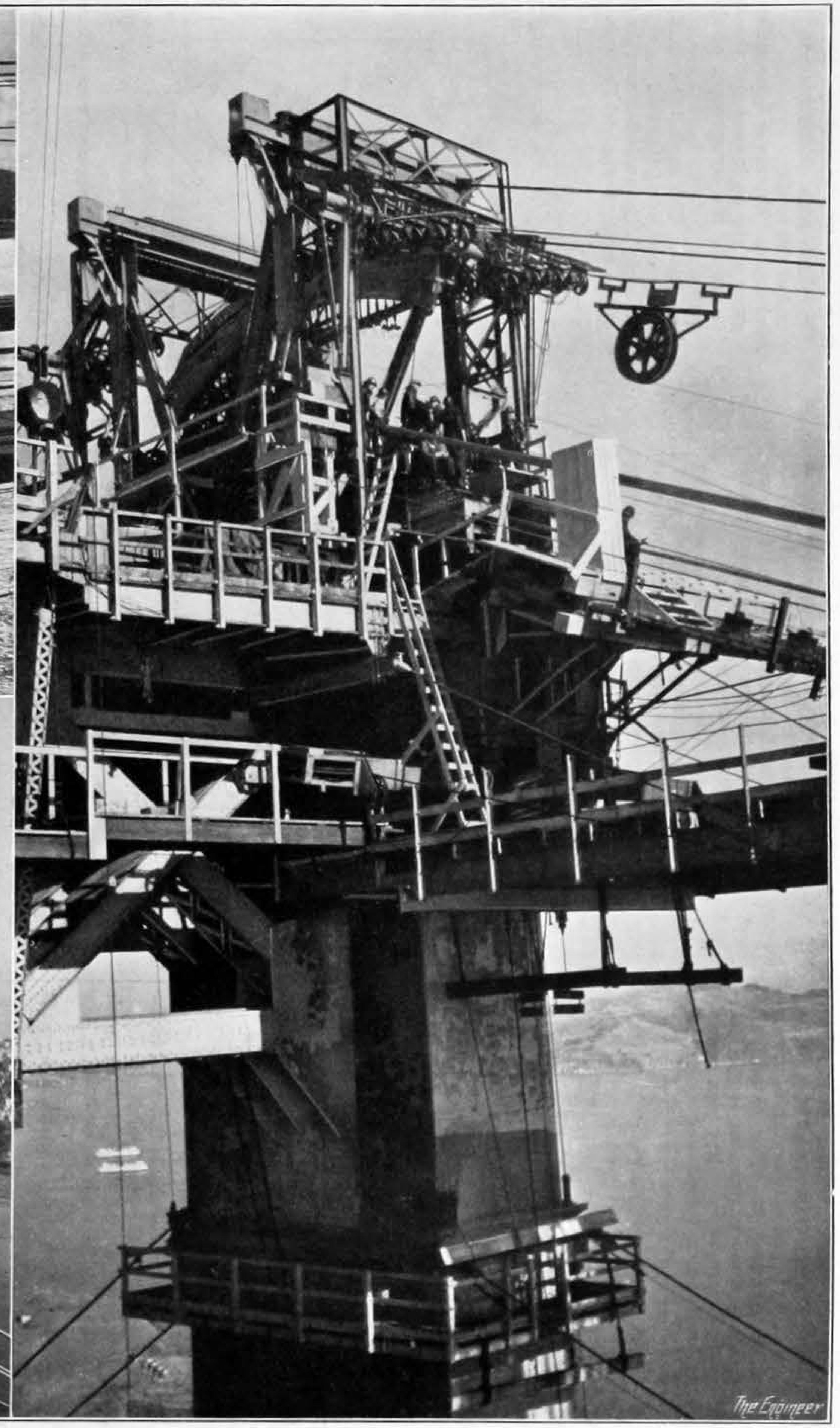
SPINNING THE CABLES OF THE GOLDEN GATE BRIDGE, SAN FRANCISCO

(For description see opposite page.)

TRANSFER STATION AT MID SPAN
CARRIAGE APPROACHING MARIN TOWER



CABLE SPINNING STATION ON TOWER

The Golden Gate Bridge.

No. III.

(Concluded from page 108, July 31st.)

Main Towers.

As both towers are identical in all main features a description of one will be sufficient. Each tower consists of two posts or columns composed of ninety-seven rectangular cells that decrease in number from the base upward. Each cell is 3½ft. square and fashioned of steel plates ⅞in. thick, strengthened internally with riveted angles. By reducing the number of cells at successive levels, the posts have been given a tapered appearance, with broken lines that add to their architectural grace. The uppermost section of each post is made up of unit cells that have an area of 3670 square inches, while the cellular units just above the base of each leg have an individual horizontal section of 7192 square inches. The base of each leg covers an area of 32ft. by 53ft., and there has been worked into each tower a total of 21,500 tons of steel, most of which was prefabricated in sections in the eastern part of the United States and carried to San Francisco in ships. At their bases, each tower has a spread of 122ft. The average weight of the fabricated units of the tower legs is 45 tons, and the heaviest members that had to be lifted and placed in the structure represented a load of 85 tons. The tower above the roadway is stiffened transversely by four horizontal braces without diagonals. The bracing below the roadway consists of two diagonally placed panels. The tower legs and the braces were erected by means of a creeper traveller, which climbed between the legs as they were raised. The traveller was equipped with two derricks, with 90ft. booms, and each was capable of lifting a load of 60 tons. At each stage of its ascent the creeper traveller was held in its position by four big plungers that entered a corresponding number of holes in the erected steel. The work of erection was started on the south tower on February 1st of the year gone, and the last of the steel was in place by the end of June following. The contractor was required to have the tower completed by September 1st, and by saving sixty days he won a bonus of 90,000 dollars. This meant that the bridge could be opened to traffic that much earlier and be earning money. The upper sections of the towers are of silicon steel, and the lower ones are of carbon steel. The assembling of each tower required the driving of 600,000 rivets in the field, and the rivets were heated at strategically located forges, and blown to the riveting gangs through flexible pneumatic tubes. This reduced the hazards and uncertainties incidental to hand passing. The north tower was finished months before the erection of the south tower was taken in hand. The two cable saddles on top of each tower are 170-ton castings, each made up of three segments, 21ft. long, 10ft. wide, and 10ft. 6in. high.

Cable Anchorages.

The anchorages at the north and south ends of the bridge are partly embedded in the rock at their respective sites—that is, in Marin sandstone on the north side of the Golden Gate, and in serpentine on the San Francisco side. The excavations for the two anchorages on the San Francisco shore were carried somewhat deeper than on the Marin shore to assure the desired bond with the serpentine. The bottom of the excavation for the anchorages was deeply grooved transversely to provide thoroughly effective bonding between the rock and the base blocks of the anchorages. Each of the four anchorages for the two suspension cables is made up of three parts—the base block, the anchor block, and the weight block. The lowermost, or base block, was poured so as to give its rearward sloping upper surface a stepped finish to key with the concrete of the anchor block poured upon it after the vertical steel girders and the attached steel eye-bars were in place. The weight block is the topmost part of each anchorage and not only adds to the direct resistance offered to the pull of the cable, but exerts a vertically downward force that transfers the cable stresses to the foundation rock. Each of the south anchorages, with its associate cable housing, is made of 65,750 cubic yards of concrete. Within each cable housing, the end of the cable is splayed so that each of its component strands may be secured to its proper anchorage eye-bar link—each eye-bar consisting of several links extending to the associate girder at the rear of the anchor block.

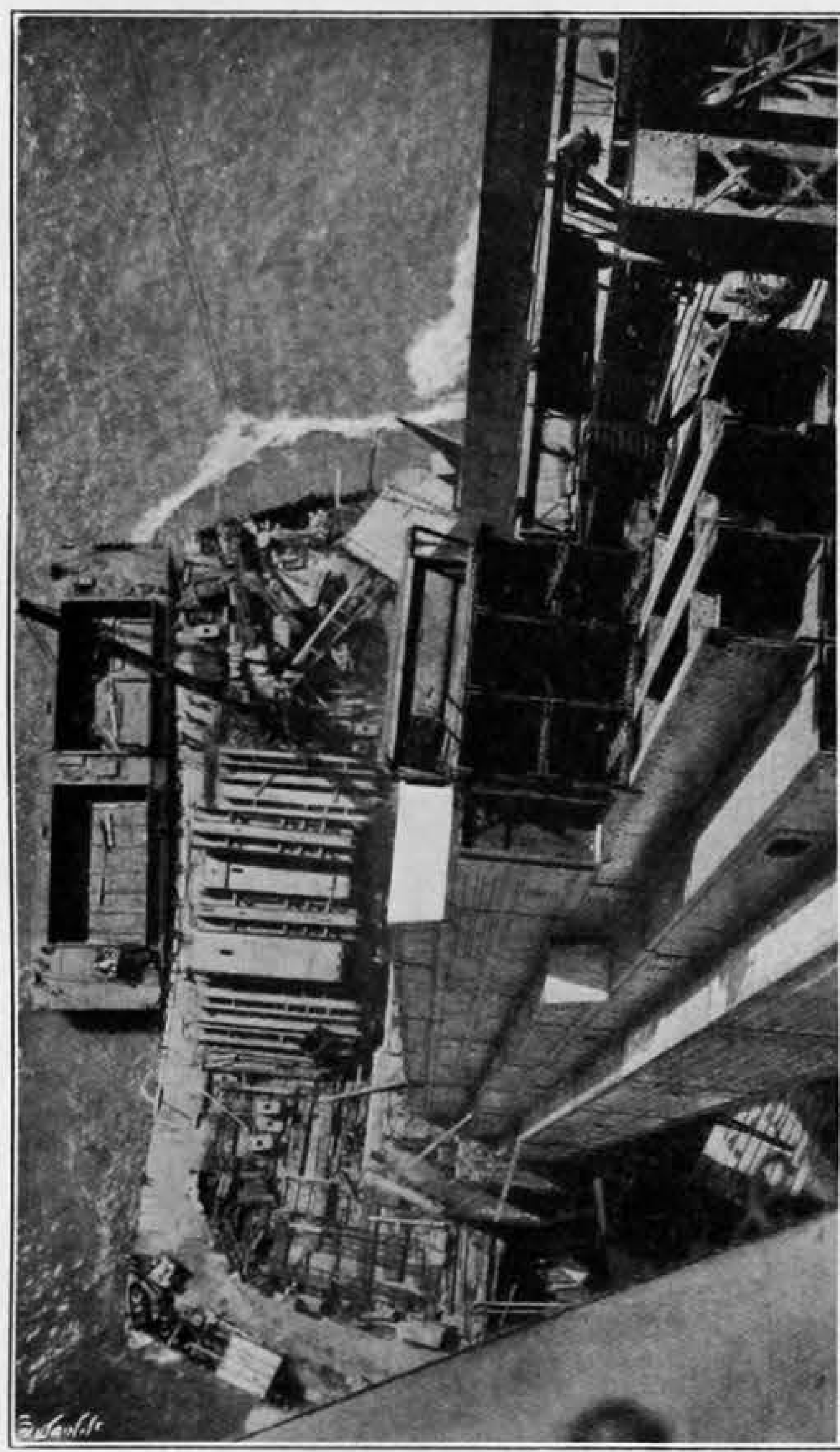
At the inshore end of each side span the cables pass through the pylons at those points, namely, Pylon North 1 and Pylon South 1, on their ways to their several anchorages. Within these two pylons, each cable is there restrained from vertical movement by a series of six wire-cable tie-downs passing over a sleeve, fitted with bronze shoes, on the cable and connected to steelwork below in the concrete body of the corresponding column of the pylon. The tie-downs will maintain the relation between the ends of the side span and the connecting approach roadway, so that no vertical play, due to expansion and contraction of the cables, will take place at these junctions.

Main Suspension Cables.

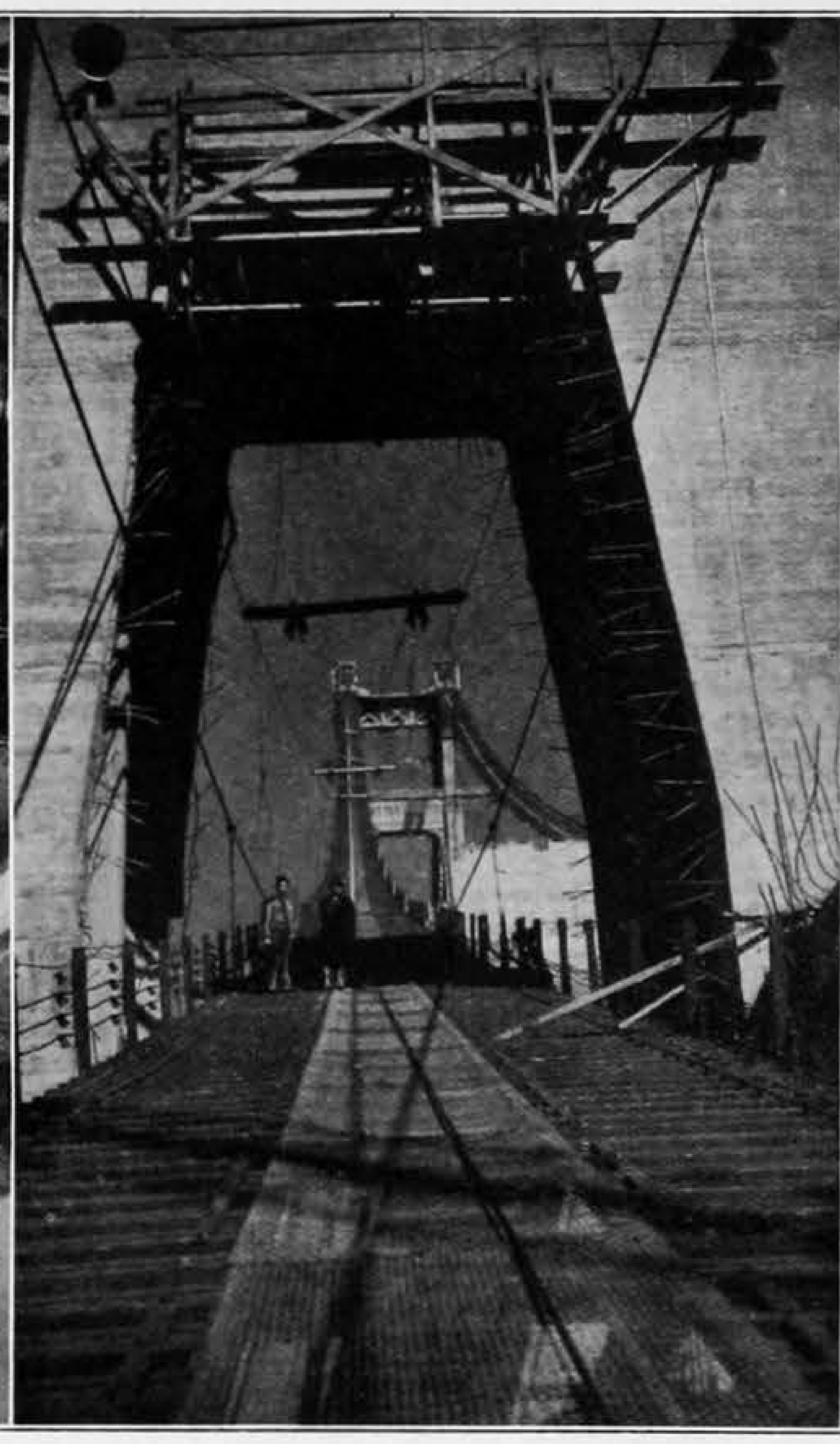
Each main suspension cable is made up of sixty-one strands, and, contrary to previous practice, the strands differ in size, depending upon their respective positions in the cable—the number of individual wires therefore in the several strands ranges from 256 to 472 wires, and each wire is 0·196in. in diameter. After spinning, all the strands, which are ranged parallel with one another, were compacted by squeezing machines, each of which is equipped with twelve hydraulic jacks that can be operated by a special liquid, and the jacks make it possible to apply to the strands during compaction a pressure of approximately 4000 lb. per square inch. To keep the cables compacted they are banded at regular intervals, and the final work in their fabrication consisted of wrapping them circumferentially with an envelope of steel wire.

Both the arrangement of the sixty-one strands forming each of these suspension cables and the procedure and facilities employed in spinning the strands mark a long step forward in the art, as practised in the United States. The contractor who has provided the cables for the Golden Gate Bridge also furnished the cables for the George Washington Bridge, and the procedure adopted in the case of the Golden Gate Bridge reflects some of the things learned in doing work between 1929–30 on the George Washington Bridge.

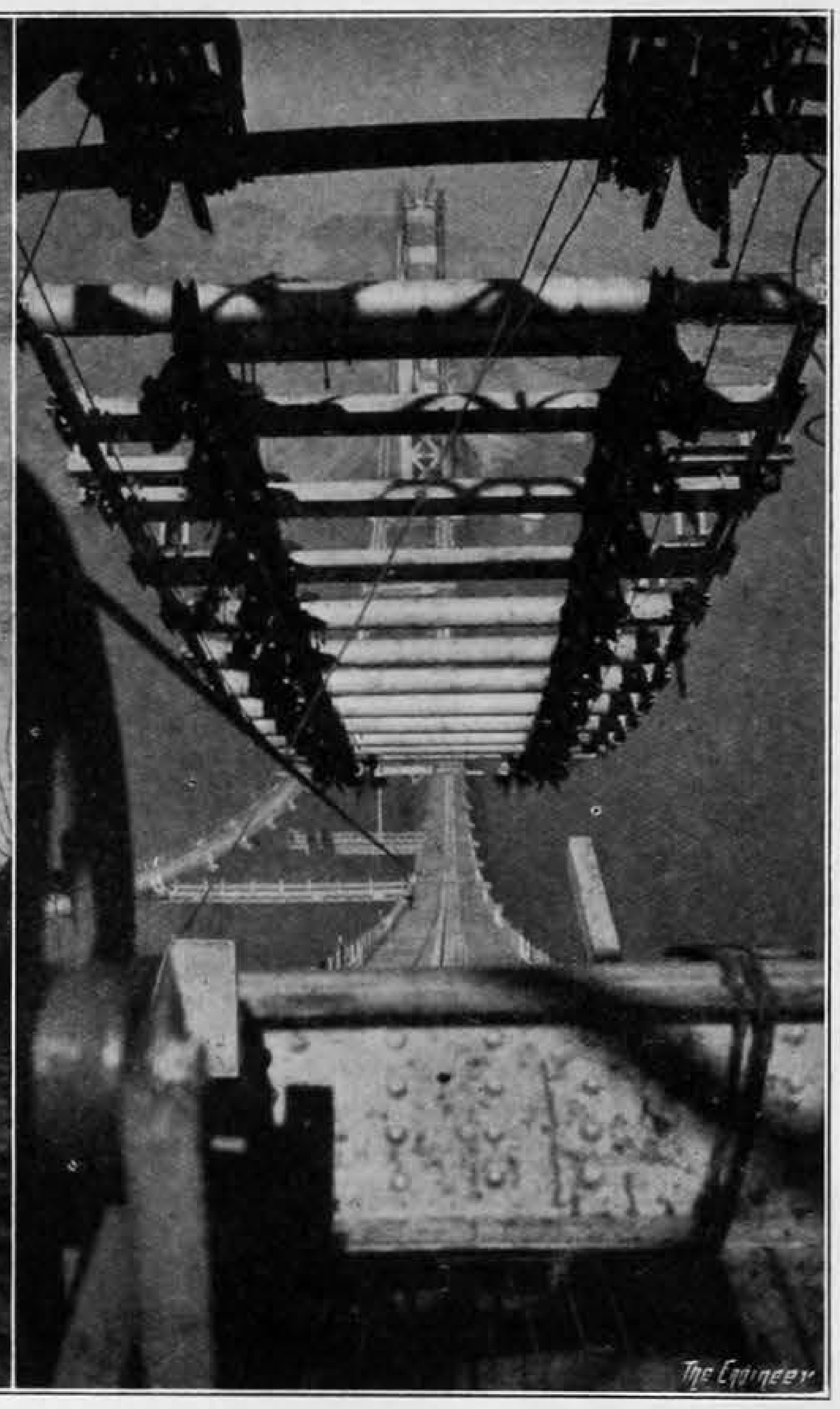
As designed and contracted for, the sixty-one strands of each main suspension cable were to have a hexagonal arrangement in cross section after compacting—allowing for an ultimate disposition of the component strands that would result in a lateral spread in which the horizontal axis would be greater than the vertical axis. This does not subscribe to the theoretically perfect and desired cross section of such a cable, and after the contract was awarded the contractor, John A. Roebling Sons Company, proposed that the design be so modified that the cable, in cross section, should be curved at the top and the bottom with the vertical sides straight. By this change the strands are arranged in nine parallel vertical lines, the centres of the strands forming a line being upon the given vertical axis. To achieve this, the number of wires in the various strands is not uniform as heretofore, but it has thus been found possible to produce a cable which, where it passes through a saddle, comes considerably closer than previously to subscribing to the outline of a perfect circle. Cast zinc fillers are inserted between the two sides of a saddle and the straight upright sides of the new form of cable to prevent any lateral displacement of the strands after they are arranged in vertical rows; and the fillers, of course, are modelled to suit the shape of the respective voids in which they are inserted. It is believed that the new cables will be better able to meet the changing stresses of service than cables in which the strands are arranged to produce a hexagonal cross section, and it is reasonable to assume that the Golden Gate cables will have a lower vertical displacement of their component wires than those other cables in which the strands are laid in horizontal rows. Before compacting, the strands of the Golden Gate Bridge cables were kept in their relative positions to one another and held apart vertically by spacers, which permitted the air to circulate freely between them and so maintain a uniform temperature



Marin Tower under Erection



West Footbridge and Pylon

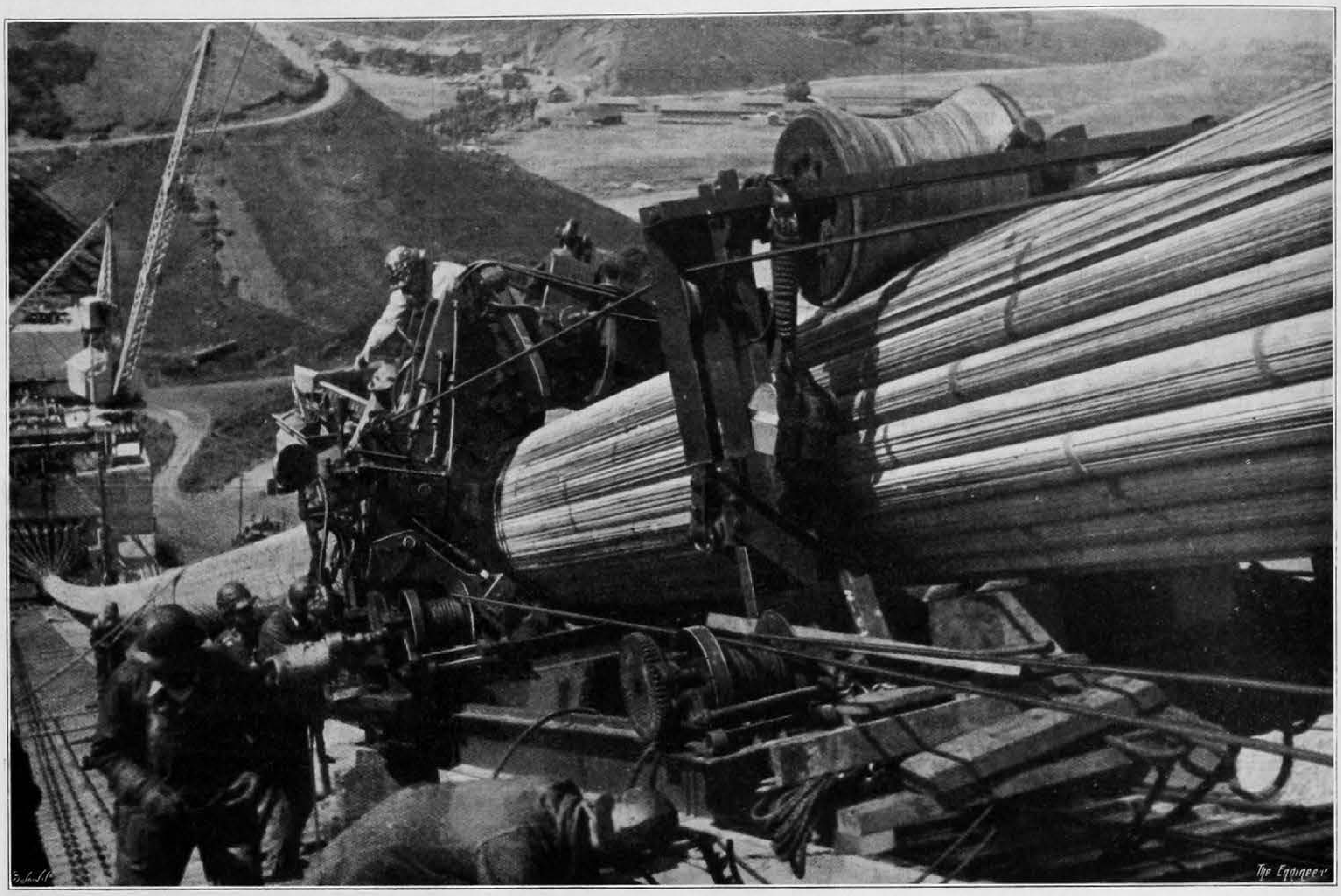


Equipment at Tower for Cable Spinning

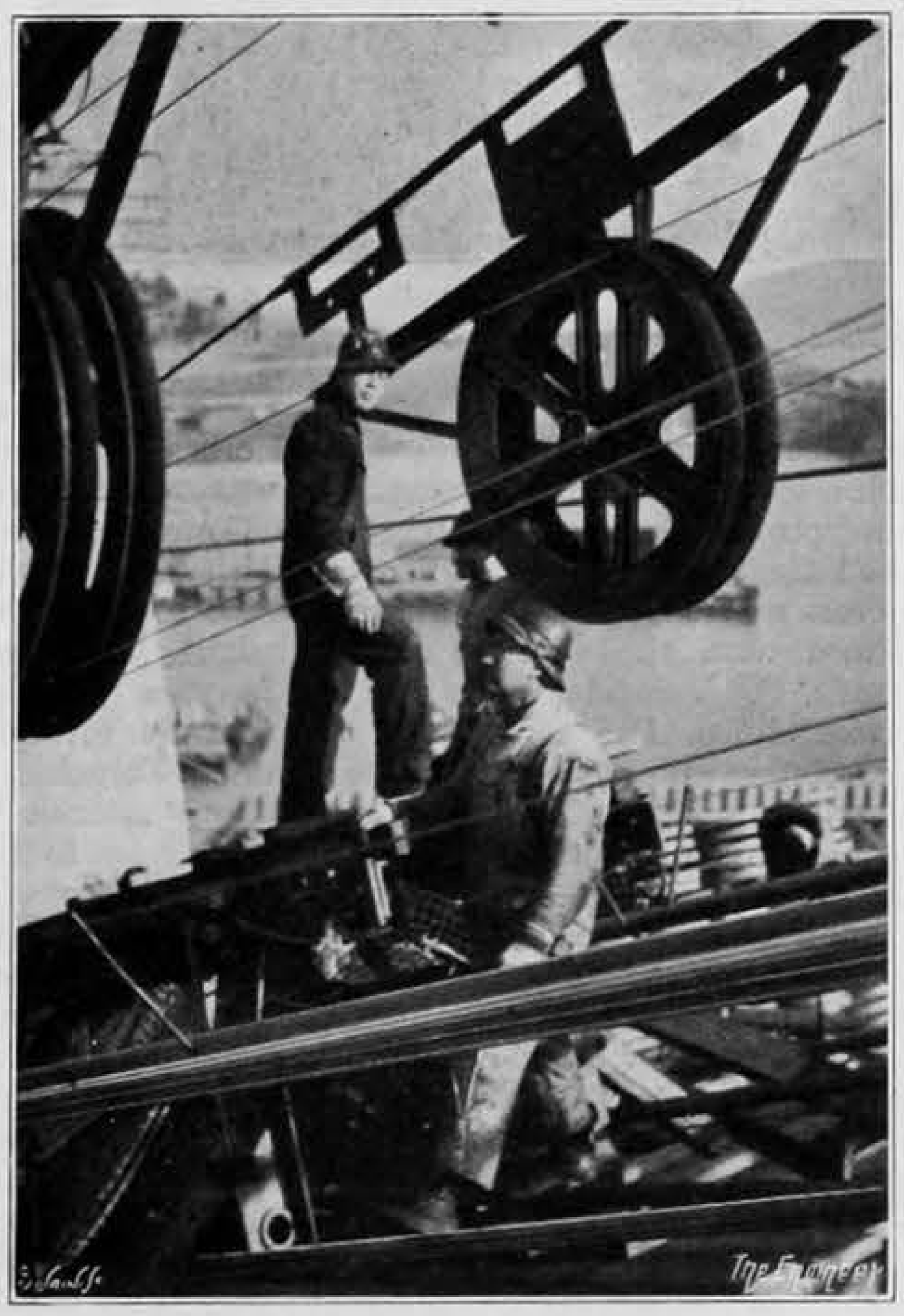
throughout all the associate strands. This has aided in bringing about final and relatively speedy adjustment of the strands.

It will be recalled that during most of the spinning of the cables for the George Washington Bridge that work was done with carriages equipped with single spinning wheels—each spinning wheel making a complete run from one anchorage to the other, and during that run stringing two wires in a given strand. The two wires were the two members of a single loop, and one wire was " dead " or fastened at the anchorage end, while the top wire was paid out from a reel as the carriage was drawn toward the far anchorage. The carriage was pulled along the tramway cable at a speed of 650ft. per minute, which was 200ft. faster than the stringing speed on the Delaware River Bridge, built between 1924–25. Just before the cables were completed for the George Washington Bridge, the contractor spun two strands with a carriage equipped with two spinning wheels, and the performance was generally satisfactory, although some doubts had existed as to the practicability of such a rig. There were some drawbacks that called for further study.

When work was started on the cables for the Golden Gate Bridge, arrangements were made for the use of carriages equipped with two spinning wheels, and a further potential gain in stringing speed was counted upon through the adoption of a distinctly novel departure in wire-stringing practice. That is to say, instead of having each carriage travel on each run the total distance between opposing anchorages, two tramways instead of one tramway were substituted, and the run of a carriage ended in mid span, at which point was to be established a transfer station where the loops of wires drawn outward from the north anchorage would be shifted to the carriage arriving simultaneously at the transfer station from the south anchorage, and, conversely, the loops of wire from the south carriage would be shifted to the spinning wheels on the north carriage, after which the two carriages would return to their respective starting points. This modification has made it possible to increase virtually two-fold the stringing speed attained on the George Washington Bridge, while the double-wheel carriage was in experimental service. In earlier cable spinning, the hauling rope was an endless line that extended from anchorage to anchorage and back to the starting point. On the Golden Gate Bridge the hauling ropes, also endless loops, were run from the driving machines at one anchorage to the top of the remoter tower, while the driving ropes from the farther anchorage also followed a corresponding course to the tower near the distant shore. This may appear somewhat complex, but, in fact, the arrangement was withal fairly simple, and proved more desirable than any other suggested substitute. In practice, four carriages were used in stringing the wires for each cable—when two of the carriages were at the transfer station in mid-span the two other carriages were at their respective anchorage terminal point, and the synchronised movements of the four carriages were under the direct control of a dispatcher located in a central office provided with a comprehensive signalling and communication system that kept him completely informed as to the positions of the carriages and the timeliness of every move to be made.



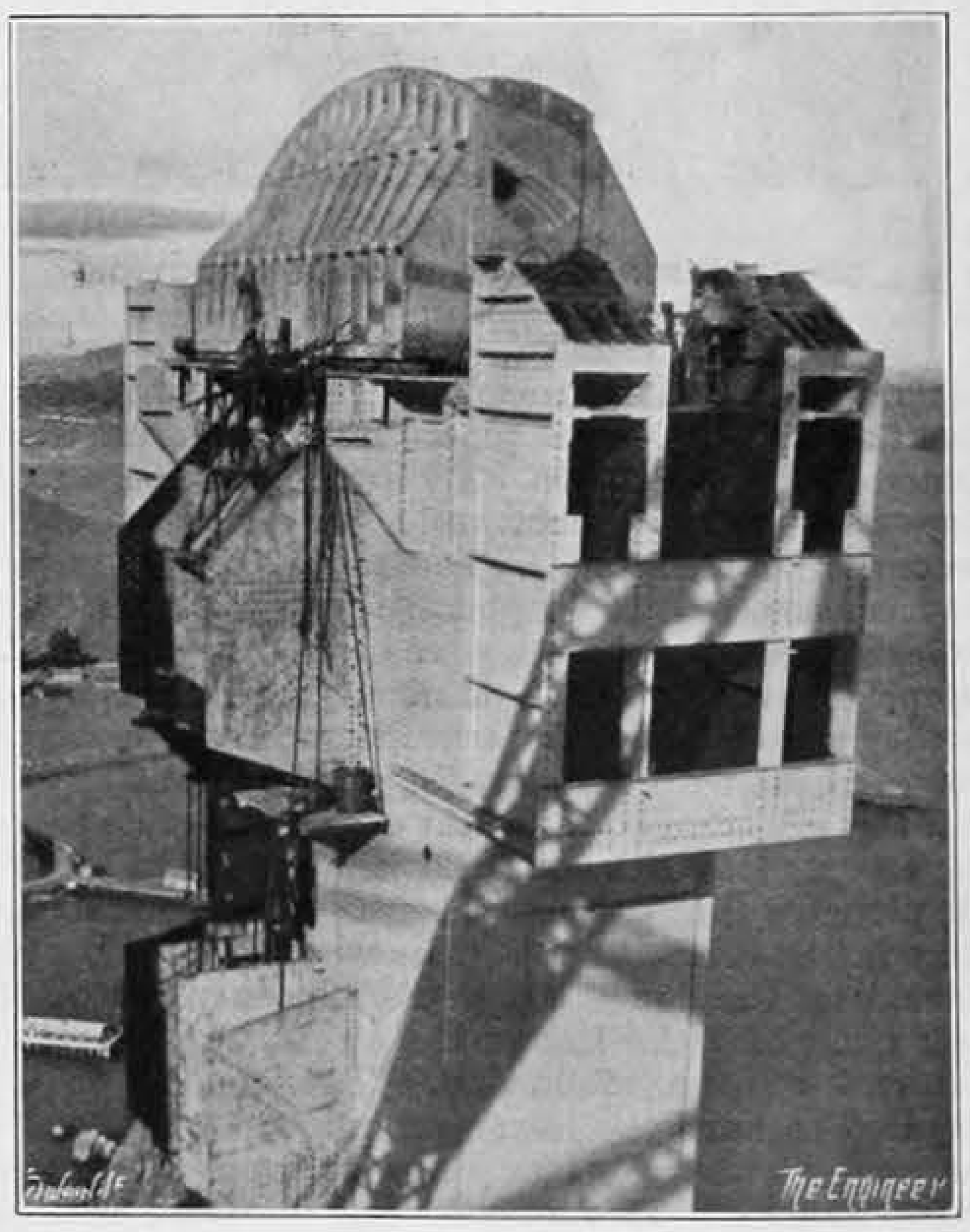
HYDRAULICALLY-OPERATED CABLE COMPACTOR AT WORK



SPINNING WHEELS AT TOWER STATION

At a linear speed of 650ft. per minute, a carriage took approximately 6½ minutes on a run between an anchorage and the transfer station at mid-length of the span, and the average time required to shift the loops of wire from the spinning wheels of one carriage to the spinning wheels of another carriage was half a minute, after which the two carriages were ready to reverse their movements and return to their respective starting points. There were four carriages stringing wires for each cable. A carriage handled two loops or four wires as it was hauled away from its anchorage terminal and brought back a similar number of wires on its return run. During a co-operating round trip of two carriages they were able to string a total of eight wires from anchorage to anchorage, while the four carriages duplicated that performance. Thus, in a given period, sixteen wires were strung on the Golden Gate Bridge, as against four on the George Washington Bridge, when the double spinning wheel carriage was first tried out. On the George Washington Bridge the rate of stringing reached as much as 61 tons in the course of a day on a cable, while it was found possible to string 271 tons per diem per cable in the case of the Golden Gate Bridge.

Ultimately, as the men acquired greater co-operative skill, the Roebling engineers adopted carriages fitted with three spinning wheels each, and by so doing they increased the rate of stringing 50 per cent., and made it possible for the carriages to place twenty-four wires simultaneously in a cable instead of four, as had generally been the case in previous bridges. The spinning of the cables of the Golden Gate Bridge was started on November 11th, 1935, and the work was completed on May 20th of this year—twenty-six days earlier than the schedule set for that job.



CABLE SADDLE ON MARIN TOWER

Each main cable contains 27,572 wires and a total of 10,750 tons of wire. Into the two cables have been worked 80,000 miles of wire. In the case of the George Washington Bridge, each cable has a diameter of 36in., a length between anchorage of 5270ft., and is composed of sixty-one strands of 0·196in. wire, having a total weight of 7125 tons. The George Washington Bridge has four cables, whereas the Golden Gate Bridge has two. As can be seen, nevertheless, the tonnage of wire in the two Golden Gate cables is slightly more than 50 per cent. greater than that of the four cables of the George Washington Bridge. The spinning, however, was four times faster in the later structure by reason of mechanical improvements and the methods devised for doing the work. This was achieved without actually increasing the spinning wheel speed. Confusion at the transfer station in mid-span was obviated by spraying distinctive colour coats on certain of the wires, so that the adjusters at the station, who shifted the wires manually, could do their work surely and rapidly.

In the past, the customary practice has been to remove the foot-walk cables after they had served their purpose in connection with the construction of the main suspension cables and then to cut the foot-walk cables into the prescribed lengths and to fit them to serve as suspender ropes for the deck. For the Golden Gate Bridge the suspenders have been cut to length and socketed from unused cable at the plant of the contractor, and then marked, reeled, and shipped from Trenton, N.J., to San Francisco. This change in procedure will undoubtedly save considerable time and have other advantages. The foot-walks have been sustained by parallel lines of cables weighing but 5 lb. per linear foot, and one foot-walk is carried on twelve such cables, while the other is supported by thirteen. This arrangement has reduced by quite 60 per cent. the load on the hoisting engines used in lifting and stringing the foot-walk cables. The tramway sheaves used in connection with the spinning of the cables for the Golden Gate Bridge have been carried by an independent overhead catenary system instead of employing the facilities heretofore used for such work. This arrangement has saved weight and has contributed to the stability of the footbridges which have been sustained by their own cables. This stability is of importance because of the high winds that prevail at times at the Golden Gate, where the winds sweeping in from the ocean strike the bridge broadside on. The steadiness of the footbridges has been such that the workmen could continue spinning operations with winds having a maximum velocity of 45 m.p.h. The catenary system provided for the spinning carriages has been used to facilitate the manœuvring of the compactors and the serving or external wrapping machines, the placing of the cable bands, and the adjustment of the deck suspenders. Recurrent fogs, characteristic of the San Francisco Bay region at some seasons, would have slowed up cable spinning and associate work had not unusually elaborate and complete systems of communication and control been provided. Foresight has thus offset the vagaries of Nature and made it possible for the workers to carry on under conditions that otherwise would have proved extremely hampering and even obstructive.

The computed load of the bridge is 22,000 lb. per linear foot, and the design live load is 4000 lb. per linear foot. The load supporting capacity of the two cables is 2·6 times the maximum load. The horizontal wind force to which either tower will be subjected is stated to be 1,900,000 lb. The bridge is designed to be safe against a wind pressure of 30 lb. per square foot. At each tower the deck structure will be provided with an expansion joint to take care of any longitudinal changes due to temperature variations. In short, the physical requirements of the structure have been most carefully considered in every particular, and unrivalled as the Golden Gate Bridge will be when ready for service, as a technical achievement it probably is a milestone along the way to still greater spans. Despite all the hazards connected with such an undertaking, it was reported, in April of the current year, that there had been no permanent injuries nor a single death up to that time on the work.

The engineering staff is composed of the following members :—Joseph B. Strauss, chief engineer ; O. H. Ammann, Charles Derleth, jun., and Leon S. Moisseiff, consulting engineers ; Andrew C. Lawson, consulting geologist ; and Irving Morrow, consulting architect. The general manager is James Reed. The following concerns are the principal contractors :—McClintic-Marshall Corporation, steel for towers and superstructure ; John A. Roebling Sons Company, cables, suspenders, and accessories ; Pacific Bridge Company, San Francisco pier and fender and Marin pier ; Barrett and Hilp, cable anchorages and piers for approach spans ; Pomeroy and Raymond Concrete Pile Company, approach spans ; Eaton and Smith, Presidio approach spans ; and Alta Electric and Mechanical Company, Inc., electrical construction and installation.

Water Vapour (Vacuum) Refrigeration.

By WILLIAM T. TAYLOR, M. Inst. C.E., M.I.E.E., &c.

No. I.

THIS system uses only water and steam to produce cold, the water being cooled to low temperature by evaporating a very small part of it at low absolute pressure, *i.e.*, water as the refrigerant is alternately vaporised and liquidified to produce cold. The ordinary phenomenon of water as a refrigerant is such that by artificially reducing the pressure on it, the water is made to boil at a point very much below normal temperature, thus making it almost perfectly suited to moderate temperature refrigeration or cooling, such as general application to the cooling of foods and liquids and gases, the cooling of deep mine workings, cooling of cargo on board ships and magazines on board battleships, heat exchange in processes and products in the various industrial operations for temperatures between a minimum of about 35 deg. Fah. to a maximum of about 65 deg. Fah., or higher, also suited where constant temperature or/and humidity are needed to produce better products and/or give greater comfort. In this system, advantage is taken of an old principle which permits the ordinary freezing point of water to become its boiling point so that the very characteristics which make water unsuitable for very low temperatures adopt it especially for general air conditioning and comfort cooling.

To the wider use now made of air conditioning in mines and industries and places of entertainment, and to the increasing number of new applications for cooling as aids to industrial processes and betterment of foods and other products, this method of manufacturing cold seems to have spanned a gap long recognised as commercially impossible. The desired vacuum and compression can now be obtained and maintained in the simplest way and for the least relative cost in plant and energy consumption ; in fact, the initial investment for plant is less than for any other system. The water vapour system may be installed almost anywhere, indoors or outdoors ; if offers greater reliability and flexibility in operation ; it requires no heavy foundations ; it is easier and cheaper to install and operate ; there is total absence of chemicals, smell, poisonous fumes, danger of explosion, &c.; it offers greater adaptability to general working conditions ; it has more desirable partial-load characteristics ; its upkeep costs and electric power costs are lower ; refrigerant does not have to be drawn off and it can be circulated so that there is no transfer loss or loss of charge, and the refrigerant can be cooled down to the desired condition in a minimum of time ; refrigerant does not have to be stored in containers during the cold winter ; it operates without chemicals of any kind ; operation is practically noiseless ; evaporation is the most direct possible, hence the most efficient ; the plant, excluding auxiliaries, has no rotating parts and is almost free from wear ; it uses low-pressure piping only ; it has an inherently large reserve tonnage capacity for increase in chilled water temperature above normal rating temperature ; it permits the cooling of brines directly by evaporation, also vacuum crystallisation ; where cold water for the condenser is available at a temperature favourable to the cooling range, the capacity rating of a given plant may be reduced (output increased), steam consumption reduced, and cooling tower and pumps may be omitted or disconnected ; where sufficient condenser and evaporator capacity are available, the tonnage output of a plant may be increased by merely adding another steam jet ejector ; where steam and water costs are definitely favourable, the selection of the water vapour system may, from this one view point, very often be justified in preference to other systems of refrigeration ; and, added to all the above merits, there remains the outstanding advantage of very long life maintained at high factor of safety and efficiency.

Every water vapour refrigerating system must have a steam pressure-increasing device, *i.e.*, a steam jet ejector (sometimes called thermo or thermal ejector, booster ejector, &c.), or a mechanical high-vacuum compressor of the centrifugal or other modern type. The steam jet ejector has a steam chest with nozzle or jets, air chamber and diffuser. The ejector may well be called a thermal booster or compressor in that the steam and water vapour passing through its air chamber is compressed in the diffuser and there boosted to a higher absolute pressure, after having already passed through one transformation in the steam jet nozzle throat where the energy is transformed from potential into kinetic energy. High-velocity steam leaving the nozzle creates such an intense suction that the water vapour from the flash chamber is entrained and carried towards the diffuser. A velocity of 2238 ft. per second represents a frictionless adiabatic heat drop $\sqrt{(h'-h'')}$ of 100 Btu. only. The theoretical velocity of the steam jet at exit of nozzle (due to adiabatic expansion in the jet) is given by

$$V=\sqrt{(2g)\ 778\ (h'-h'')}=223\cdot 8\sqrt{(h'-h'')}\ \text{feet per second} \quad (1)$$

And when allowing for heat loss, the velocity of steam jet issuing from nozzle is

$$V=\sqrt{n}\ 223\cdot 8\ \sqrt{h'-h''}\ \text{feet per second} \quad (2)$$

If nozzle efficiency e_n

$=90$ per cent, then $\sqrt{n}=\sqrt{1-0\cdot 10}=0\cdot 9487$.

88 ,, ,, $\sqrt{1-0\cdot 12}=0\cdot 9381$.

86 ,, , $\sqrt{1-0\cdot 14}=0\cdot 9274$.

84 ,, ,, $\sqrt{1-0\cdot 16}=0\cdot 9165$.

80 ,, ,, $\sqrt{1-0\cdot 20}=0\cdot 8944$.

75 ,, ,, $\sqrt{1-0\cdot 25}=0\cdot 8660$.

With initial state of steam at 100 lb. per square inch gauge, heat drop of 380 Btu., and nozzle efficiency of 87 per cent., the initial velocity of exit of steam from the nozzle is

$$V=0\cdot 9327\times 223\cdot 8\times\sqrt{380}=208\cdot 6\times 19\cdot 49$$
$$=4070\ \text{ft. per second.}$$

Sometimes written

$$V=223\cdot 8\sqrt{(0\cdot 87\times 380)}=223\cdot 8\times 18\cdot 18$$
$$=4070\text{ft. per second.}$$

The corresponding friction heat is given by

$$H_f=(h'-h'')\ (1-e)=380\times 1\cdot 0-0\cdot 87$$
$$=49\cdot 4\text{Btu. per lb.}$$

The diffuser must receive and remove effectively all the steam vapour issuing from the nozzle throat (changed to low density at its exit) and the water vapour from the evaporator as both enter the air chamber under a high vacuum. The volume of steam vapour issuing from the nozzle is vastly greater than the water vapour from the evaporator. The density of the steam vapour is decreased in a definite ratio with the higher vacuum ; hence the vapour at the lower density can flow with much less friction than vapour of higher density, which in turn means that it will flow with much higher velocity—indeed, it must flow at very high velocity to permit maintenance of the high vacuum and remove the very large volume of vapour. For example, with steam pressure of 100 lb. per square inch by gauge, steam consumption of 930 lb. per hour, maintained vacuum in flash chamber of 0·3in. abs. (corresponding to 45 deg. Fah.), and maintained vacuum in condenser of 2·0in. abs., then, specific volume corresponding to steam pressure in the nozzle of $100+14\cdot 7=114\cdot 7$ lb. per square inch (abs.) is 3·9 cubic feet per pound (density of 0·0256), but the specific volume corresponding to the required vacuum in the air chamber is 2039 cubic feet per pound (density of 0·00049), and specific volume corresponding to vacuum in the condenser is 340 cubic feet per lb.; hence the 930 lb. of steam must be expanded and compressed to meet existing conditions between the nozzle and diffuser exit. Neglecting the relatively small volume of water vapour from the flash chamber, also losses for work performed, the volume of vapour may represent $930\times 2039=1{,}896{,}000$ cubic feet per hour in the air chamber for vacuum of 0·3in. Hg. Then it is compressed by the diffuser down to $930\times 340=316{,}200$ cubic feet per hour for vacuum of 2·0in. Hg. in the condenser. But the total volume of steam in the nozzle throat is only $930\times 3\cdot 9=3627$ cubic feet per hour, or about 1·0 cubic feet per second. Hence, the area of nozzle throat need be relatively small, so that

$$A_t=\frac{P_s}{1\cdot 135\cdot 8}\times\sqrt{\frac{v}{P}}\ \text{(area of nozzle throat, square inch)} \quad (3)$$

Thus for the above-mentioned conditions

$$A_t=\frac{930}{1\cdot 135\cdot 8}\times\sqrt{\frac{3\cdot 9}{114\cdot 7}}=0\cdot 819\times 0\cdot 1844$$
$$=0\cdot 15\ \text{square inch.}$$

The diffuser throat area is considerably larger than this, because it must remove the vastly greater volume just mentioned and created by the higher vacuum. The volume referred to here would require pumps having total displacement of $P'_s\ (v)/(60)\ e=1{,}896{,}000/60\times 0\cdot 70=45{,}140$ cubic feet per minute (based on 70 per cent. efficiency), whereas an ordinary steam jet ejector would do the work quite easily and for a very small power cost compared with the removal of this total volume of vapour by pumps.

If the diffuser area be too small to pass the volume of vapour, choking will occur ; if it be too large and/or too short in the throat, there will be leakage of air back into the air chamber. In practice, the size of diffuser throat is a little less than the length of its parallel section, and the length of the cone-shaped air chamber portion of the ejector is between two and four times the length of parallel throat section of the diffuser. Ample length of diffuser parallel throat section usually results in maintaining satisfactory