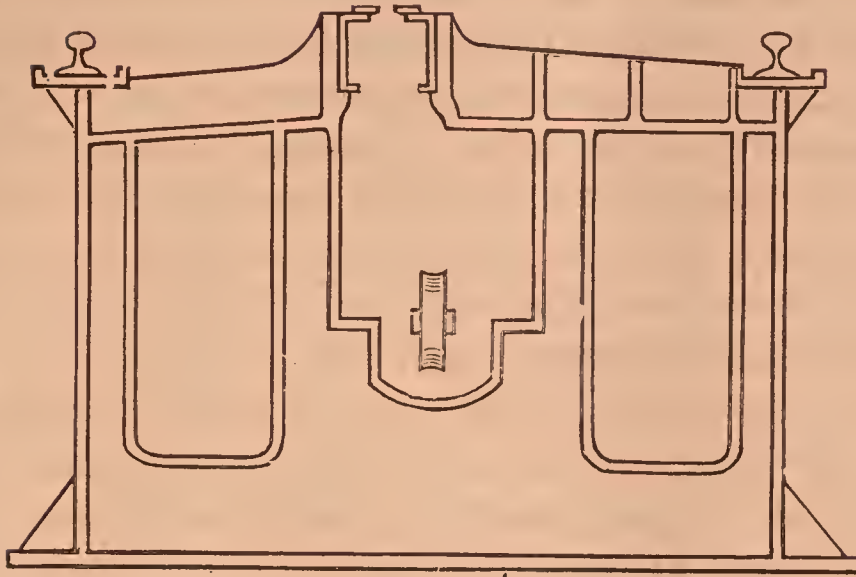


FIG. 6.

I have thus stated generally the most important features of construction in the Clay Street Hill Road, and in referring to the other roads will only allude to the more prominent conditions which involve changes in construction and operation, when they vary from the Clay Street Road. The next road to be operated by cable in this city was the Sutter Street Road, which had been operated by horses, but in 1876 was converted to a cable road. The more prominent change was in the construction of the gripping apparatus, which was arranged so that the jaws which take and hold the cable are moved vertically, so that the cable enters between the jaws of the grip from the side instead of from the bottom, as does the one in use by the Clay Street Road. These are distinguished from each other by the direction from which the cable enters the jaws. That of the Clay Street entering from the bottom is called a "bottom grip," and that of the Sutter Street entering from the side is called a "side-grip."

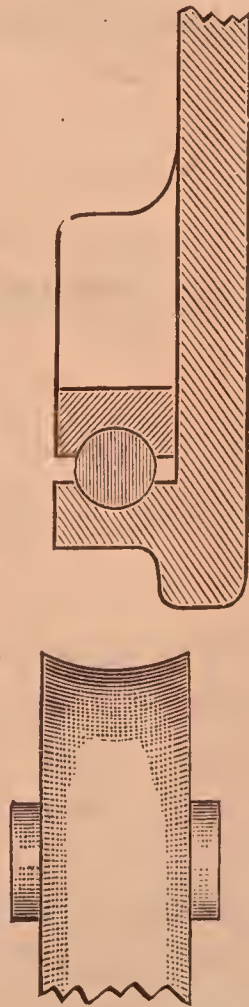


FIG. 7.

The side-grip is so constructed that it cannot be lowered like the Clay Street grip to take the cable, but has a fixed position when placed on the dummy. As the cable will normally lie directly under the jaws of the grip, either the jaws

or the cable must be moved sidewise to allow the cable to be brought up to a height which will allow it to enter the open jaws of the grip. As the readiest means of accomplishing the raising the cable, a sheave is so placed in the tube that the cable will be raised by it to a height corresponding to the opening of the jaws; but as without lateral movement of the grip it would strike the sheave, the rails and iron forming the slot are deflected, to carry the dummy and with it the grip to one side sufficiently to pass the sheave, and immediately again the track and slot is deflected into its normal direction, thereby bringing the opening of the jaws over the cable before the cable has sagged or dropped sufficiently to prevent it entering the grip.

In the later constructions of the grip, the points at which it is supported on the car are so arranged that it may vibrate from this point laterally, so that the dummy need not be carried bodily sidewise; therefore only the irons forming the slot are deflected. Wherever it is desired to let the rope out of the grip and take it up again the road is formed in this way, these points having been determined upon in advance.

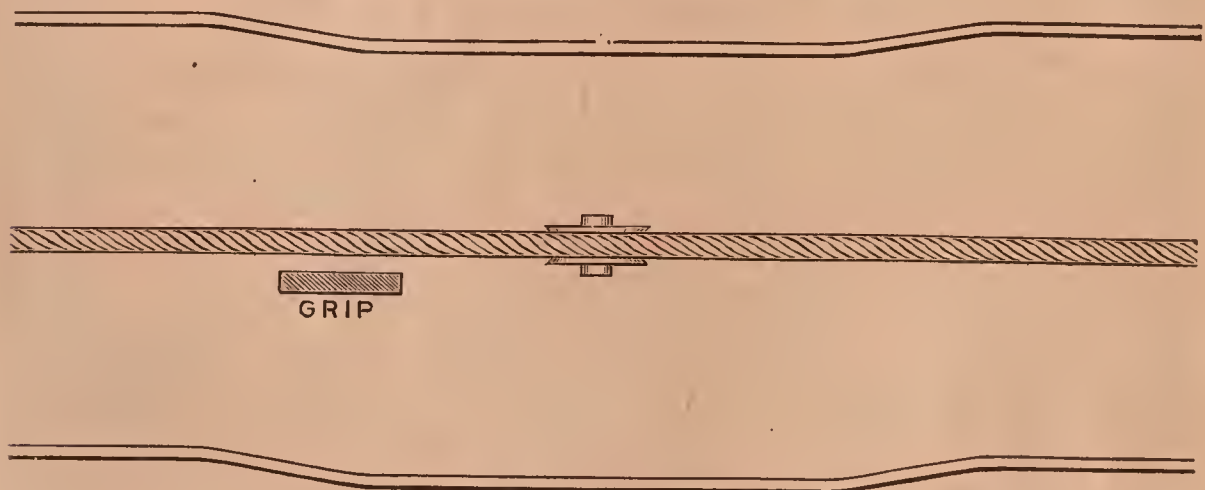


FIG. 8.

The plan for switching from one track to the other is different from that in use on Clay street. A tube is constructed leading across from one main tube to the other, and, following the curve of the rails which transfer the car and dummy from one main track to the other, the tubes are joined at the point of intersection. The slots of the tubes join similarly, and a tongue is placed at the junction of the two slots to cover the large opening into the tube at this point, and is also used to direct the shank of the grip into the proper slot.

These dummies and cars are not turned round in the operation of switching, as by the method by turn tables on Clay street, so that the cable lies on the same side of the tube, or rather the same side of the slot, in both of the main tubes. Of course, in switching or passing from one main tube to the other the rope is dropped from the grip, and as the dummy passes on to the main line the cable is brought up so that the grip may run on to it, as before described. At points where the car and dummy are transferred through a switch it is necessary to have a falling grade, so that, after dropping the cable, gravity may assist in carrying the dummy through the switch and on to the other main line. Where the street is officially level, latitude has been allowed the cable companies to make a grade to suit their desires.

At the point where the cables enter and leave the engine-house there is an intervening space between the two large sheaves which deflect the cable from and into the tube and engine-house. The cable is dropped from the grip just before reaching these sheaves; and a slight grade is given the street in the direction in which the car is moving, so that the car and dummy will start themselves or be carried over by gravity.

The driving drums are different from those in use on Clay street, where the drum has clips on its periphery in principle of action like Fowler's for driving wire ropes; while in Sutter street there are two single grooved drums in line with each other, one being slightly higher than the other.



FIG. 9.

These are so placed that the cable coming in from the street will lead fairly on to the highest, which is in the rear, or farthest from the street. Passing around this, the cable is led forward and up, over, around and down under both of the drums form-

ing the figure eight nearly. Thence the cable goes backward and around a vertical sheave, which is carried by a carriage which can be moved on ways or rails provided for it. After passing around this latter sheave it goes forward again over the two driving sheaves or drums to the sheave in the street, by which it is again deflected into the tube.

The movable sheave around which the cable passes before reaching the street is arranged with a chain and weight, so that a definite amount of tension can be placed upon the cable, proportionate to its size and the work it has to do. This road has one other feature not in the Clay street road. That is, horizontal curves. The Larkin street cable passing a right angle from Polk into Post and from Post into Larkin and back again on the return track for deflecting the cable around these curves, which are from 40 to 50 feet radius; a series of horizontal pulleys, having no groove—but straight faces with a flange on the lower edge, are placed on the inner side of the curve about three feet apart, so that the deflection from one pulley to the next is slight. These pulleys are about 20 inches in diameter, and are set in iron cases which carry the bearings for the upper and lower journals of the upright spindles or shafts. The cable runs against the faces of these pulleys and they are set far enough to one side of the slot so that the grip in moving along would easily pass them; but to avoid positive contact between the grip and these pulleys, a bar of iron is placed around the curve, just above and a little in advance of the face of the pulleys, and, at a point on the shank of the grip, which would come opposite this bar, is placed a piece of iron called a wearing piece, which, being made smooth, comes in contact with and slides along the bar, thus keeping the jaws of the grip from contact with the pulleys.

The method of applying power to the grip used on this road is by a long lever, the short arm of which forms one part or joint of the knuckle or toggle lever, while the power is applied on the Clay street grip by means of a screw, or rather to a nut working on a screw, the nut being enclosed in and fastened to the hub of a hand wheel.

The construction of the tube for this road was originally similar to that first used on the Clay street, that is cast iron

frames and a tube of wood, but later the construction of the tube has been made by the use of wrought iron frames reaching to and supporting the rails, and making a skeleton tie for the rails, slot irons and tube, which latter is formed of concrete.

The California street road, which was the next one built after the Sutter street, is similar in its conditions to the Clay street, but having some steeper grades, and as it was intended for heavier traffic a larger cable was used, being one and one-quarter inches in diameter.

The tube is constructed of a frame of wrought-iron, reaching out and supporting the rails, which was copied in the later construction of portions of the Sutter street road above alluded to. In the case of the California street road, however, the main element of the wrought-iron works was made of old rails.

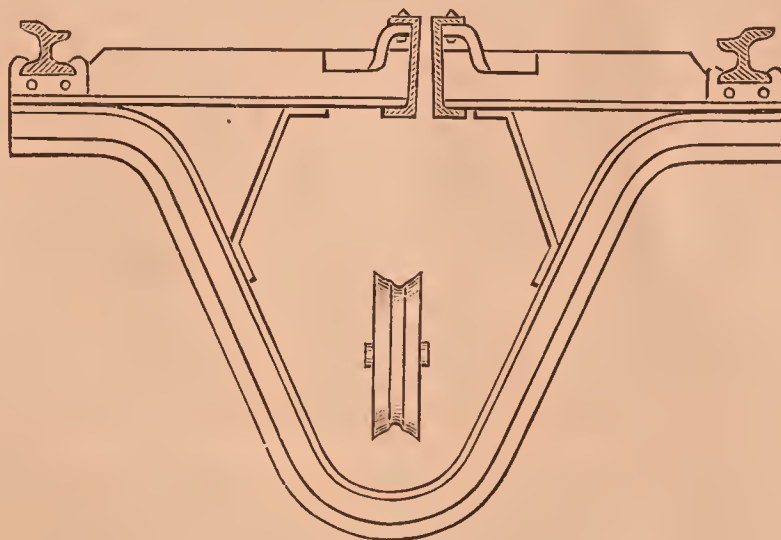


FIG. 10.

At the location of the engine house, ground area being limited, the driving drums for the cable were placed under the street, one under and in line with the center of each track. The drums are the same as those used on Sutter street. Tension sheaves are used, the cable passing over them both before going onto the driving drums and after leaving them, and before passing into the tube. The action of these tension sheaves was by gravity, but instead of having a weight attached to the movable carriage which carries the sheave, the track on which the carriage runs in this case is on an incline, so that gravity acts directly upon the carriage and sheave. The carriage is so constructed that weight may be added as desired in a boxed part.

Switches are used at the termini for transferring cars and dummies from one track to another, a tube being used for the grip to pass through the same as on the Sutter street road. The grip used is the same as on Sutter street, that is a "side" grip.

The Geary street road is similar in general conditions to the Sutter street, except that it has no curves, the road being straight from end to end, and the angles at the changes of grade are so slight that no depression sheaves are used to keep the cable down.

The grip used on this road is a "bottom" grip, but is operated by a lever applying the principle of the toggle joint.

The cars are transferred at one end of the road by a switch like Sutter and California streets, but at the other by a turn-table. The turn-table being of a diameter sufficient to hold one car is placed with its center of revolution in a line with the center of the out-going track. The incoming track is curved, and the straight portion running onto the turn-table forms an angle with the out-going track of about 30 degrees. This economizes space, and dispenses with the second table as used on Clay street. The driving drums in use on this road for moving the cable are different from any other road, there being two, and each having several concentric grooves so that the cable is passed around the two drums until a sufficient number of wraps are made to prevent slip. In this case, no tension sheaves are used to give adhesions to the cable around the drum. Four or five wraps of the cable are all that is necessary. The tension sheaves, for taking up the stretch and slack of the cable are on movable carriages, and are drawn backward by a long screw.

The Union street or Presidio and Ferries road has the steepest grades of any road in the city, and has one horizontal curve, where the line passes from Montgomery Avenue to Union street. In this case, the cables are led away from the curve of the track, passing around large horizontal sheaves to change the direction of the cable from one street to the other, and the grades at the curve have been so modified, that the cable having been let out of the grip, the train passes the curve by its momentum, assisted somewhat by gravity.

The driving drums are the same as used on Clay street; also the grip.

The transferring of cars and dummies at the termini are by switches, turn-tables being used only at the engine house for turning the cars on and off the road.

The Market street road, the latest built, has some features different from all others. The construction of the entire railroad bed is the same as California street, except in the form of iron work of the frame for the latter, which is of the same kind of materials as are used on California street. The cars carry the grip instead of having a dummy, as on all the other roads.

The driving drums are the same as are used on California and Sutter street roads. At the junction of Market with Haight and also at McAllister streets the Market street cable is dropped, and the cable running in Haight and McAllister streets is picked up, as the car is carried by its momentum around the curves into either of these streets, assisted by gravity due to a grade modified for the purpose. At the curve on Market and Valencia streets an auxilliary cable is used for bringing the cars past the engine house. This cable is used only on one track coming east, the cars going west having to drop the cable and are carried around the curve by gravity. The speed of this cable is one-half that of the main cables and it is driven by a grooved pulley or sheave on the line shaft which carries all the other driving drums.

The cables on Market, Valencia and Haight streets are driven by the same engine, while a separate engine is used for operating the McAllister street cable. At Haight street, the curve from Market street is passed the same as on the Union street road at Montgomery avenue and Union street, but at the junction of McAllister and Market after dropping the Market street cable, the McAllister street cable is picked up before reaching the curve, and the grip holds the cable while passing it, the horizontal pulleys around which the cable passes being arranged similarly to those heretofore referred to at the corner of Post and Polk, and Post and Larkin streets on the Sutter street roads.

At the termini of these roads, the Market, Valencia, Haight and McAllister streets, which comprise the Market Street Company roads, the cars are transferred from one track to the other by a turn-table somewhat similar to that used at one end of the Geary street road, with this difference: On Geary street the

dummy or car is not turned around, but either end runs foremost, so that in changing the turn-table from the incoming to the outgoing track the table is moved through only thirty degrees.

On the Market street cars the grip is placed on the truck at one end of the cars so that the car requires to be turned half way round at each end of the route. The table in this case has to be moved through 180 degrees, and there are two parallel tracks across this turn-table, each equidistant from the center, the distance between the centers of the tracks being equal to the distance between the centers of the main tracks, so that when the table has been moved so that a car is in position to go off, the other track on the table is in position to receive a car from the incoming main line. As these turn-tables are large and heavy they are turned by gearing driven by the main cable, through a grooved pulley, which being connected with the gearing is brought against the cable with sufficient pressure to give the desired power. The cables used by this company are the size of the ones used on California street ($1\frac{1}{4}$ inch in diameter).

On McAllister street where the road crosses to Fulton street, there are four curves of about 45 degrees each, with the horizontal pulleys arranged similarly to those on Post, Polk and Larkin streets of the Sutter street road.

These facts concerning the general features of the various roads are incidental to important questions, that of the economy in construction, maintenance and operation of the cable system of propulsion for street cars.

In order to direct an intelligent inquiry into the subject, I have divided it into three general heads:

- 1st.--Construction.
- 2d.--Maintenance.
- 3d.--Operation.

Each of these divisions, of course, have many details, but for the purpose of this paper I have made them somewhat general.

Under the head of Construction, I have placed the construction of :

- 1st.--Road-bed and tube.
- 2d.--Driving machinery.
- 3d.--Gripping apparatus and cable.
- 4th.--Cars.

Under the division of maintenance I have placed:

- 1st.—Road-bed and tube.
- 2d.--Driving machinery.
- 3d—Gripping apparatus and cable.

Under the division of operation, I have placed:

- 1st.—Power for driving the cable.
- 2d.—Power for driving the cars.
- 3d.—Power for hauling passengers.

In the construction of the road-bed and tube, it will be noticed that we have advanced from the first experiment of wood and iron to concrete and iron, with stone paving for the surface of the street and with steel for rails. Probably we have gone to the extremes in this respect as far as cost is concerned, for we have constructed the tube and the road-bed of the most lasting materials, with all the strength to support the heaviest traffic which will ever be allowed over the streets of any city, the surface being composed of materials which are best known, by experience and judgment, to resist the wear to which they may be exposed; and these materials have been used in a generous manner. The increase in economy will consist in the reduction of material to the minimum required to meet local conditions, and an exercise of careful judgment in the manner and distribution of labor in the combining and placing in position the materials of construction. The apparent cost of similar forms of construction of the road-beds and tubes of the cable roads in this city vary so much that it would be delusive to base estimates of the cost of a projected road upon the generally reported statements concerning the cost of those already built. The conditions to be observed for the street surface are that the grades of the street shall not be disturbed, or that no protuberances or depressions shall be made to interfere with traffic of teams or vehicles, and that the strength of the tube shall be sufficient to easily support

the heaviest weight which may ordinarily come upon it without disturbing its shape.

In the construction of the driving machinery, some basis for consideration may be had by a comparison of the weights of the moving machinery for the roads in this city, when they are each compared with the weight of the cables which they propel and support. It may be taken for granted that the weight of supports and foundations for the moving machinery will be proportionate to the weight they have to carry.

The weights of moving machinery include the moving parts of the engines, shafts, fly wheels, pulleys, sheaves and gears, in the engine house; also, the deflecting sheaves, which change the direction of the moving cable, and the carrier sheaves, which support the cable in the tube along the street.

The approximate weights of moving machinery and cables on the various roads of San Francisco are as follows:

Name of Road.	Weight of Machinery, pounds.	Weight of Cable, pounds.
Clay	22,000	15,400
California.....	100,000	65,000
Sutter.....	240,000	68,000
Geary.....	60,000	37,800
Union.	80,000	30,500
Market, Valencia and Haight.....	240,000	164,412
McAllister.....	100,000	68,000

To compare the weight of moving machinery with the weight of cable, let the weight of cable be 1, then the weight of moving machinery will show as follows:

Name of Road.	Weight of Rope. =1.	W't of Machinery
Clay	1	1.428
Market, Valencia and Haight.....	1	1.459
McAllister.....	1	1.47
California.....	1	1.538
Geary.....	1	1.587
Union.....	1	2.622
Sutter.....	1	3.529

These figures are somewhat suggestive. As the cost of machinery of this character is generally sold in the market by the pound, it is comparatively easy to estimate the cost of the driving machinery, and as the cost will be generally in proportion to the weight, due consideration should be given to this division of the construction account.

In the construction of the gripping apparatus there are several considerations which have much influence on the cost: First, is the work which they are required to do; second, the conditions under which this work has to be performed; and third, the promptness with which they can be manipulated. In referring to the first condition, the work which the grip has to perform depends to a large extent on the grades over which they have to act. Allowing 20 pounds per ton for the friction of cars, then a grade of one in one hundred, or one per cent., doubles the strain on the grip. The steepest grade on the roads of this city requires as much power to be developed by the engine in hauling one train over it as would be required to haul eighteen trains on a level.

While the amount of work put on the grip calls for strength and power, the requirements of passengers and care for human life necessitate a construction which will admit of prompt action, and this is a very important feature in their construction.

There may be conditions existing under which it would be greater economy for the grip to break than to withstand the strain to which it is liable to be exposed, but as a general proposition it is a fallacy to assume anything of the kind. It is a condition of things which should not occur, and will not, with competent engineering ability.

The first consideration is to construct the grip to meet the actual requirements as to work, promptness, ordinary wear and convenience in handling.

In the construction of the cable much has yet to be learned. The principal condition is that it shall be sufficiently strong, after considerable wear, to withstand probable extraordinary strains; at the same time it shall not be unduly large, which adds to the weight and cost. Having an exterior surface, which is hard, so as to withstand the abrasion of the jaws of the grip, yet the

flexibility of the cable shall be of such a degree that it will easily bend in passing over the sheaves and drums which change its direction.

The greater the diameter of the cable the more friction and abrasion, and power required to bend it around the sheaves which it passes. Various kinds of cables have been used on these roads—both of iron and steel, and large and small—and with various degrees of hardness. So far, the crucible steel cable has been adopted in preference to any other, possessing hardness and strength, with flexibility. It is probable that changes in the lay or twist of the strands in making may effect an improvement in working.

In the construction of cars there is at present but little difference, in general views. Whether a dummy and car should be used together, or each car have a grip attached to it, is a question which will be answered differently by different local conditions, a prominent condition being all intelligent provisions for the safety of passengers in boarding and alighting from. As the larger part of accidents on these roads occur by the negligence of the injured, all means consistent with convenient access to and departure from the cars and dummies should be provided to prevent accidents.

In the maintenance of road-bed and tube, the present method of uniting concrete and iron leaves not much to be desired, the rails and the paving being the only parts that require renewals during many years. The rails and slot irons should be so put down that they may be taken up and renewed without detriment to the tube or unnecessary disturbance of the materials of which the tube is constructed.

Concerning driving gear and the moving machinery connected with the cable, the engines which may be used are so well known that any style, kind, or power may be obtained to meet any condition which would arise under local circumstances. In the various arrangements for carrying and deflecting the cables we have some differences in detail, but in plan all are similar. This is a matter that has not received the consideration that its importance demands. As a large portion of the power expended is exhausted in wearing out the driving machinery and carrying

and deflecting sheaves, these should have careful study that they may do the work assigned them with the greatest economy of wear and friction.

The first table shows the comparative weights of driving and carrying machinery and the cables which they carry. For the maintenance the cost may not always be in proportion to the weight, but the more weighty it is made the more is the wear and the more attendance and lubrication is required, as well as the increased cost of construction.

The third division under maintenance is the gripping apparatus and cables. These are mutually dependent one on the other. In the grip the wear comes on the jaws which clasp the cable, and these are now made removable, so that they can be made of the least possible weight and easily renewed, they being composed of soft cast-iron, that having with the experience so far proved the most economical of any material yet used. As the contact or connection between the grip and rope is entirely one of friction, it becomes a question of how great an abrasion or wear of the jaws of the grip can be allowed in saving the wear of the cable without costing more than the wear of the latter. When cables are newly laid they cause a much more rapid wear of the jaws of the grip than after they have been in use some time. The cause is that when new the exterior wires composing the cable are comparatively sharp cutting edges, but they are gradually worn down or flattened by the action of the grip jaws upon them, and, in addition, a coating of tar is put on the cable, which fills up the interstices, and by frequent applications the surface of the cable becomes so smooth as to resemble a bar of iron in passing rapidly along. This condition reduces the wear of the jaws and their life is increased from 200 to 400 per cent., and even more. There are two advantages in this filling of the cable with tar, one of which is to lubricate the cable to a certain extent, so that when taking hold to start a train the slip of the cable through the grip causes the train to start more gently and at the same time the wear on both grip jaws and cable. The tar alone on the cable would not effect this purpose, but by the addition of a small quantity of oil the surface of the tar is prevented from adhering to the grip or to the sheaves over which it

passes. The maintenance of the cable is one of the great expenses in the operation of cable roads, or rather it has been, from several causes, first of which is the excessive wear or action upon it by the jaws of the grip, especially when a road is first built and new men have to learn the road and get experience in the handling of the grip in starting and stopping. Whatever kind of cable may be used the abrasion may be increased very largely by this action of the grip, and the experience with cables in this city has demonstrated that the life of a cable may be doubled nearly by the manner of applying the grip to the rope.

Another cause is the construction of the grip for relieving the cable from frictional contact when the car or train is standing still and the cable allowed to pass through the grip. The grips are usually so constructed that the cable is supported and guided by grooved rolls when the jaws are loosened, the rolls keeping the cable from coming in contact with the jaws. Some of them, those called "side" grips, support the cable by rolls under the cable, the jaws having a vertical movement.

The rolls being stationary, so far as vertical movement is concerned, when it is desired to start the car, the upper jaw is forced downward on to the lower jaw. In one grip in use in this city, the upper jaw extends over the friction rolls, so that the cable is forced against the rolls, and the lower jaw being shorter than the upper in this case, the lower jaw has to be at such a height that the cable will be compressed between it and the upper jaw as well as between the upper jaw and the friction rolls, so that the cable must lie partially on the lower jaw, whether compressed or when moving freely through the grip. Another grip, the rolls are placed so far apart that both upper and lower jaws are considerably shorter than the distance between the friction rolls, and the upper jaw in being forced down on to the lower jaw, carries the cable with it, and when raised, the cable travels entirely on the rolls, being free from the lower jaw. In the grip in use on the Geary street road, the grip opens at the bottom, and not having any friction rolls, the cable lies and moves on the jaws of the grip when the cars are standing still. On roads where frequent stops are made, the wear of the cable increases. Other things being equal, the wear of the cable will be in proportion to the number of stops made, and its life inversely.

So far, the greatest factor in the destruction of the cable is the grip, and experience shows that skill in operating it adds to the life, and consequently economy of maintenance of the cable. The length of the jaw, which embraces the cable, is not known yet to affect the life much, but it seems that a jaw having a length of 8 to 10 diameters of the cable, is sufficient to prevent any pressure from bruising the cable, and yet will hold any load that has yet been taken up the steepest grades in this city. The practical requirements for economy of maintenance of cable, are that the grip shall be so constructed that friction rolls shall support the cable free from the jaws when it is passing through them, and the frictional contact shall be between the jaws entirely when propelling a car; that the operator of the grip shall be a man of intelligence, who can apply the grip to start the car quietly, and have the least amount of slip of the cable through the jaws. It does not follow that the one who starts the car the easiest or most gently, will wear out the jaws the soonest. Experience has proved the contrary. Lastly, continuous care of the cable, in keeping it well filled with tar and properly oiled.

Under the head of operation, I have placed the power required to propel—1st, the cable; 2d, the cars; and 3d, the passengers. In order that a comparison may be made, I have taken indicator diagrams from the roads in San Francisco, and the table herewith shows the amount required for driving the cable alone—I mean by this, without any cars being on the road; but included is the friction of the engines and driving machinery; also the friction of the carrying and deflecting sheaves, as well as the power consumed in bending the cable around the sheaves. I have not attempted to segregate the power required for driving the cable from that required to move the engines and driving machinery without the cable on, because all this power is in constant use, is a constant expense, and the fuel expense for driving a certain amount of cable at a certain speed, depends upon the ability of the constructing engineer to design, and a proper direction of the labor having the care of it when in operation. For the purposes of this paper, I have reduced the work done on the various roads, to the number of pounds of cable moved one mile per hour with one horse power.

NAME OF ROAD.	Horse power to drive cable.	Pounds of cable moved 1 mile per hour with 1 horse power	Proportionate power required for driving cable, Clay St. being 1.
Clay	22.6	4,084	1.00
Sutter, estimate.....	83.6	4,538	.90
Geary, estimate.....	58.0	4,538	.90
California	84.0	4,743	.861
Union	39.0	4,788	.852
Market.....	201.0	6,221	.656
McAllister	60.0	9,066	.45

In this table the power for moving the cables of the Sutter Street and Geary are estimated by taking the average of the work done on the Clay, California and Union Street roads.

For the power to haul the cars I have allowed 20 pounds per ton at all speeds. This would give for the various roads an approximate power for each train, consisting of dummy and car, and on Market and McAllister, for the car alone:

Name of Road.	W't of Car & Dummy.	Horse Power for ea. Car.	Average No. of Cars.	Total Average Power for Cars.
Clay	4,900	.08	7	5.60
Sutter.....	7,500	1.50	18	27.00
California	8,600	1.40	14	19.60
Geary.....	8,400	1.94	19	36.86
Union.....	8,600	1.42	10	14.20
Market and Haight.....	9,600	2.07	44	91.00
McAllister	9,600	2.07	18	37.00

The following table gives the approximate average speed of each road, the average distance that passengers are carried, the total number running hours each day, and the average horse power required to haul 1,000 passengers on each road:

Name of Road.	Average speed.	Average distance that passengers are carried. Miles.	Total hours running time each day.	Average power for each 1000 passengers carried. Horse Power.
Clay.....	6	$\frac{1}{2}$	$17\frac{1}{2}$.0971
Sutter.....	$7\frac{1}{2}$	$1\frac{1}{2}$	$19\frac{1}{2}$.261
California .	6	1	19	.178
Geary.....	$7\frac{3}{4}$	1	19	.177
Union.....	6	1	$17\frac{1}{2}$.194
Market.....	8	$2\frac{1}{2}$	$20\frac{2}{3}$.412
McAllister. . .	8	1	$20\frac{2}{3}$.163

This table shows that the power required to convey passengers by themselves is a small factor of the total power required in operating cable roads. It is assumed here that the average distance which each passenger is carried will be about half the length of the road.

The following table will give the total daily average power for operating the cable roads in this city, and also the per cent. of power required for moving cable, for moving cars, and (assuming numbers) for moving passengers:

Name of Road.	Total Power	For Cable.		For Cars.		For Passeng's		Number of Passengers.
		Power	Per ct.	Power	Per ct.	Power	Per ct.	
Clay.....	28.56	22.6	79.0	5.60	19.0	.36	2.0	4,000
Sutter (estimated)	114.60	83.6	72.9	27.00	23.5	4.00	3.6	15,000
California.....	105.02	84.0	80.0	19.60	18.6	1.42	1.4	8,000
Geary.....	96.63	58.0	60.0	36.86	38.0	1.77	2.0	10,000
Union.....	54.55	39.0	70.0	14.20	26.0	1.35	4.0	7,000
Market.....	301.00	201.0	66.7	91.00	30.6	9.06	2.7	22,000
McAllister.....	98.30	60.0	61.0	37.00	37.6	1.30	1.4	8,000
	798.66	548.2	68.0	231.26	28.0	19.26	4.0	74,000

These results are the average percentages for estimated average number of cars and passengers. The following table gives the average number of feet of cable for each car, except Market

Street, to which should be added the cars which are switched from the McAllister Street road:

Name of Road.	Number of Cars.	Feet of Cable.	Feet of Cable to each Car.
Clay	7	11,000	1,571
Sutter	18	37,736	2,096
California	14	25,895	1,844
Geary	19	27,000	1,421
Union	10	21,000	2,100
Market	44	65,765	1,472
McAllister	18	27,183	1,510
	130	215,579	12,014
Average	18.5	30,797	1,716

This table shows the average distance apart of cars to be 1,716 feet for average running, but on holidays and Sundays these distances have been reduced about 45 per cent., so that cars have run 1,000 feet apart, average. I am aware that in some instances they have run much less distance than this, but at eight miles per hour the speed would be 704 feet per minute, or an interval of about $1\frac{1}{2}$ minute between cars, allowing for stops. Of course, if traffic demanded it, this number of cars could be kept on the road. That would be one car to each 1,000 feet of rope, and taking the totals from table above, there would be added 85 cars; and if each car carried the average number of passengers, they would be increased 48,000, or 65 per cent., so that 65 per cent. would be added to the power required for hauling the cars, which would be $231.26 + 150.31 = 381.57$ for cars, and 65 per cent. for passengers would be $19.26 + 12.51 = 31.77$ horse power. Then the total power would be—

For cables	548.2
For cars	381.57
For passengers	31.77
	961.56

Of which 57 per cent would be for cable.

39 " " " " " cars.

and 4 " " " " " passengers.

100

This is taking the average of all the roads, but if we take the road which has the least per cent. of power expended in moving the cable, the Geary Street, and add cars so that they may be only 1,000 feet apart, we shall have 8 more cars—an increase of 42 per cent. and also an increase of 42 in the total power for hauling cars and passengers, thus:

For moving cable.....	58.	H. P.
For moving cars....	52.34	“
For moving passengers.....	2.84	“
	113.18	
Total H. P.....		
Of which 51 per cent. would be for moving cable.		
46 “ “ “ “ “ “		cars.
and 3 “ “ “ “ “ “		passengers.
100		

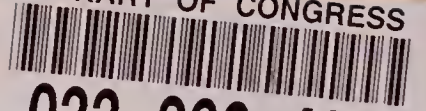
This is within the capacity of the road as it in this case assumed, carried 14,200 passengers; while it has actually many times carried from 20,000 to 22,000 passengers in one day.

Therefore we may conclude that it is practicable to utilize 50 per cent. of the total power expended in moving the cars and passengers. That this is much within bounds will be admitted when it is seen that the comparative power expended in moving the Geary Street cable is .90, and that of McAllister Street is only .45, or one half.

There is one other point which I will refer to, and that is the comparative power required over grades or level roads. While the average will remain about the same, the fluctuations will be much greater and the consequent maximum strain on the cable will be greater over grades, and this variation of work calls for an engine that will keep a uniform speed under more severe conditions than usually obtain even in rolling mills, for if the speed of the engine in the mills varies somewhat human comfort is not affected by it; but in cars moved by cable, any variation in the speed of the engine may be easily detected by the surging movement which is given to the car. There is no difficulty in providing engines that will run at a uniform speed under all the changes or variation of work that may come upon it.

There are other points of importance which might be referred to in this paper, but it has already extended beyond the primary intention. Our future experience will be guided and aided by the past, and the divisions of the subjects which are but little understood at present, will become as familiar as household words.

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