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The Canadian Engineer

An Engineering Weekly

THE CONSTRUCTION OF THE SOUTH MAIN PIER OF THE QUEBEC BRIDGE.

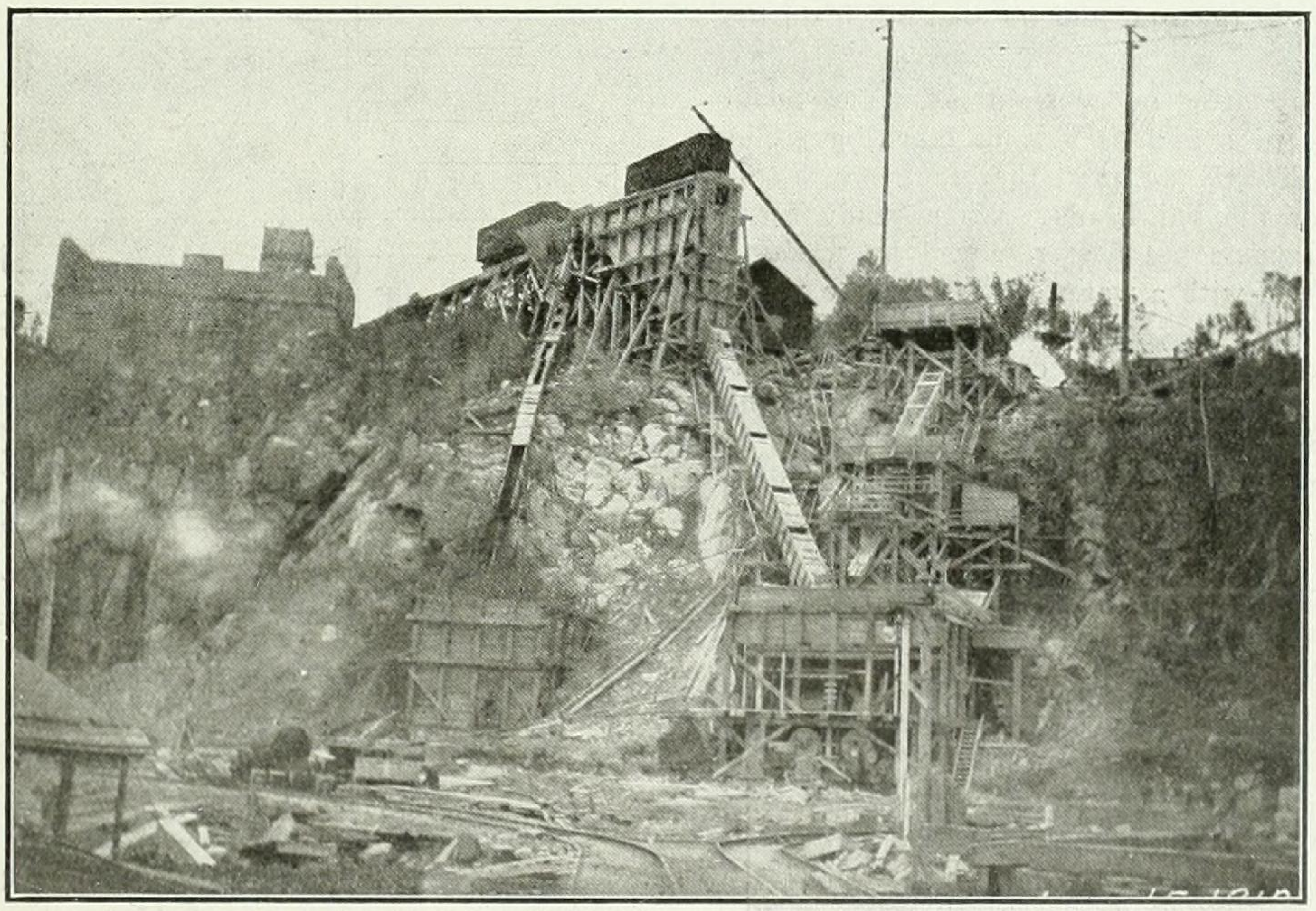
By H. P. BORDEN, Assistant Engineer Quebec Bridge Commission.

Owing to the fact that the steel superstructure of the new Quebec Bridge is some 21 feet wider and nearly twice as heavy as the old bridge, it was necessary to construct entirely new piers for the new structure. This work has been going on for the past two years, and will probably require another year to finish.

The bridge has three approach spans, two on the north side and one on the south, having a total length of 409 feet, two anchor spans of 515 feet each; two cantilever spans 580 feet each, and one suspended span 640 feet in length, or a grand total of 3,239 feet face to face of abutment. The channel span is consequently 1,800 ft. centre to centre of main piers, being the same as the old bridge.

Last season the caissons for the north main pier were successfully sunk to a solid bottom some 80 feet below high water, or 50 feet below the bed of the river. This season the contractor has concentrated his efforts upon the sinking of the mammoth caisson for the south main pier. The caissons for the north main pier were in two sections each 60 ft. x 85 ft. with a 10-foot span between, this space being filled with concrete after the sinking was effected. On the south side one single caisson is being employed 180 ft. x 55 ft., which, taking into consideration the great depth it must go, is by far the largest caisson ever employed on a work of this kind. The caisson is being carried down to solid rock 85 feet below the level of the river bed and 100 feet below extreme high water.

The caisson was floated into position last season and grounded on a prepared bed which is exposed at low water. It remained here all winter, guard piers of rip-rap being placed along its sides to protect it from the ice. The rip-rap was mostly broken concrete taken from the old pier in course of demolition situated just outside the caisson. Weep holes were provided in the roof over the working chamber to allow free movement of water during the high tides, and thus guard against any floating of the caisson when once properly grounded. As the water rose several feet each tide above this roof it was feared that if snow were allowed to accumulate ice would form and tend to strain the structure. To guard against this contingency, the caisson was entirely housed over, and as a further precaution steam pipes were led around the walls just above the roof of the working chamber, steam being supplied by a boiler on top of the caisson. It was found, however, that the steam heating was not necessary as the interior kept sufficiently warm to prevent ice from forming.

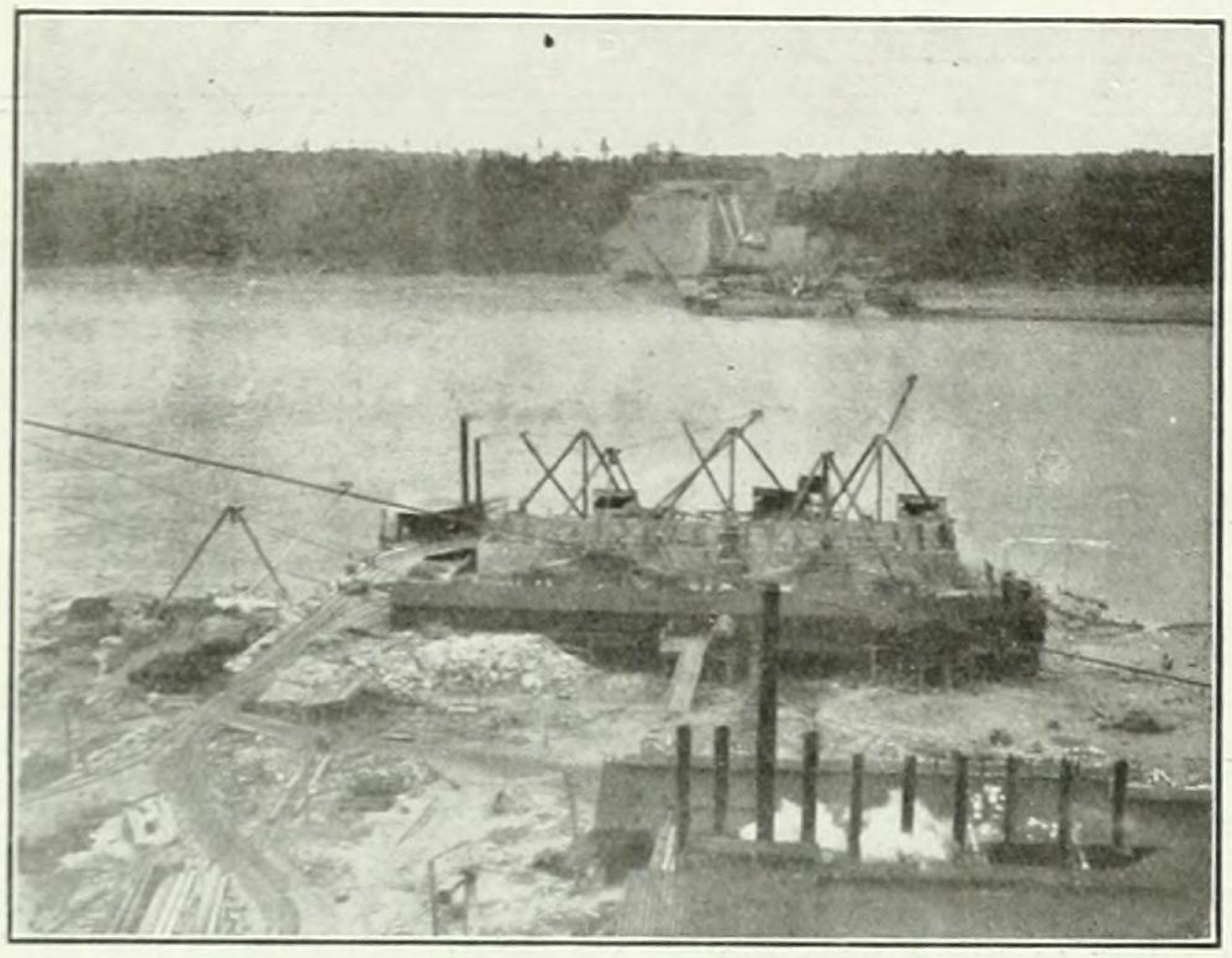


The Plant on the Side of the South Cliff.

(There can be seen the quarry to the right, with crushers and stone chutes leading to the concrete mixers, also the sand and coal hoppers and chutes leading to the lower level. At the left is the south abutment). June 15th, 1912.

Owing to a very late spring, actual sinking operations were not started until June 15th. Since that date the work has progressed steadily, and at the time of writing the caisson has reached bed rock, some 85 feet below the bed of the river. The material, being mostly sand, has been exceptionally easy to penetrate, the rate of progress having averaged nearly 9 inches per day for the entire time. Some weeks, however, the rate has averaged as high as 15 inches per day.

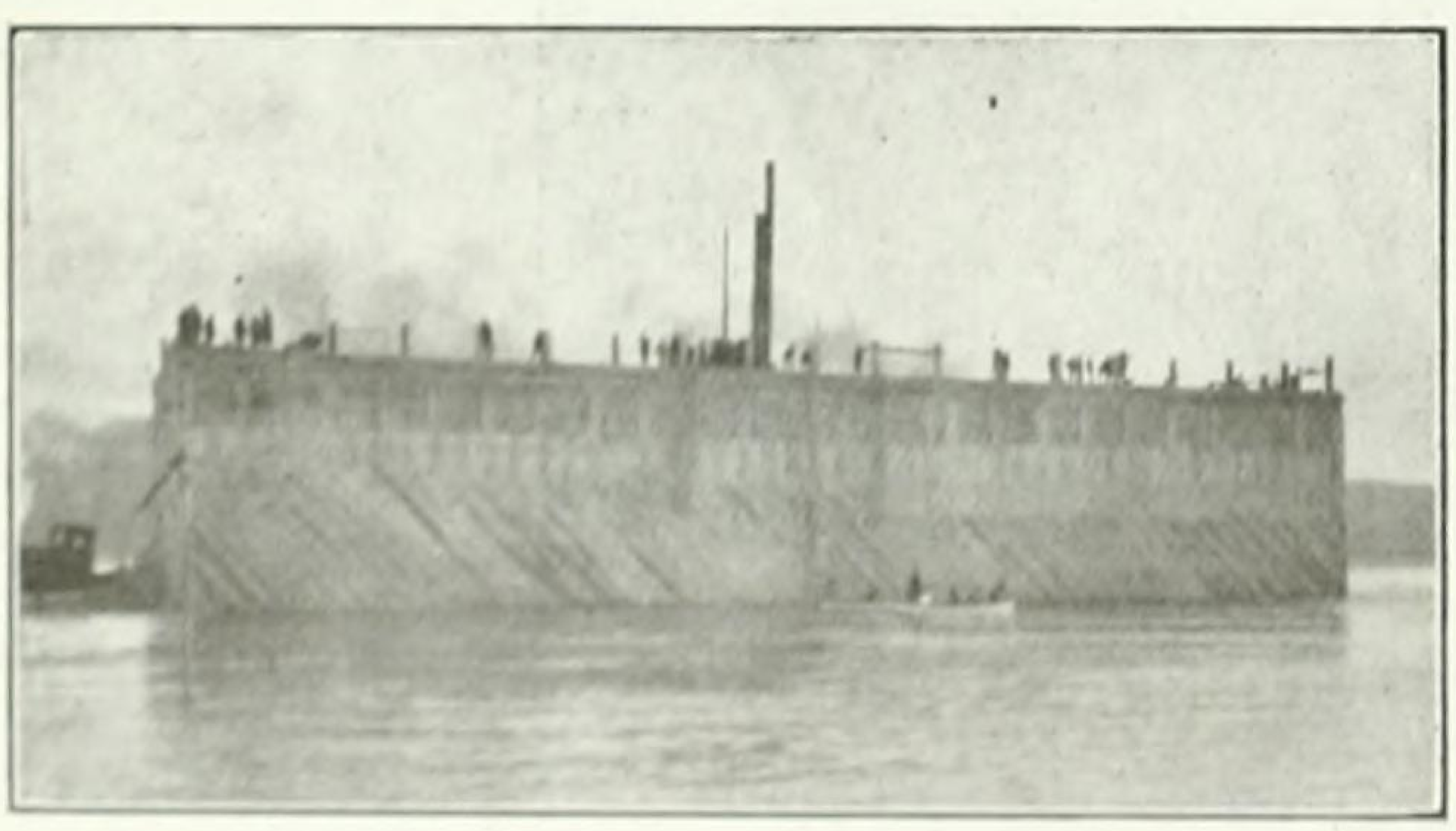
Owing to the unusual size of the caisson, extraordinary precautions were considered necessary to provide against any unequal settlement or any twisting or other movement of the caisson which might tend to open up the joints and seams and consequently allow air to escape. On this account it was decided that the ordinary method of sinking, where all the load is carried on the cutting edge, would not allow the movements of the caisson to be sufficiently controlled during the actual sinking. The rather unusual method has therefore been employed of carrying the entire



The Plant on the South Side, Showing Caisson During Sinking.
(The plant on the north shore across the river can be distinguished).
July 15th, 1912.

load on the bulkheads and the roof and no load at all on the cutting edge.

The caisson was supported on 40 sand jacks and about 25 posts 12 x 12 yellow pine and 54 sets of blocking. The jacks and posts bear directly against the roof while the blocking is piled under the bulkheads. When ready for a drop the blocking and posts are first removed by washing the sand from under them with a water jet. Then the whole caisson is lowered by operating each sand jack simultaneously. The sand jacks are of simple construction, consisting of a steel cylinder 29 inches in diameter closed in at the bottom. Near the bottom are two holes about 3 inches in diameter with a sliding cover. The plunger is a single piece of timber fitting easily into the cylinder. The cylinder is

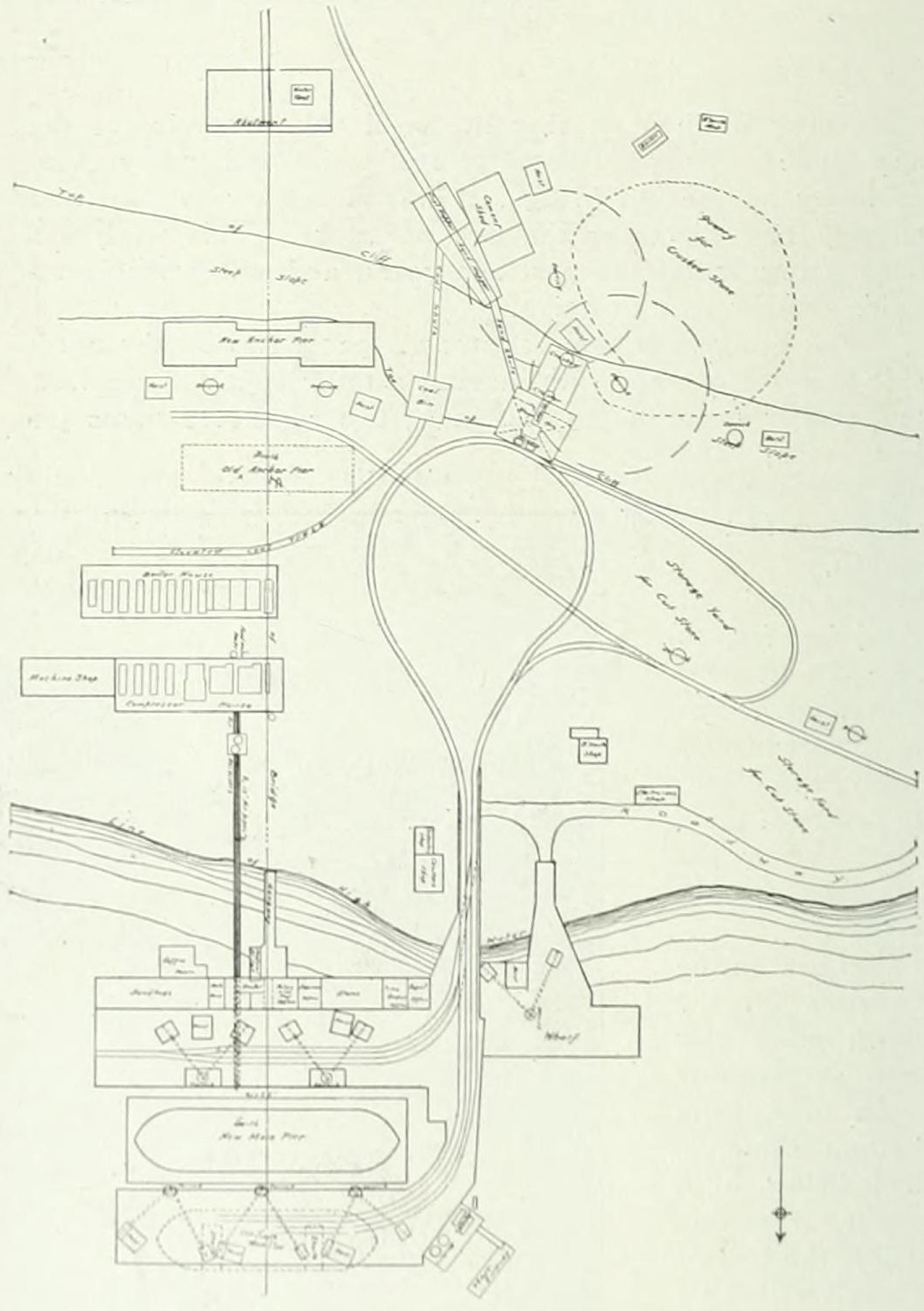


Floating the South Caisson Into Position.
(Its huge proportion shows up in comparison with the men and boats).
May 28th, 1911

filled two-thirds full of sand and the plunger inserted, the upper end being blocked against the roof.

The operation of lowering consists in opening the lower holes and placing a water jet therein, thus working the sand out. These jacks have been found to work admirably on this work, the result being that the caisson has been sunk absolutely level and in its proper location. Before each drop a trench was excavated under the cutting edge to a depth of two or three feet. This space was then filled with clay, which tended to prevent the escape of the air, and further acted as a lubricant during sinking. This scheme was followed throughout the entire sinking and seemed to materially facilitate the operation. The material encountered varied from small boulders and sand at the top to practically 95 per cent. sand towards the bottom. The sand is blown out through four-inch pipes by means of the compressed air. Ten of these pipes are in use and remove the fine material very rapidly. The larger material is removed through the material shafts in half-yard steel buckets. It has been necessary to do very little blasting.

Owing to the great depth of the caisson, special means have been employed to enable the men to enter and leave the working chamber with the least possible loss of time and labor. To this end an open shaft extends down to a horizontal steel lock placed over the roof of the working chamber.

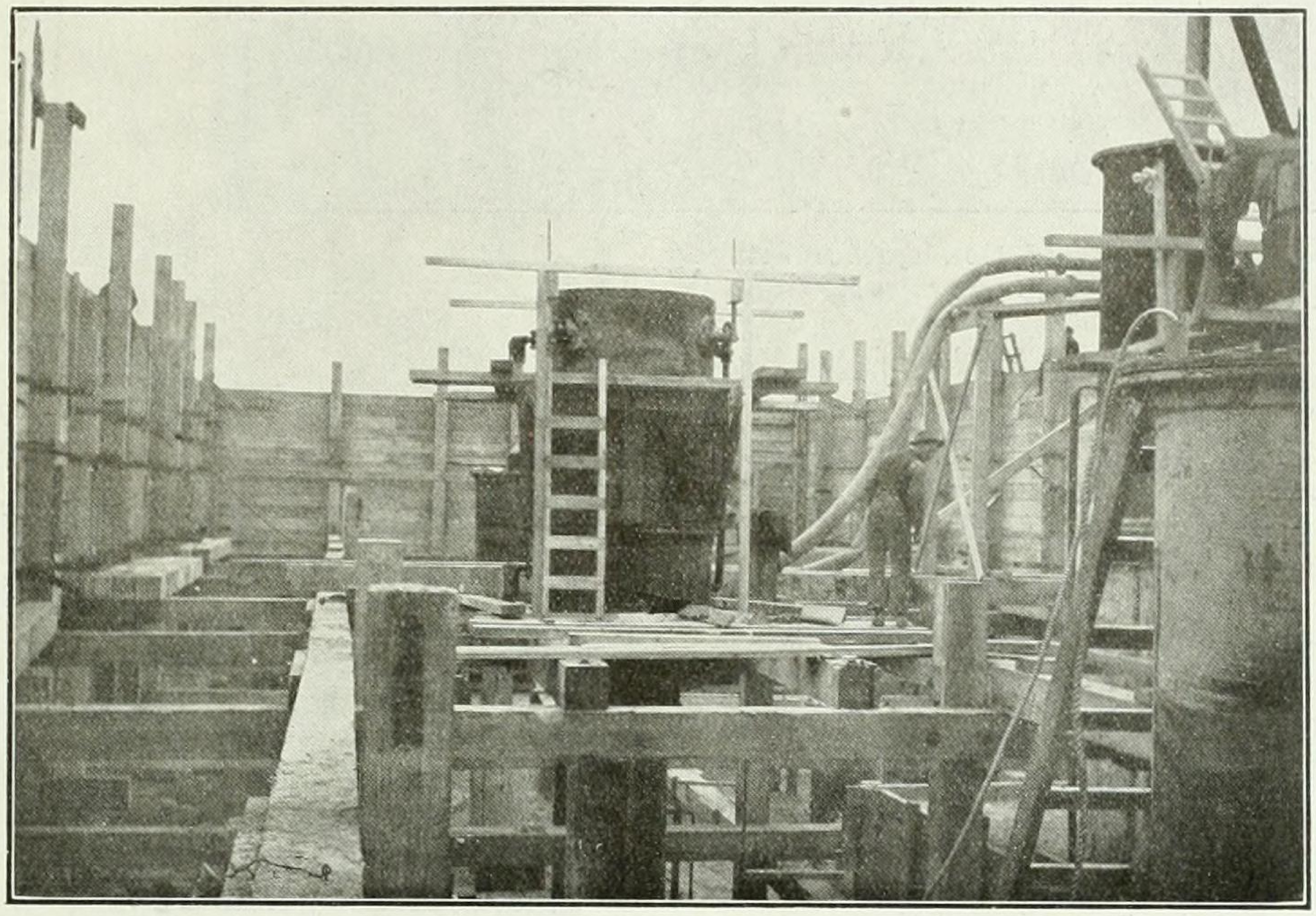


Contractors' Plant on South Side of River, New Quebec Bridge

This lock is large enough to hold the entire shift. Communication with this lock and the outside air is made by means of a spiral stairway. There is an air valve at the foot of this shaft and also at the top of another shaft in the bottom of the lock leading down to the working chamber. As an extra safeguard, there are four other 30-inch ladder shafts. The excavated material is hoisted out through three material shafts.

At the beginning of the work about 300 "sand hogs" were used in three eight-hour shifts of 100 men each. As the caisson was sunk and the pressure increased the length of the shift decreased. At 50 feet below average high water or a pressure of about 22 lbs. per square inch, a change in working hours was made to four shifts of six hours each. At 65-foot depth or 32 lbs. pressure six shifts of four hours was required. Again at 75 feet the shifts were changed to eight of three hours each. When the caisson reached its full depth of over 90 feet below average high water two one-hour shifts per day were required, this being the greatest length of time that the men could stand the very heavy pressure.

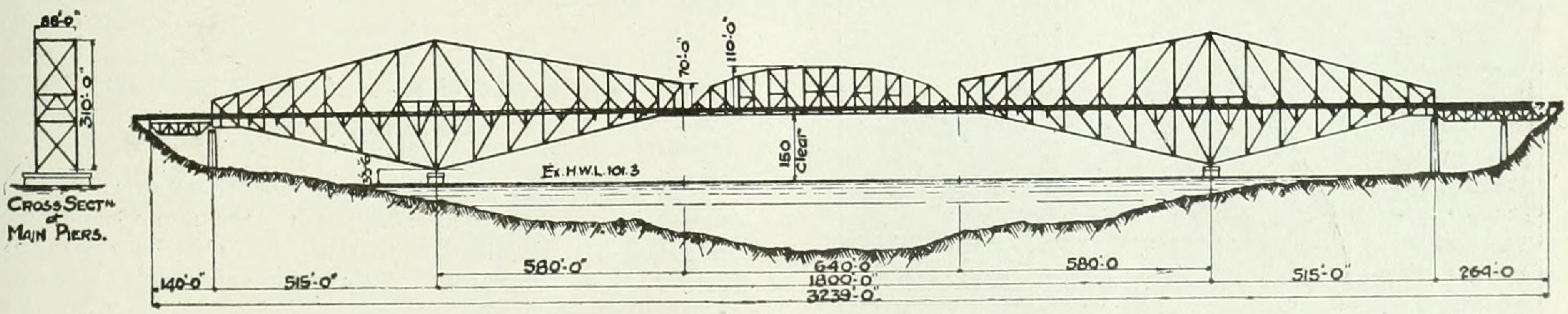
Outside the caisson the contractor has made provision for the care of the men in many ways. In addition to a bunk-house and dining-room, there is a dressing and coffee house where "sand hogs" coming out of the caisson may change their clothes immediately and be supplied with hot coffee. Next door is an hospital with cots and a qualified doctor in constant attendance. Adjoining the hospital is a steel hospital tank connected with the compressed air pipes where men who have come out of the pressure too quickly and are attacked by the "bends" can be placed immediately under pressure again before any serious or injurious effects can develop. The caisson is surrounded on three sides by a heavy platform supported on bents. On this platform is a double line of track leading to the concrete mixers and stone yards. The skips with the loaded concrete buckets run from the mixers to the caisson by gravity, the empty skips being hauled back by horses. Three 15-ton stiff-legged derricks are placed on each side of the caisson and are used to deposit concrete, stone, or hoist the



View of Interior of South Caisson.

(The large shafts are for material, while the smaller are ladder shafts for the men). June 15th, 1912.

The compressor plant consists of five Ingersoll-Sargeant direct compressors, four with a capacity of 1,250 cubic feet, and one with a capacity of 2,500 cubic feet per minute. This plant was used on the north shore last season. To this has been added, this season, two compound two-phase air compressors bringing the total capacity up to 13,100 cubic feet per minute. These two latter compressors were used only when the pressure got above 30 lbs. per square inch. The air is first compressed in the low-pressure cylinder up to 30 lbs. per square inch, then it is passed through a cooling chamber into the high-pressure cylinder where the compression is increased as desired. There is in addition a smaller high speed compressor for supplying air tools, etc. In the compressor house there is an automatic register indicating on a diagram the pressure at all stages of the tide during the whole 24 hours. Another gauge, by means of a finger operated by the tide, indicates on an adjustable scale what the pressure should be at any stage of the tide. By this means the operator can, by watching the finger, so adjust his compressors so that a pressure is intelligently maintained conforming to the height of the tide. The air is led from the compressor house into two receiving tanks, which tends to absorb the sound and shock from the compressors; thence into two 12-inch mains which are laid in a trough of cold, running water.



General Elevation and Cross Section of New Quebec Bridge.

(St. Lawrence Bridge Co. Ltd., contractor for superstructure).

loaded buckets through the material locks. On this platform is also the pump which supplies the water to the boiler plant and for various other uses as required.

The boiler and air compressor plant is situated near the foot of the cliff. A portion of this plant was brought over from the north shore last fall after the sinking of the north caisson was finished, but this has been increased nearly 100 per cent. in order to afford a greater reserve supply in case of break-down and also to furnish air for the increased number of blow pipes necessitated by the greater quantity of fine material encountered in the sinking.

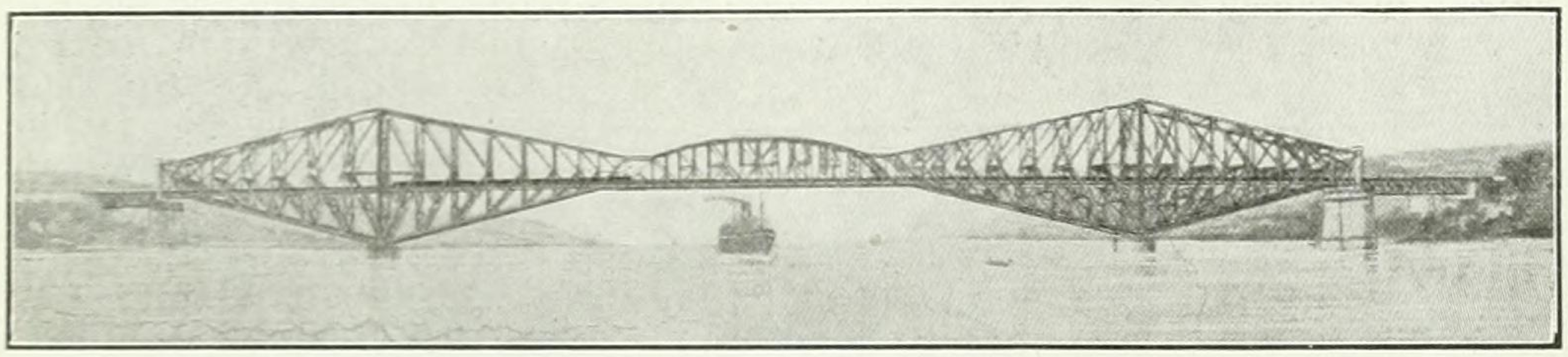
The air, therefore, enters the caisson comparatively cool, the temperature of the working chamber rarely exceeding 80 degrees Fahr.

The boiler plant consists of one 75, six 100 and three 125 horsepower horizontal boilers, and three 250 horsepower Heine water tube boilers with a total capacity of 1,800 horsepower. A number of 50, 75 and 100 horsepower boilers are also used throughout the work, crushers, mixers, derricks and pumps.

The whole plant, as well as the working chamber of the caisson, is lighted by electricity supplied by the city.

In case of break-down on the power line the contractor has provided a complete generator plant located on the compressor house. It is equipped with a 30- kilowatt General Electric Company generator capable of operating 16 arc lights and 100 sixteen-candle-power incandescent lights.

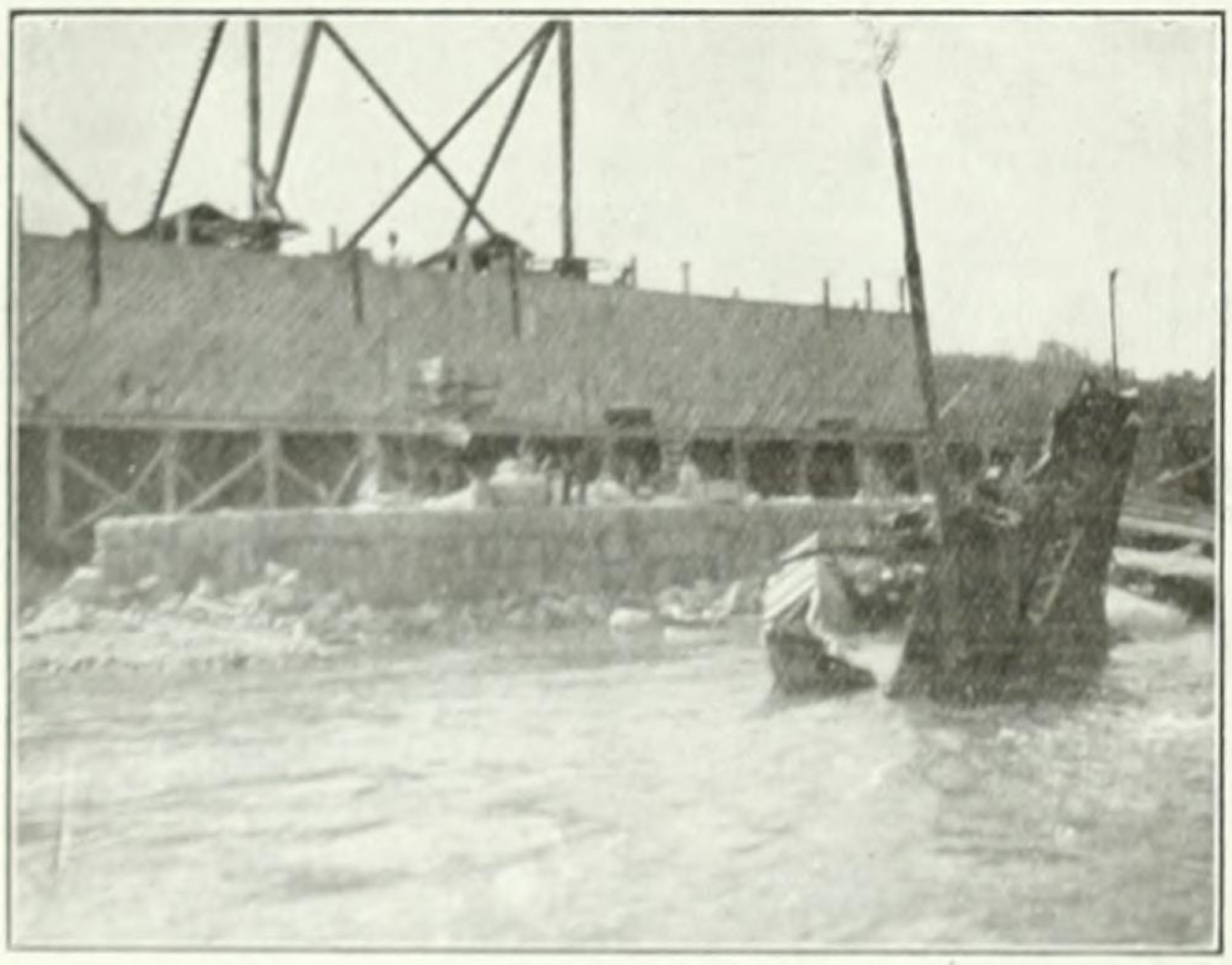
The concrete masonry plant is situated at the foot of cliff which rises almost perpendicular for 125 feet. Half way up the cliff a No. 5 and No. 8 rock crusher is situated. The stone is quarried directly on the brow of the cliff, and is so situated that one derrick can pick up the buckets of stone from the quarry and dump it into the chute leading to the crushers. Coming from the crushers the broken stone is led through a revolving screen, thence through another chute to a hopper opening onto the mixing platform. Two Smith mixers are used, each having a capacity of 1⅓ cubic yards. The sand is brought to the brow of the cliff in cars and dumped into a large hopper. A chute leads from this hopper directly to the mixing platform. The coal is brought to the lower level in the same manner and is carried to the boiler house in side dump cars.



Sketch of New Quebec Bridge
(as it will appear when finished).

For the convenience of the "sand hogs" the contractor has erected a bunk-house adjacent to the work with sleeping accommodation for about 100 men. A dining-room is run in connection, which will accommodate about as many more.

The south main pier, when completed, will contain about 35,000 cubic yards of masonry. For a height of 75 feet above rock, or some 6 feet below low water, it will consist of a solid mass of concrete the full size of the caisson.

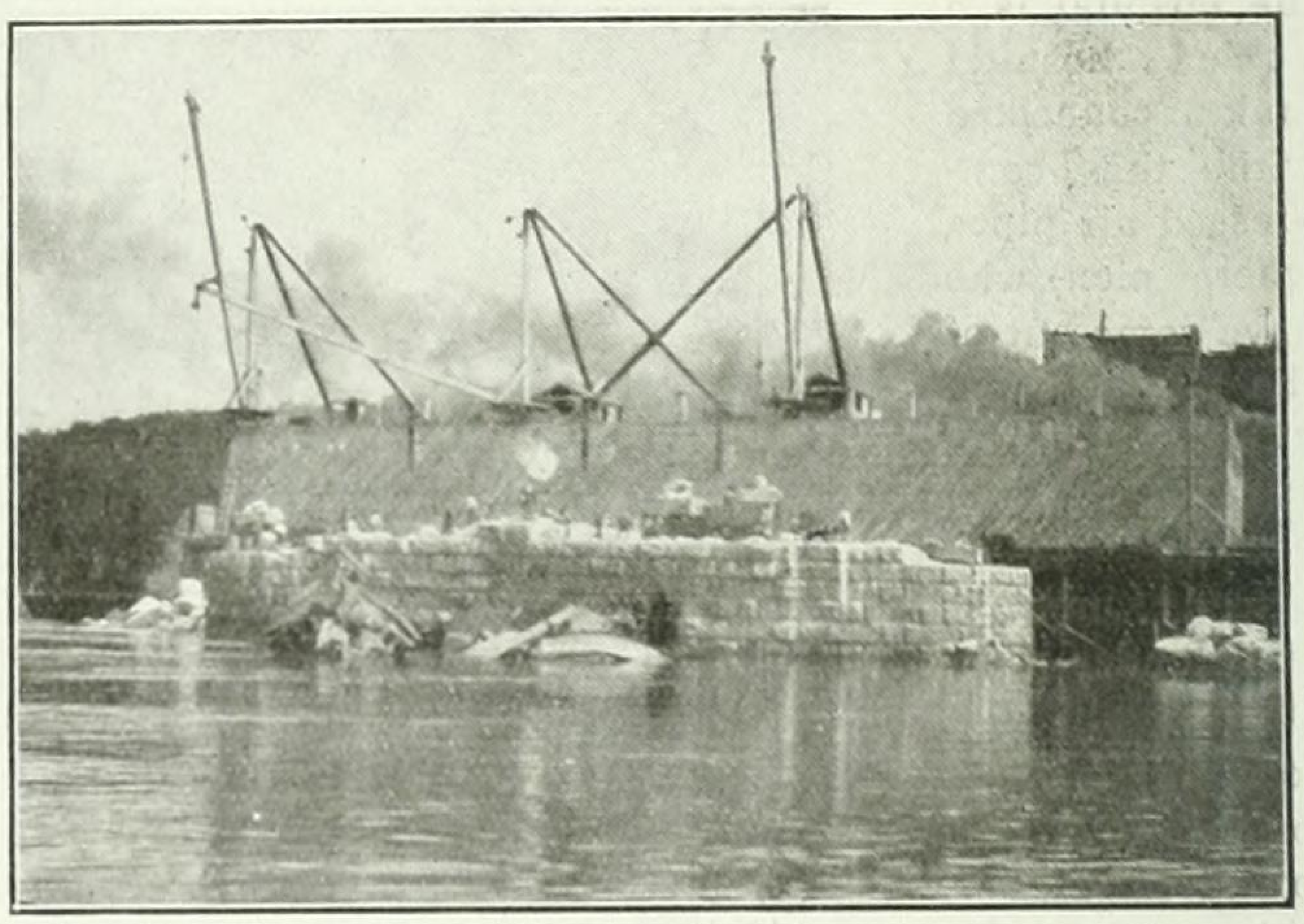


The Work of Demolishing the Old Main South Pier.
(A portion of the wreck of the fallen structure is seen in the foreground).
August 25th, 1911.

From this point the shaft of the pier will start having a solid granite face and backing of concrete. The upper 18 feet will be of solid granite.

The concrete used for the main body of the caisson is composed of one part cement, two and one-half of sand, and five of broken stone. For sealing the working chamber a somewhat richer mixture is specified, viz., one of cement, two and one-half of sand, and four of stone. Displacer stones one-half a cubic yard and over are used in the concrete, no two stones to be closer than 9 inches vertically or 12 inches horizontally.

The work is under the supervision of a board of engineers, appointed by the government, of which Mr. C. N. Monsarrat is chairman, having associated with him Mr. Ralph Modjeski, of Chicago, and Mr. C. C. Schneider, of Philadelphia. Mr. J. D. Wilkins is resident engineer for the board at Quebec, and has charge of all inspection. Messrs. M. P. and J. T. Davis, of Quebec, have the contract for the masonry, Mr. S. H. Woodard, of Noble and Woodard, consulting engineers, New York, being superintending engineer for the contractors in charge of the entire work.



The South Caisson in Place, Behind the Old South Main Pier.
August 10th, 1911.

NICOL HALL, A NEW ADDITION TO QUEEN'S UNIVERSITY.

On Wednesday, October 16th last, there was formally opened for inspection an addition to the many handsome buildings of the University that will in future be known as Nicol Hall in recognition of the many philanthropic deeds of Prof. William Nicol.

This building will be occupied by the mining and metallurgical departments and the basement of the building is given over to the fire laboratories, gasoline furnaces, gold and silver work, balance-room with chemical laboratories, metallurgical laboratory, equipped with roasting furnaces, blast furnaces and accessory appliances, etc.

On the main floor there is a large classroom, with accommodation for eighty students; there are research laboratories, and Prof. S. F. Kirkpatrick's room. The halls are very bright and it is the intention to use them for a museum.

The second floor contains a drafting-room, lecture-room, with the office and library of Prof. John Gwillim.

The third floor has not been fitted up as yet.

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The Canadian Engineer

An Engineering Weekly

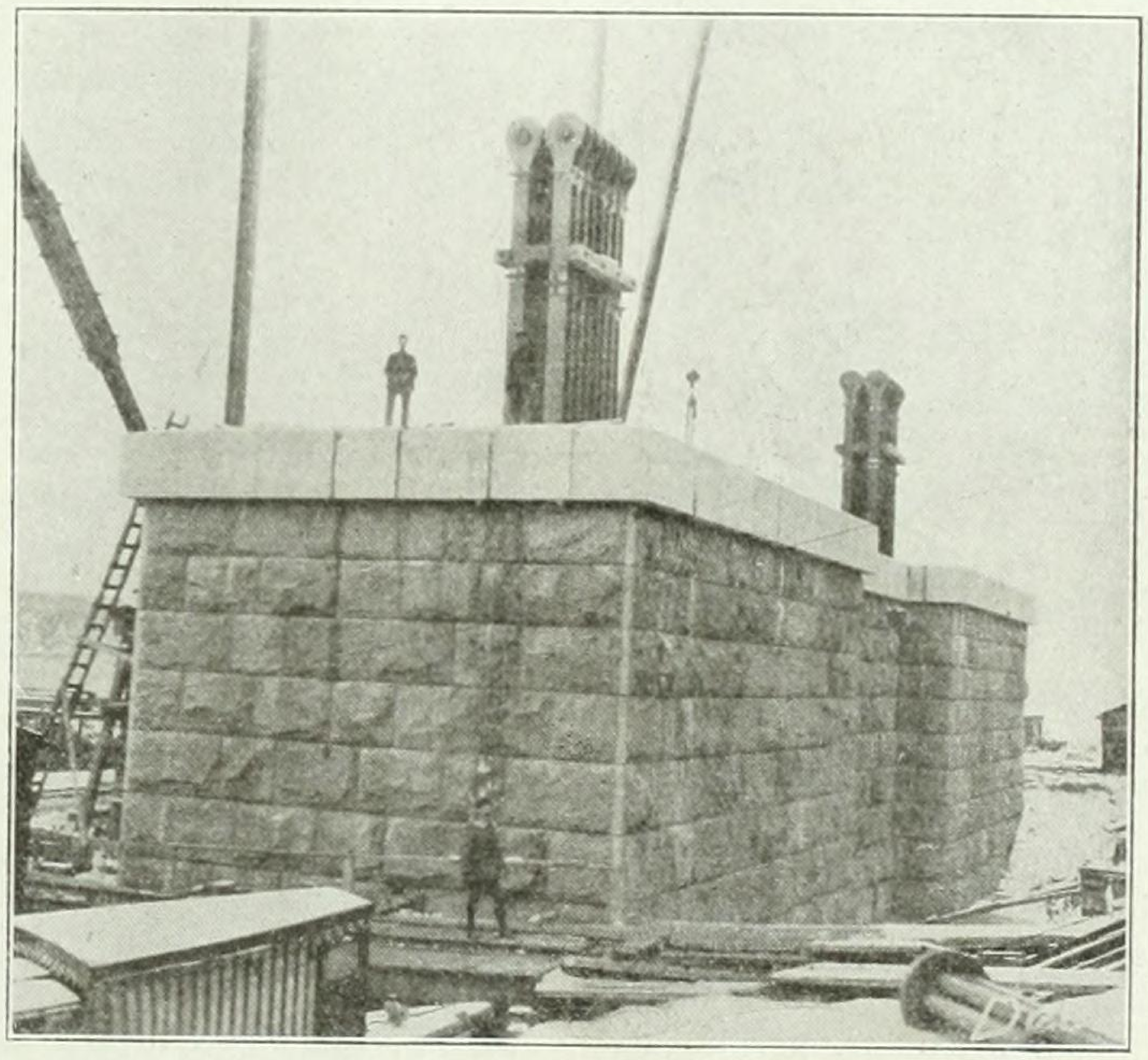
PROGRESS IN CONNECTION WITH THE CONSTRUCTION OF THE QUEBEC BRIDGE.

Very satisfactory progress has been made in connection with the construction of the huge Quebec bridge, situated some seven miles above the city of Quebec.

The contract for the substructure was let in January, 1910, and the contract for the superstructure in April, 1911. The work on both contracts has gone ahead as rapidly as possible since these dates, and at the present time there are material evidences to prove that before very long the River St. Lawrence will be successfully spanned by the largest bridge in the world.

Owing to the increase in weight and width of the superstructure, the piers of the old bridge had to be removed and new ones constructed in their place. All the more difficult work in connection with the substructure is now practically completed. The caissons for the north and south main piers have been sunk to the required depth, that for the nortn pier about 50 feet and that of the south about 85 feet below the bed of the river. All the rest of the work in connection with the substructure is above high-water mark or protected from the water, and presents no serious problems. The masonry involved in this contract includes alterations to the existing abutments and the entirely new construction of one intermediate pier, two anchor piers, and two main piers. The total yardage in these various pieces of masonry amounts approximately to 105,000 cubic yards. The timber used in the caissons is mostly 12-inch by 12-inch long leaf southern pine, and some 18,000,000 feet B.M. were used in the construction. The piers on the north side of the river are well advanced, and will be ready to accommodate the steelwork early in the coming season.

Since the awarding of the contract for the superstructure, the contractors, the St. Lawrance Bridge Company, of Montreal, have had a staff of between thirty and forty men engaged in their offices working on the detailed plans of the design. The design, details and problems in connection with this bridge are to a large extent without precedent, and as a result much time has been spent in investigation and studies that would not have been necessary with a smaller structure.



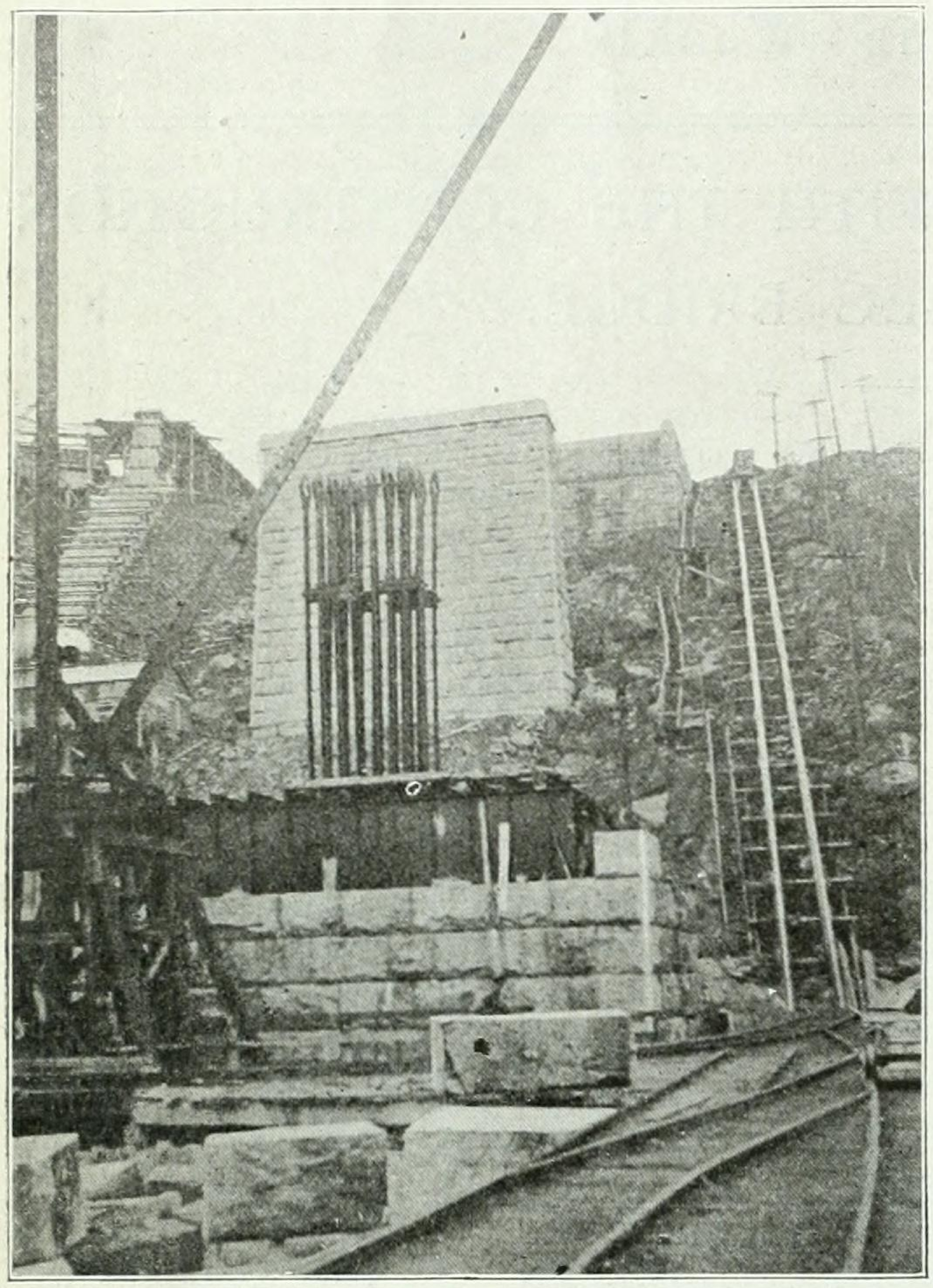
View Showing North Anchor Pier with Eyebars Extending Above.

This pier will be extended 100 ft. higher than is shown here. Some idea of the enormous size of the stones can be gained by comparing with men in the picture. Dec. 2nd, 1912.

Plan after plan has been made, studied and revised, no detail of construction or calculation being too insignificant to court the minutest investigation. The contractors work in conjunction with the designers and calculators of the board of engineers, and no detail was passed unless thoroughly approved by both. Entirely independent sets of calculations were made by the board of engineers, each calculation being checked and re-checked independently so that there could be no possibility of error creeping in. Therefore, each simple calculation was subjected to two independent investigations by the contractors and two independent investigations by the board before it was finally approved. The suspended span was first designed and shop drawings completed from which the actual dead loads were computed before starting on the cantilever arm, which is in turn being completed before the drawings of the anchor arm are made. It can therefore be seen that there can be no chance of over-run in dead weight in the completed structure, as was the case in the old bridge.

The enormous proportions of this bridge cannot be properly appreciated until actually viewed in place. Some idea, however, may be gained from the following facts:—The completed bridge will probably exceed 50,000 tons of steel, equivalent to 1,700 carloads of 30 tons each, or over 500 train loads of 30 cars each. While this is an enormous quantity of steel to go into any one structure, yet there would be no difficulty in handling it were it manufactured in the ordinary commercial sizes used in bridges and structures to which we are accustomed. The great difficulty of the mechanical side of this enterprise arises from the fact that nearly all the members of the bridge are of such enormous proportions that the ordinary shops or equipment are entirely inadequate to manufacture or handle them. Shops with columns and girders of unusual strength are required to carry the heavy cranes which handle the enormous members. Almost every piece of machinery used must be of the largest capacity, and in the majority of cases are specially designed for this job.

The main posts of this bridge are about 10 feet by 10 feet in outside area and approximately 320 feet high, or equal to the height of a thirty-story building. The shoes on the main pier upon which each of these posts rests are 21 feet by 26 feet square and 15 feet high. Many a family lives in a house



View Showing Lower Anchorage. Girders and Eyebars in Place.
(Also completed intermediate pier and abutment in the background).

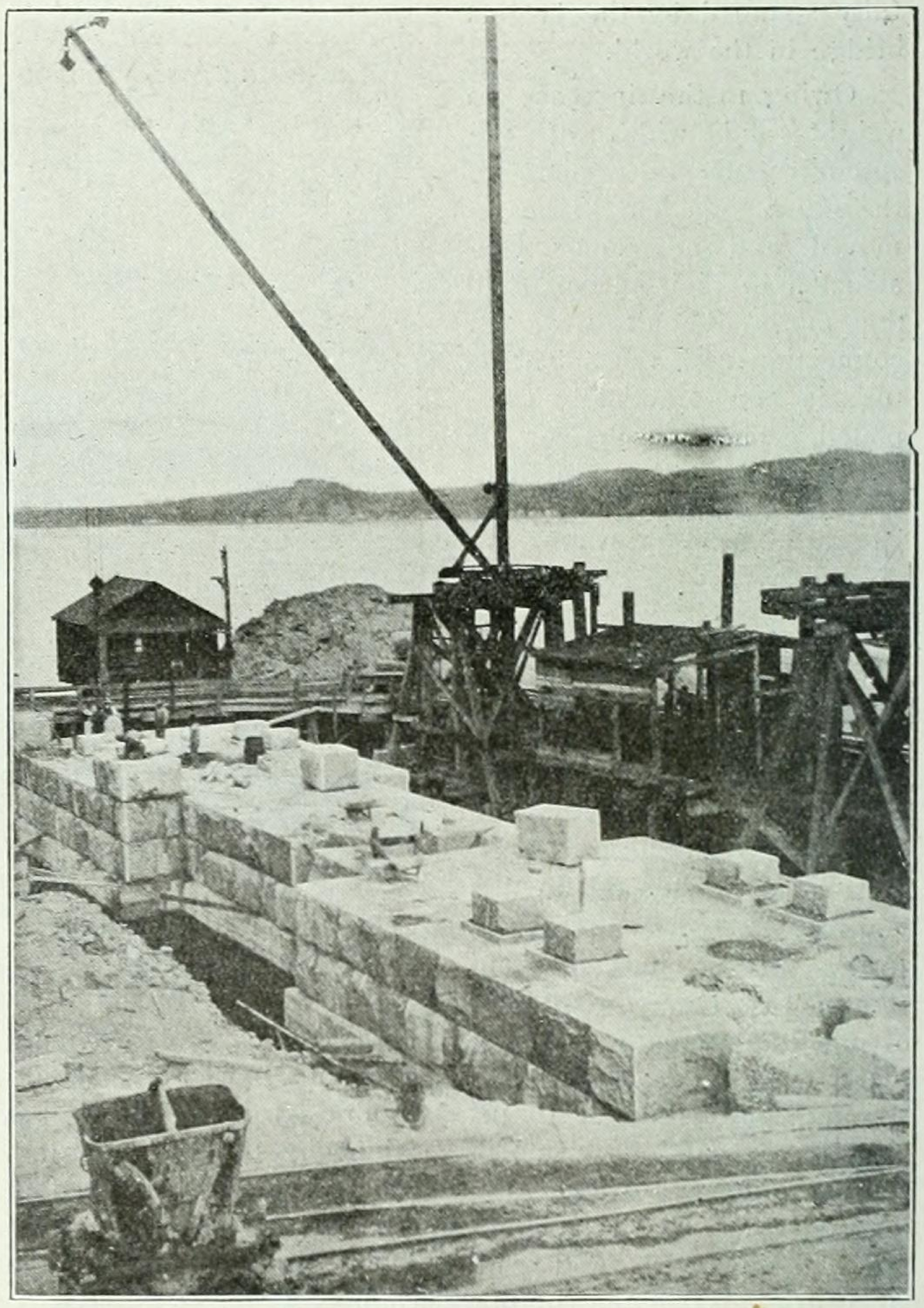
considerably smaller. The main bottom chord near the pier is about 10 feet wide and 8 feet high. If it were not for the interior webs and diaphragms six men could walk abreast inside this chord without crowding or fear of hitting their heads. This chord will weigh about 8,500 lbs. per lineal foot and is erected in sections weighing from 75 to 100 tons each. The main floorbeams are approximately 90 feet long and 10 feet deep, and weigh between forty and fifty tons. In most cases they are connected to the truss by pins in order to do away with the secondry stresses in the posts. The top chords of the cantilever and anchor arms are composed of two banks of eyebars of half panel lengths, and are supported by light Warren trusses between main panel points.

The floor system is designed to carry two railway tracks and two sidewalks for pedestrians. No allowance is made for highway traffic.

Elaborate preparations are being made by the contractors for the erection of this steel work. Erection will be carried on on both sides of the river simultaneously, which means a duplicate erection plant throughout. While this entails somewhat more expense for the contractors it will be justifiable by the saving of time. The anchor arms will be erected on heavy steel falsework which is so designed that the trusses will be carried on falsework independent from that which carries the traveler. The main traveler will be an enormous structure about 200 feet high and weighing, inclusive of hoisting machinery and tackle, about 900 tons. The traveler is constructed with an overhang from which heavy blocks are suspended and operated by means of electric hoists. Each hoist is capable of lifting 50 tons simultaneously, 60 feet beyond the point of support. The traveler is also equipped with cross gantrys and electric cranes and enormous booms which can handle material in practically every position. The blocks for the dozen or more hoists used in this traveler have all to be specially designed and constructed, many of them being over 5 feet in height and weighing over 5,000 lbs. each.

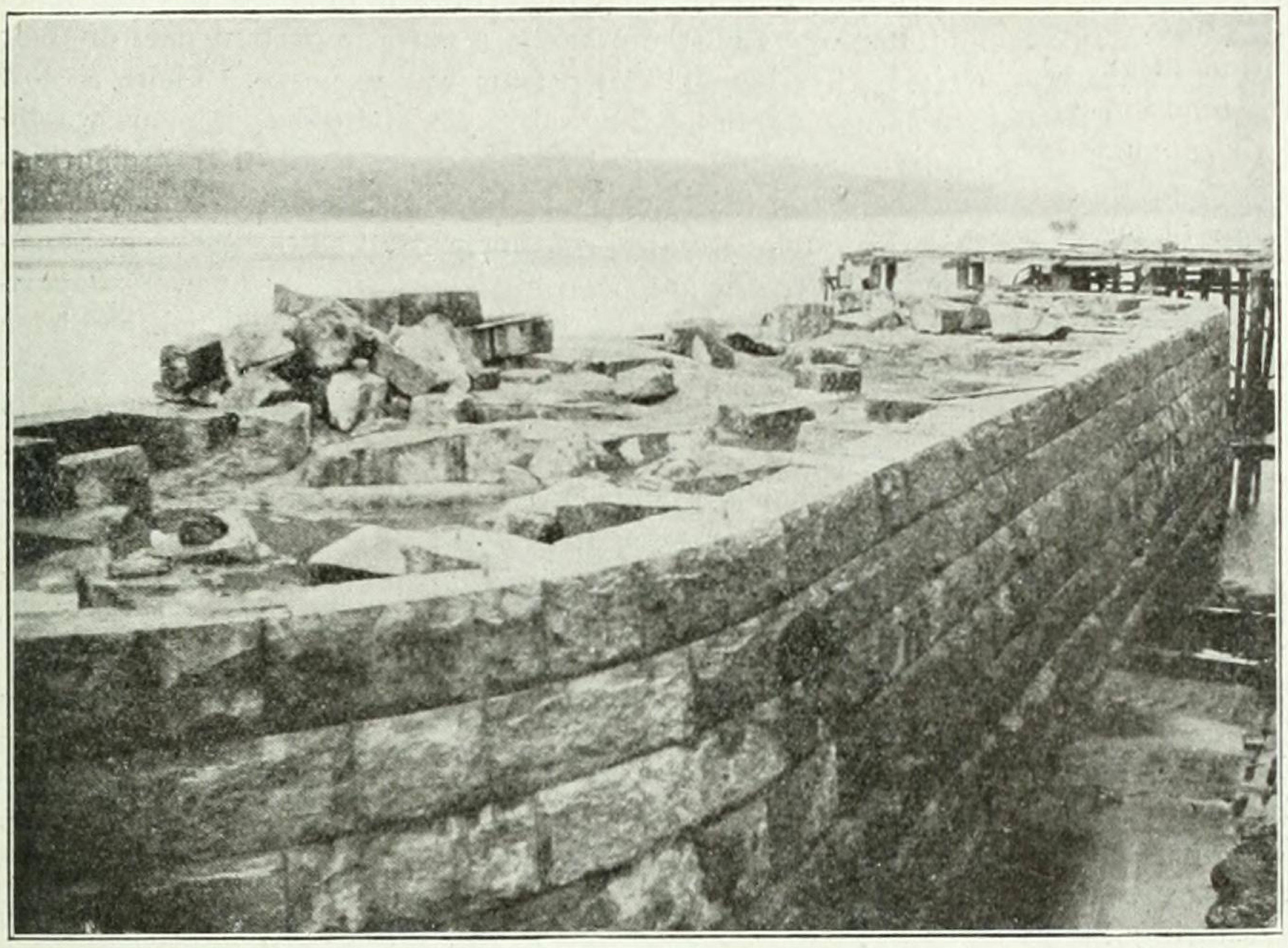
Probably one of the most interesting features of the erection will be the floating in of the 640-foot centre span. By means of this scheme of erection the difficulty of joining up at the centre is overcome and one year saved in the erection of the bridge.

While the floating in of a bridge span is a common enough occurrence to bridge erectors, yet, taking into consideration the length, weight and height of this span, and also the fact that there is a seven or eight-mile current and a 20-foot tide at this point, it can be seen that this part of the work is also without precedent. It is proposed to erect this span on steel falsework or staging on the shore or in shallow water at some point near the bridge site. This falsework is founded on concrete piers so spaced as to allow pontoons to



Starting Construction of the North Anchor Pier.
(View shows granite bed rock in place upon which steel anchorage is to be placed. Sept. 11, 1912.)

float in between them and under the falsework. When the span is completely erected and ready to be floated, the pontoons are placed in position under the falsework when the tide is low. As the tide rises the pontoons lift the bridge off the concrete piers. After the span has been towed to its proper position under the bridge it has yet to be lifted over 130 feet in the air and connected to the ends of the cantilever arms. This is done by means of hangers with slotted holes which can be quickly attached to the four corners by means of pins. After this has been done at highest tide the pontoons are floated from under and the span is lifted in place by jacks at each corner of the cantilever arms.



View Showing North Main Pier.
(Completed up to high water mark and the caisson removed. Nov. 8th, 1912)

Entirely new shops have been constructed by the St. Lawrence Bridge Company, of Rockfield, near Lachine, and manufacturing has just been started. This shop is completely equipped with the latest and most powerful electrically driven machine tools, and will have a capacity of about 2,000 tons a month.

The supervision of the entire work is under the direction of the board of engineers appointed by the government. Mr. C. N. Monsarrat is chairman and chief engineer, with whom are associated Mr. C. C. Schneider, of Philadelphia and Mr R. Modjeski, of Chicago.

THE PRINCIPLES OF SCIENTIFIC MANAGEMENT.

On the occasion of his visit to Toronto to address the Canadian Club, Frederick W. Taylor, M.E., gave an address on "The Principles of Scientific Management" to the Engineering Society of the University of Toronto, on January 21st, 1913.

In his opening remarks Dr. Taylor presented his subject as referring principally to workers of co-ordinated industry, in distinction to isolated workmen, it being applicable only to the former.

Nineteen of every twenty workmen believe that it is to their best interest to turn out as little rather than as much work as possible. It is the most serious fallacy that possesses our working class, and is attributable to two causes, for neither of which are the workmen themselves to blame.

First, if it be suggested to a group of workmen that they double their output, they reply that the procedure would throw one-half of their fellow-workers out of employment. To them it appears self-evident, and others, among whom are many of our philanthropists, uphold the belief, heralding over-production as one of the greatest social evils conducive to national idleness. It is immensely true in every trade, so its followers believe, that in going slow, their interests are advanced. Any device, therefore, tending to increased output is rebelled against by this deeply rooted nature.

No more fallacious than such belief exists, and it is borne out by history everywhere, with but one exception, that the introduction of such a device or system, into any trade, instead of forcing men out of work, has provided more work for men of that trade The exception is in farming. Improved processes in the United States have reduced the providers of food supplies from eighty per cent. in years past to thirty-five per cent. at the present time, because the human capacity for food does not increase from generation to generation. This is the only instance where such a condition obtains.

As an illustration of the effect in other forms of labor, Dr. Taylor referred to the cotton industry, its history being comparatively older and its evolution more spectacular. The power loom was invented early in the last quarter of the eighteenth century, but the year 1840 witnessed the climax of its introduction, after a struggle many years in duration, to gain entrance into the manufacturies. In Manchester, Eng., the workmen felt that these looms would throw 3,500 of their 5,000 men out of work, and they strongly resented such outside intervention between them and their daily bread. Conditions were grave, as it was most difficult in those days to change one's trade, or even to move from one works to another. No alternative means of livelihood presented itself. The result was clear and concise. They forced the establishments, destroyed the looms, and maltreated the operators. Their rioting, however, did not affect the entrance of the loom into the industry.

Be the means what it may, bitter opposition, adverse legislation, public opinion, trade unions—all forces are powerless and futile in defeating the introduction of labor-saving development, and the effect is frequently that of accelerating its use.

The speaker stated that there is great opposition from labor leaders to scientific management, but since that opposition has become open and strong, scientific management has gone ahead more rapidly.

The result in the case of the cotton industry in the three-quarter century that has elapsed has been that the workmen have been proven wrong in their convictions. Has the increase of output thrown laborers out of work? In 1840 there were 5,000 workers. At the present time there are about 265,000 employed at the same work in Manchester. For every yard of cloth in 1840 there are now five hundred yards manufactured, though the population of England has not more than doubled within that time.

"There is a broad meaning back of it all. Wealth need only be brought into the world, for the world to use it. Although there are undeniable cases of over-production, they are abnormities, due to a general cause—the world undertaking a greater number of new enterprises than available capital warrants. It is a disease to which the public is susceptible, and the panics of 1873 and 1893 are unforgotten. On the other hand, production is necessary to wealth, which is derived from two sources, viz., out of the ground and by manufacture at the hands of man. The relation of wealth to production should be recognized, particularly by the poorer classes; their impression is erroneous that by far the major

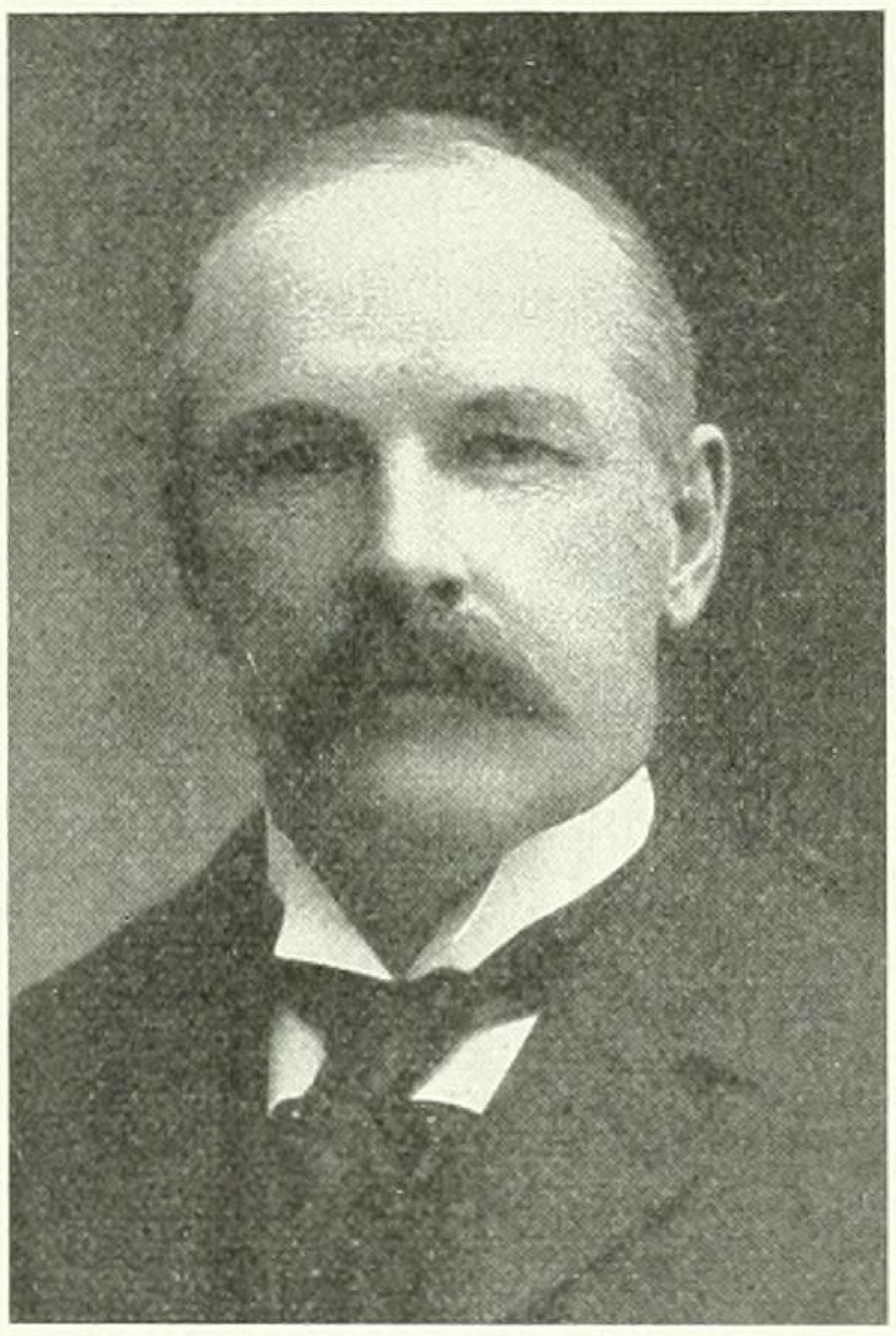
The Canadian Engineer

A weekly paper for engineers and engineering-contractors

CANADIAN SOCIETY OF CIVIL ENGINEERS

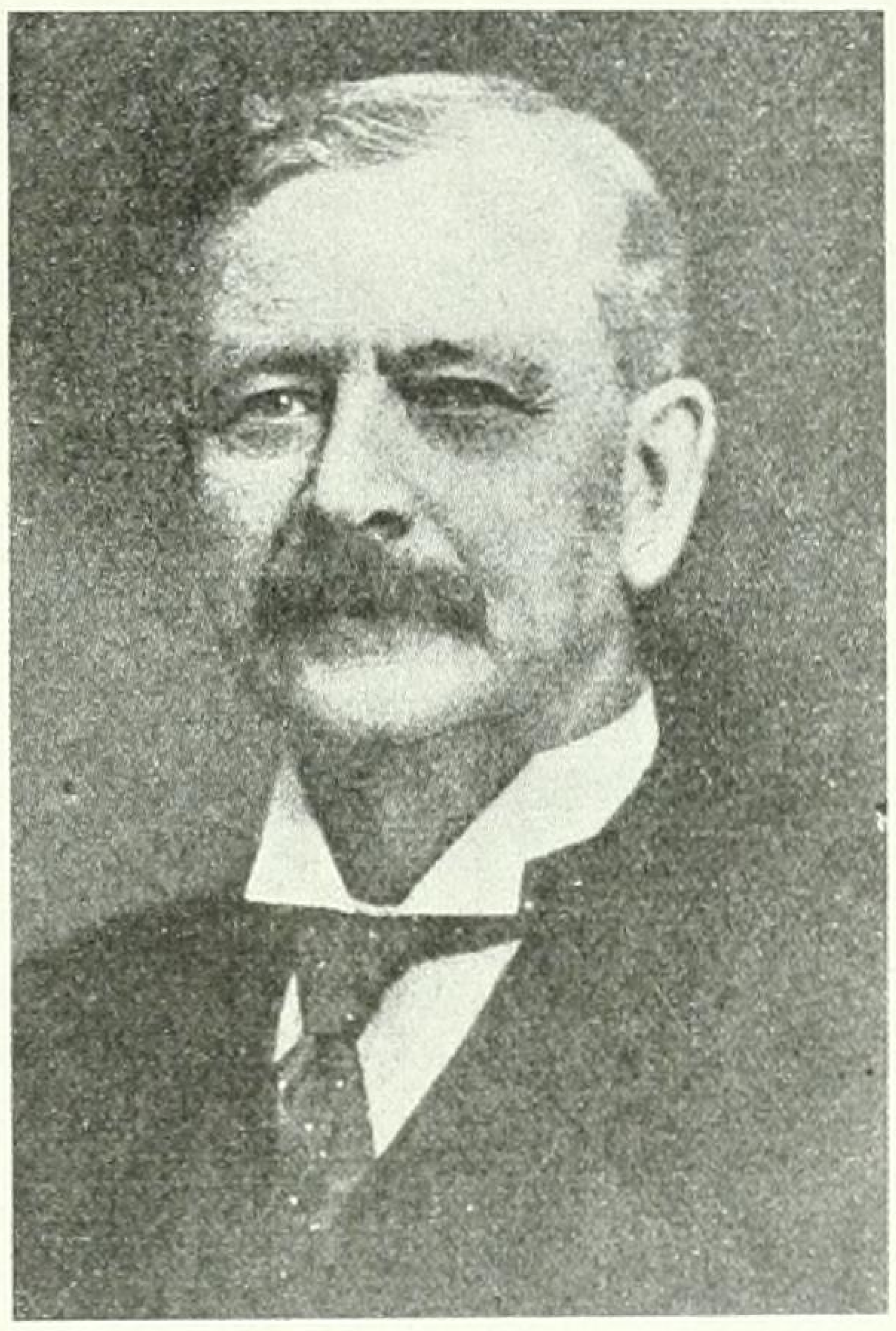
TWENTY-EIGHTH ANNUAL MEETING TO BE HELD AT MONTREAL NEXT TUESDAY, WEDNESDAY AND THURSDAY — M. J. BUTLER IS PRESIDENTIAL NOMINEE—REPORTS OF COMMITTEES—VISIT TO ST. LAWRENCE BRIDGE WORKS

FOR the first time in their new building on Mansfield Street, Montreal, The Canadian Society of Civil Engineers will hold their annual meeting next Tuesday, Wednesday and Thursday. Only a reception was held in the building—which was then only partially completed — during last year's annual meeting. Nineteen - fourteen, therefore, marks the beginning of a new era in the affairs of the Society, the members now formally inaugurating into their service the splendid new building of which the Society can properly be proud. The Engineers' Club of Montreal, at which there will be considerable entertainment for visiting members of the Society, have also greatly enlarged and handsomely remodelled their building during the past year, so the meetings this year will have the advantage of much greater facilities, both for work and pleasure, than have existed at any previous annual meeting.



Phelps Johnson

President of the Canadian Society of Civil Engineers in 1913; president of St. Lawrence and Dominion Bridge Co's.



M. J. Butler

President-elect of the Canadian Society of Civil Engineers for 1914; head of Armstrong, Whitworth of Canada, Ltd.

There will be five business meetings—at 10 a.m. and 3 p.m. Tuesday, at 3 p.m. Wednesday, and at 10 a.m. and 2.30 p.m. Thursday. The retiring president's address will be delivered Tuesday afternoon.

All visiting members will be guests of the Montreal members at a luncheon in the Windsor Hotel at 1 p.m. Tuesday. A complimentary smoking concert will be held at 8 p.m. Tuesday in the Society's building. The annual dinner will be served in The Engineers' Club at 8 p.m. Wednesday.

It is thought that there will most probably be a trip through the Mount Royal Tunnel, but the only excursion officially noted on the programme is to the works of the St. Lawrence Bridge Company, Limited, at Rockfield, near Montreal. The party will leave the Windsor Hotel at 10 o'clock sharp, Wednesday morning. By courtesy of the Montreal Tramways Company, special street cars will be provided to carry the party to and from the works. After the inspection of the works, the Bridge Company will entertain the visiting members at luncheon.

The president of the Bridge Company is the retiring president of the Society, Mr. Phelps Johnson. Mr. Johnson was born in the United States and practised as an engineer for bridge companies for some years before coming to Canada. From 1872 to 1879 he was engineer for the Hawkins Iron Works, at Springfield, Mass. In 1879 he became assistant engineer of the Wrought Iron Bridge Company, of Canton, Ohio.

In 1882 Mr. Johnson went to Toronto as engineer and manager of the Toronto Bridge Company, which afterwards became the Dominion Bridge Company. In 1888 he became chief engineer of the Dominion Bridge Company, at Lachine, P.Q., which position he retained until 1892, when he was appointed general manager of the company. He was elected president of the company at the last annual meeting, succeeding Mr. James Ross, deceased. Mr. Johnson had previously acted as

THE ST. LAWRENCE BRIDGE COMPANY'S SHOPS

DESCRIPTION OF THE PLANT BUILT AND EQUIPPED SPECIALLY FOR THE FABRICATION OF THE QUEBEC BRIDGE AND OF THE FIELD EQUIPMENT FOR ITS ERECTION

THE St. Lawrence Bridge Company, Limited, was incorporated August 5th, 1910, with an authorized capital stock of $3,000,000, one-half of which was subscribed for by the Dominion Bridge Company, of Montreal, and one-half by the Canadian Bridge Company, of Walkerville, Ont. Its directors are Messrs. Phelps Johnson, Chas. Cassils, G. H. Duggan, F. L. Wauklum, and J. F. Weber, of Montreal; and Messrs. F. C. McMath, Willard Pope, and B. S. Colburne, of Walkerville. The president is Mr. Phelps Johnson; vice-president, Mr. Chas. Cassils; secretary and treasurer, Mr. J. F. Weber; superintendent, Mr. W. P. Ladd.

The company was organized to tender for the fabrication and erection of the superstructure of the Quebec Bridge, and was awarded the contract in April, 1911. This contract, at a figure approximating $8,650,000, was awarded on the basis of designs submitted by the company, differing from those of the Board of Engineers which had been appointed by the Dominion Government in 1908 to draft designs for a new structure at substantially the same location as stood the partially erected structure which collapsed on August 27th, 1907.

Articles dealing in a comparative way with the accepted design have appeared in *The Canadian Engineer* and elsewhere, as have also descriptions of the design and construction of the substructure. The accepted design, being larger and heavier than that of the old structure, necessitated the construction of new piers and abutments throughout. These are now completed and the approach spans are also in place.

Before giving a description of the company's fabricating plant, the outstanding features of the design of the bridge will be briefly reviewed, to outline the immensity of the problem which devolved upon the company with the award of the contract.

The Quebec Bridge will cross the St. Lawrence River at Neilsonville, about 8 miles above Quebec. It will have a total length of 3,239 ft. between abutments, with clear height of 150 ft. above high tide, while the main posts will rise to a height of 343½ ft. above water. Besides two 515-ft. anchor arm spans 310 ft. deep, it will have a 1,800-ft. centre span consisting of two 580-ft. cantilever arms connected by suspended trusses 640 ft. long. The superstructure will have two lines of pin-connected trusses, in vertical planes 88 ft. apart. It will be made of carbon and nickel steel, with members of a maximum shop length of about 90 ft. and shop weight of 140 tons.

Realizing that the erection of the superstructure was the chief problem connected with it, and that the peculiar design of the bridge would evolve many unprecedented engineering features; and fully cognizant of the effect of the stresses introduced by erection in the old structure, the St. Lawrence Bridge Company decided to build and equip a shop specifically for the work. The great size and weight of many of the truss members, the accuracy of workmanship, and the rapidity of construction required, left little alternative. The result is the present plant, which has cost about $1,000,000 to build. It is situated between Montreal and Lachine, about one mile from the plant of the Dominion Bridge Company, and on the Grand Trunk and the Canadian Pacific Railway. The accompanying figures, some of which are taken from an article in June 7th, 1913, issue of *Engineering Record*, illustrate the shop in plan and elevation. To this article we are also indebted for much of the following information descriptive of the works.

The plant is equipped for the fabrication of 2,000 tons per month of heavy riveted members. It has machine tools for precise work in finishing bearing surfaces up to 10 ft. square and boring long pin-holes up to 4 ft. in diameter through compression members and eye-bars. All fabrication is done in a single long shop, with receiving and shipping storage yards at both ends, with a comprehensive system of surface tracks and traveling cranes. Electric drive is used throughout, individual motors driving most of the principal machine tools and groups of smaller tools.

General Design of Main Shop.—The main building is 660 ft. long, and 160 ft. wide, for 440 ft. of its length and 190 ft. wide for the remainder, with a lean-to to be described later on. It has a concrete roof carried on transverse trusses spaced 20 ft. apart. At the receiving end these trusses have bottom-chord runways for girder cranes and are themselves supported on the wall columns of the building and on a line of centre longitudinal trusses of 100-ft. span, thus eliminating all but three interior obstructing columns in a length of 400 ft. At the other end of the shop all of the roof trusses are supported directly on columns, which support also the crane runways, parallel to the axis of the building.

The columns rest on concrete piers, with footings proportioned for the maximum pressure on bedrock at a depth of about 4 ft. below the surface. The roof trusses have spans of 60, 75 and 80 ft. and are of heavy construction, with riveted connections at panel points and full-depth connections to the columns. The structural steel-work weighs about 2,000 tons and was fabricated by the Structural Steel Company and erected by the Dominion Bridge Company.

The exterior walls are of brick, with concrete foundations, with a stone water table about 8 ft. above the surface of the ground. The floor is of concrete, with timber sleepers for the track rails and provisions for anchoring or clamping movable equipment.

The shop has a great window surface area and is provided with arc and incandescent lighting. It is heated by exhaust steam in a fan blast system designed to maintain a temperature of 50 deg. with the mercury at 20 deg. below zero outside.

Construction was commenced in 1911, and the foundations were finished before the end of the year. The erection of the steel-work was commenced in 1912, and fabrication of steel for the bridge commenced in the spring of 1913.

The plant arrangement provides for the entrance of raw material at one end of the main shop and the performance of successive fabricating operations as it passes continuously through the shop parallel to the longitudinal axis, until the finished members are delivered at the opposite end. The equipment is arranged for the amount of the different classes of work in the order of the successive operations, so that the average proportion of different classes of work will keep the shop uniformly

Note:—Pu. = Punch; Pl. = Planer; La. = Lathe; Dr. = Drill; Gr. = Grinder; A. = Furnace; B. = Forge.

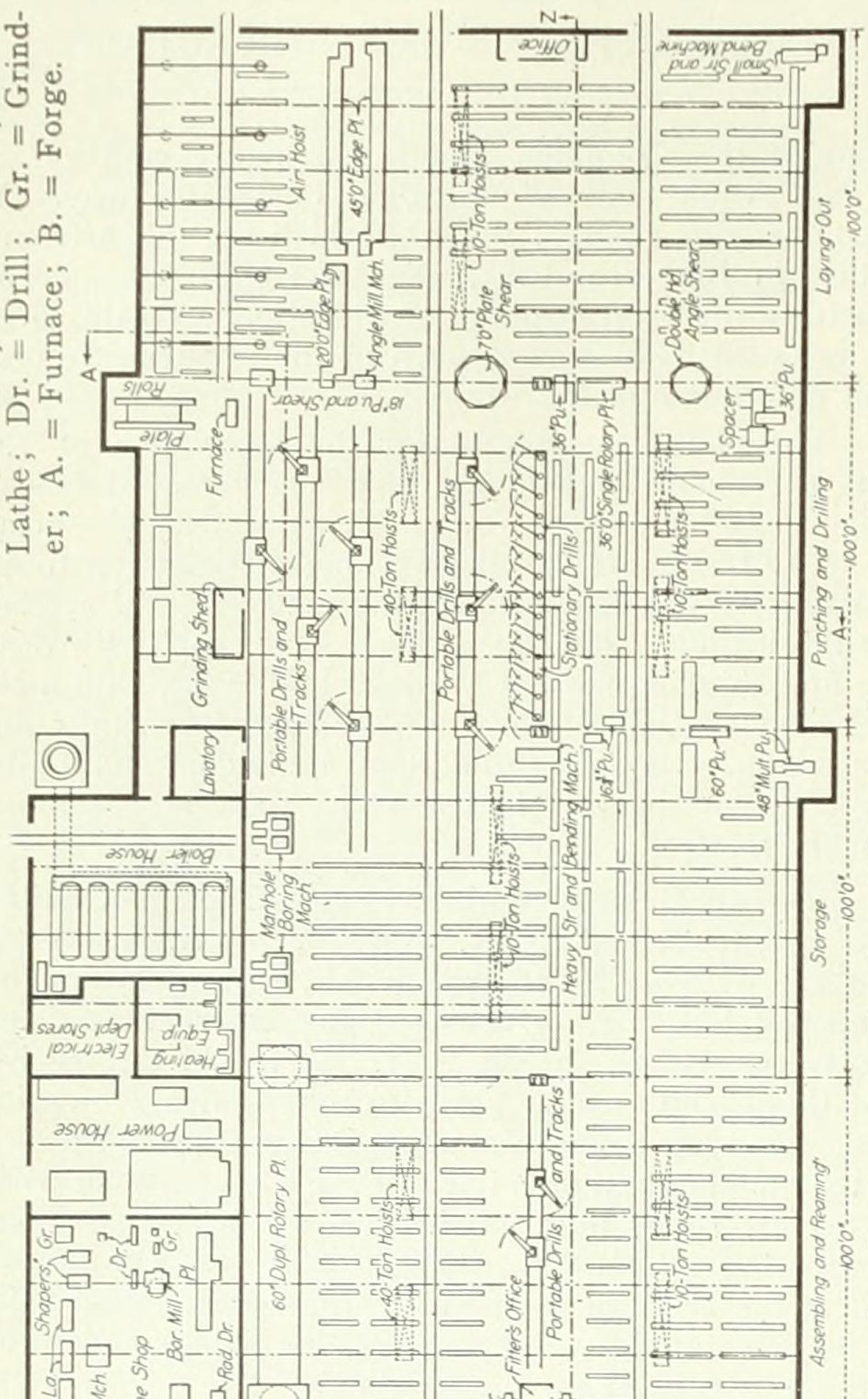


Fig. 1.—Floor Plan of Main Shop, Showing Position of Tracks, Columns, Trusses, and Machines.

busy with a constant progress of material and little lost motion or interference. Materials and supplies are received and products shipped on two tracks running through the plant parallel to the main building and commanded at both ends by cranes traversing the building. These serve the receiving storage yard at one end and the shipping storage yard at the other end of the shop.

Material is handled in the receiving yard by two 7½-ton trolley hoists on a 15-ton electric traveling crane, of 90-ft. span, with runways 500 ft. long, crossing three lines of narrow-gauge service tracks which enter the shop, two of them passing through to the other end and across the shipping yard.

Description by Panels.—The material entering the shop from the storage yard is placed on wooden skids with concrete foundations transverse to the shop axis, which occupy a large portion of the first 100-ft. panel. This panel is 160 ft. wide between main columns, besides a 30-ft. lean-to on one side, as shown in Fig. 2. It has a clear height of 21 ft. from the floor to the underside of the 80-ft. roof trusses, carried at one end of the centre-longitudinal truss. This construction is duplicated in the next panel. In the next two panels the width of the lean-to is increased to 60 ft., giving the entire shop a width of 220 ft.

In the first panel there is on one side a straightening machine with 80-ft. roller tables at each end and three large edge planers. They are served by two 10-ton assembling hoists traveling the full width of the panel on the bottom chords of alternate pairs of roof trusses. In the lean-to there is a 60-ft. roller table at one end of a set of rolls for straightening plates up to 120 in. wide, which are commanded by five 3-ton pneumatic trolley

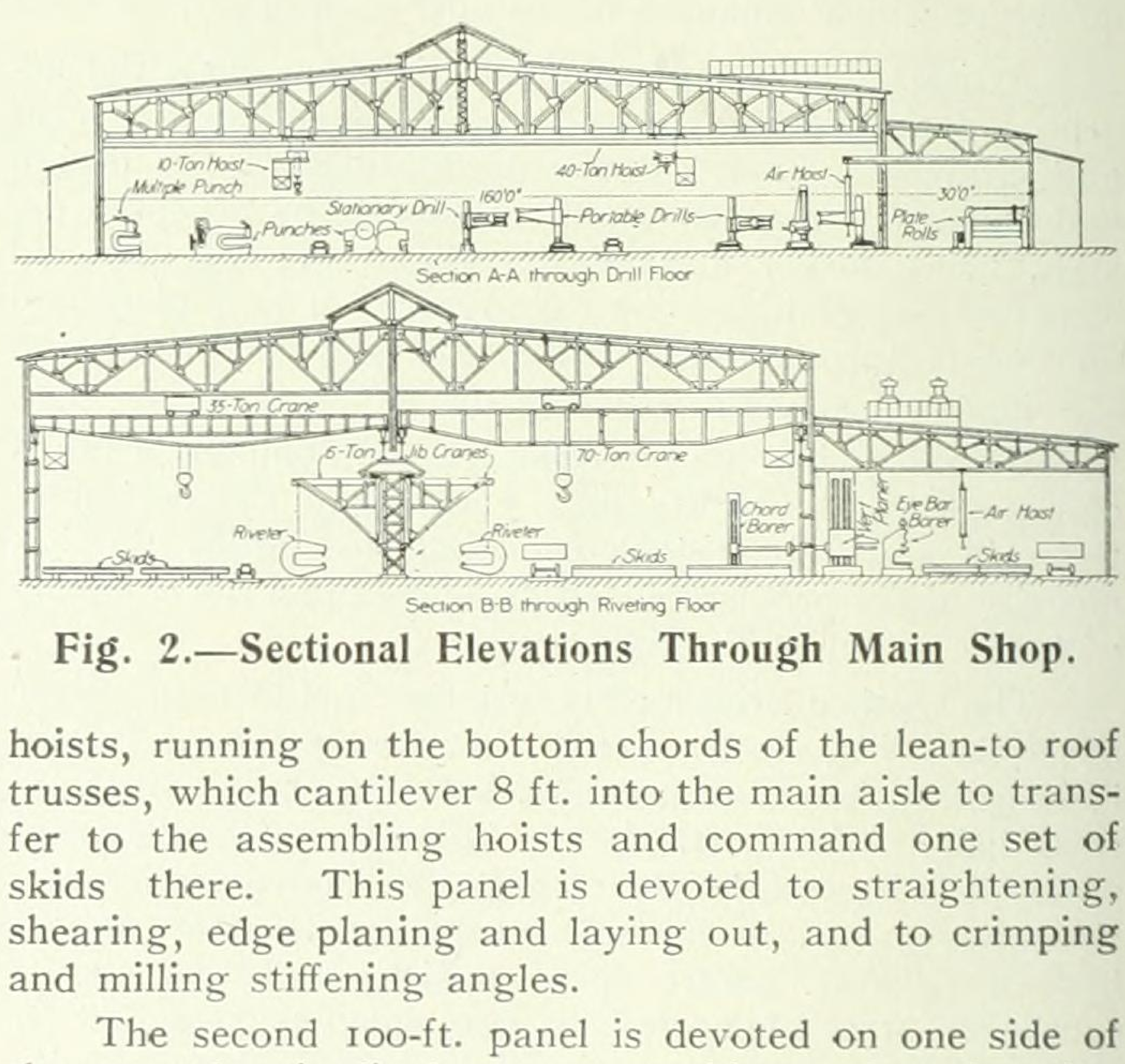


Fig. 2.—Sectional Elevations Through Main Shop.

hoists, running on the bottom chords of the lean-to roof trusses, which cantilever 8 ft. into the main aisle to transfer to the assembling hoists and command one set of skids there. This panel is devoted to straightening, shearing, edge planing and laying out, and to crimping and milling stiffening angles.

The second 100-ft. panel is devoted on one side of the centre longitudinal truss to punching and on the other side to drilling, and is served by two 40-ton and two 10-ton assembling hoists arranged, as are all of the others in this end of the building, like those in the first panel. The punching equipment is quite standard, and the machines, together with the shears, are arranged principally on the transverse lines at the ends of the panel so as to leave the interior space as much unobstructed as possible between main columns.

The special drilling plant includes 16 stationary heavy radial drills mounted on a long foundation, parallel to the shop axis under the centre truss, and 24 similar portable drills, each mounted on an individual truck, which travels on a portable track that can be clamped to the concrete floor. All of the drills have 6-ft. arms with vertical adjustments, have locking devices to the track, and are driven by variable-speed motors. There are also 12 horizontal drills mounted on trucks to work in conjunction with the radial drills and for later use in drilling the field splices in the main members. It is the intention to assemble the members in temporary sections up to 40-ton weight and drill the rivet holes en masse.

In the third 100-ft. panel, as in the remainder of the shop, except the last 125 ft., the lean-to is separated from the main shop by a solid wall, reducing the width of the shop itself to 160 ft. In the third panel there are located two manhole boring machines to rough-cut pin-holes from 10 to 45 in. in diameter. The remainder of the space there is occupied by longitudinal and transverse skids for the storage of drills and punched materials, which are handled by two 10-ton assembling hoists.

On one side of the fourth 100-ft. panel there is installed a 60-in. duplex rotary planer with a bed 110 ft. long. Provision was also made for the installation as required of the portable drills forming the reeming plant, and the remainder of the space in this panel is devoted to assembling members up to 80 tons, which are handled by two 10-ton and two 40-ton assembling hoists.

Beyond the fourth panel there is a centre longitudinal row of columns, 20 ft. apart, dividing the shop into a 75-ft. and an 85-ft. aisle, and the height of the roof is increased to 38½ ft. from the floor to the under side of the

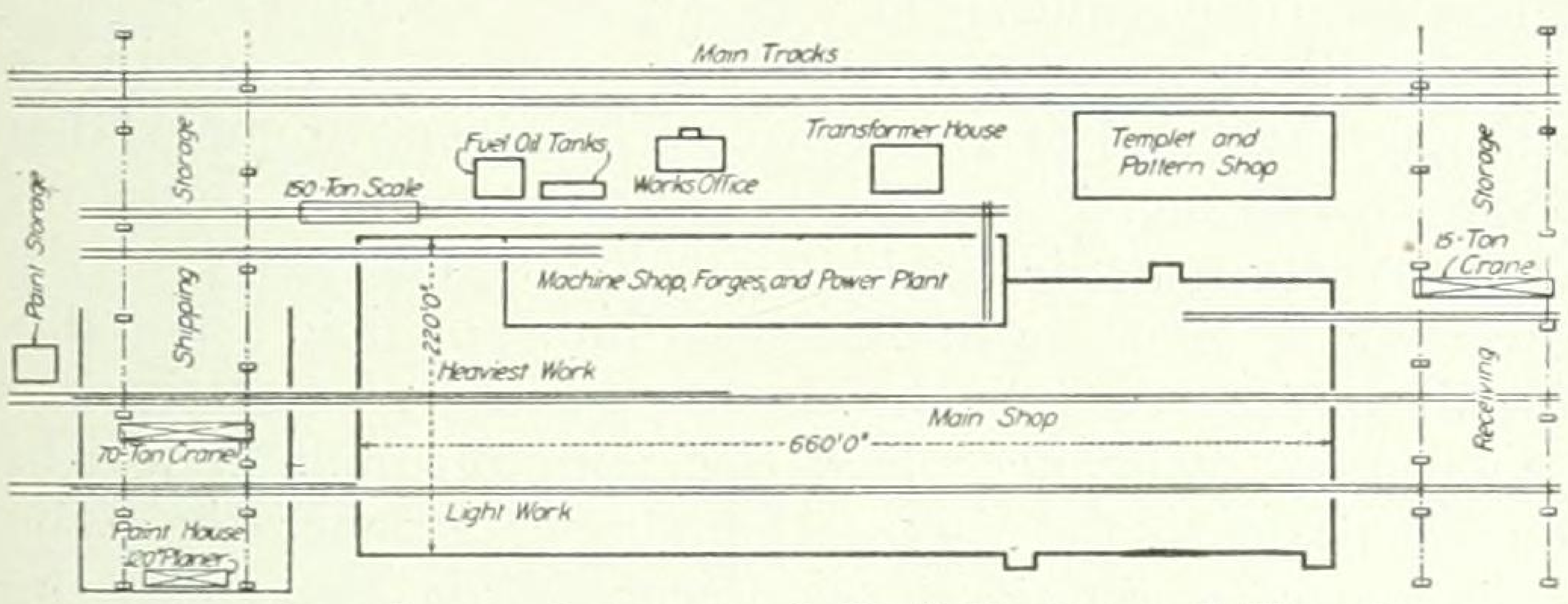


Fig. 3.—Arrangement of Buildings and Tracks.

roof trusses. Both of these aisles are 260 ft. long, and the width of the 85-ft. aisle is increased to 145 ft. for a distance of 100 ft. at the extremity by the inclusion of the lean-to space, the dividing wall being here removed and the addition thus provided being occupied by a duplex eye-bar boring machine with a bed 100 ft. long. The 85-ft. aisle is equipped with two 70-ton and one 35-ton cranes of 85-ft. span, traveling the full length of the aisle and serving to handle members weighing above 70 tons each, which will be fabricated here. At the end of this aisle there is a special horizontal boring machine for large shoes and main members, with a capacity for a 45-in. hole 11 ft. long. Each saddle has a vertical movement of 12½ ft., while the main column has a horizontal traverse of 23 ft., thus enabling it to bore several holes in the same piece at one setting.

Opposite the boring machine in the same aisle is a duplex vertical and horizontal planing machine for finishing the ends of large compression members for which rotary planing is not permissible. One of its heads is stationary, while the other has a power traverse on the 25 x 100-ft. bed, to enable it to be set for various lengths of members. The heads can make a 10-ft. cut in either a vertical or horizontal direction and are equipped with patent tool holders for cutting in the four directions, on both direct and return strokes. This machine will finish the 7 x 10-ft. bottom-chord pieces 42 ft. long, which weight 140 tons each.

The 75-ft. aisle is equipped with two 35-ton traveling cranes, one single-headed, 60-in. rotary planer with a 50-ft. bed and a duplex horizontal-chord boring machine with two movable heads on a bed 100 ft. long. This aisle is intended for the fabrication of members weighing less than 70 tons each.

Members in both the 75-ft. and 85-ft. aisles will be riveted by various pneumatic yoke machines with gaps of from 24 to 72 in., handled by 6-ton traveling jib cranes, with runways 180 ft. long on both sides of the centre row of columns. These cranes are 20 ft. high above the floor, with a clearance of about 18 ft. beyond the columns, and are special in that the bottoms are provided with vertical bearing wheels to carry the weight and with inclined reaction wheels in the planes of the braces to receive the thrust on special T-shaped tracks, inclined about 45 deg. to the vertical.

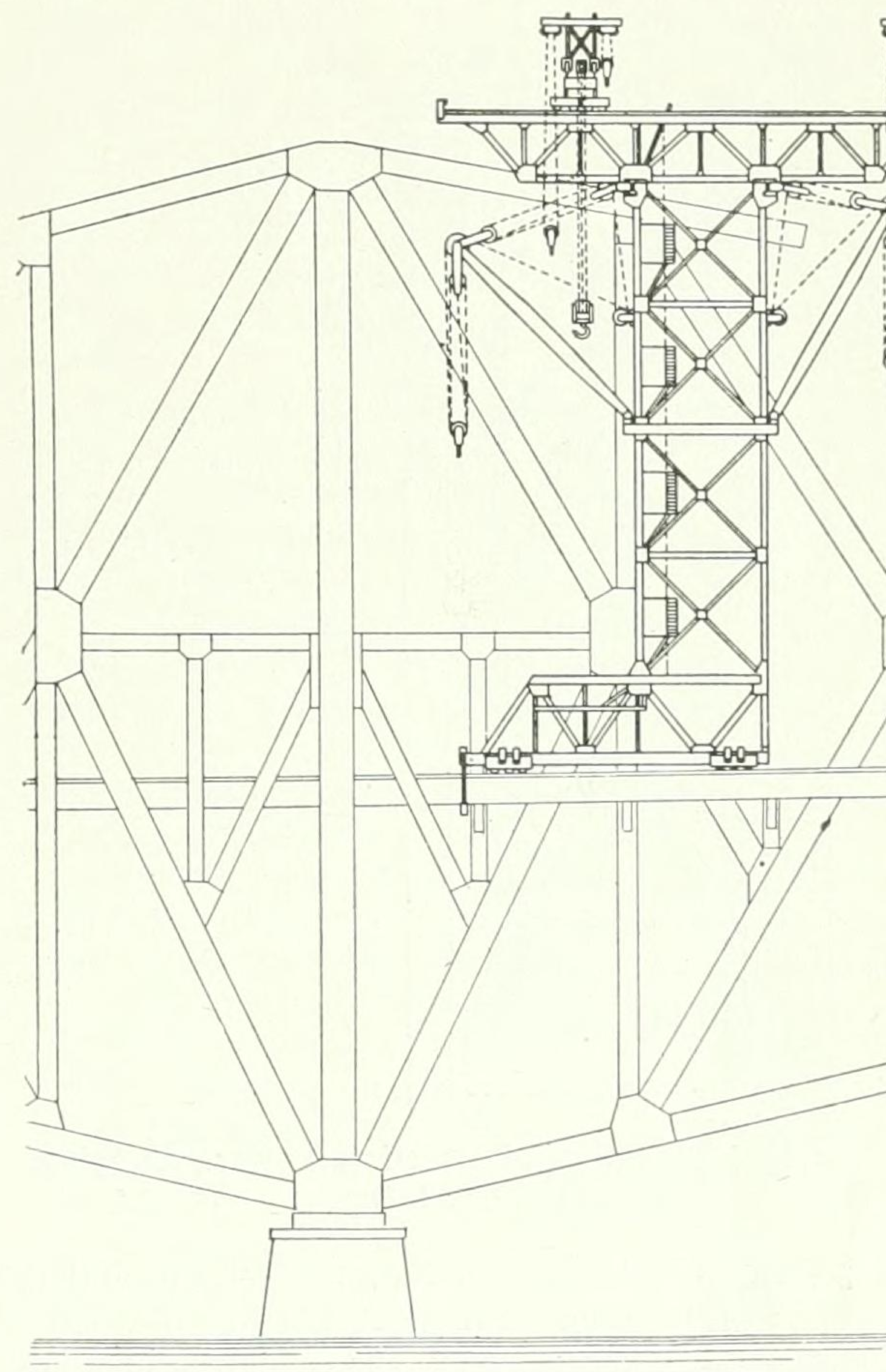


Fig. 4.—Side View of Erection Tower, on Cantilever.

The 60 x 340-ft. enclosed portion of the lean-to is occupied by the bolt and rivet shop, forge shop, the 60 x 80-ft. machine shop, generator and compressor room, boilers, coils, and fans for the heating plant, and by store-rooms, lavatory, offices, etc.

At the end of the shop there is a storage yard for finished members, which is commanded by a 70-ton crane of 80 ft. span, with runways 500 ft. long. One end of the runway is enclosed by a shed 140 ft. wide and 180 ft. long, open at one end, which provides shelter for painting and for a 120 x 120-in. x 30 ft. surface planer for finishing the larger shoes.

Opposite the laying-out panel of the shop is the 60 x 176-ft. two-story brick and steel template and pattern shop, equipped with power-driven wood-working tools and having benches nearly 100 ft. long. There is also a 30 x 50-ft. transformer house and a 25 x 45-ft. office building. The designing offices of the company are in Montreal.

Equipment at Bridge Site.—This reference to the equipment for the fabrication of the Quebec Bridge would not be complete without an outline of some of the methods which have been adopted for the placing of the various members after they arrive at the site. From foregoing descriptions of the design, it will be remembered that it was the intention to erect each of the cantilevers as an entirely separate structure, with its individual erection equipment. The centre span, weighing about 6,000 tons, will be completely assembled on barges at the river bank. When the time arrives for its erection, all navigation will be stopped at this point on the river. The span will then be floated into position, and will be hoisted by hydraulic power into its proper place, 150 ft. above the river.

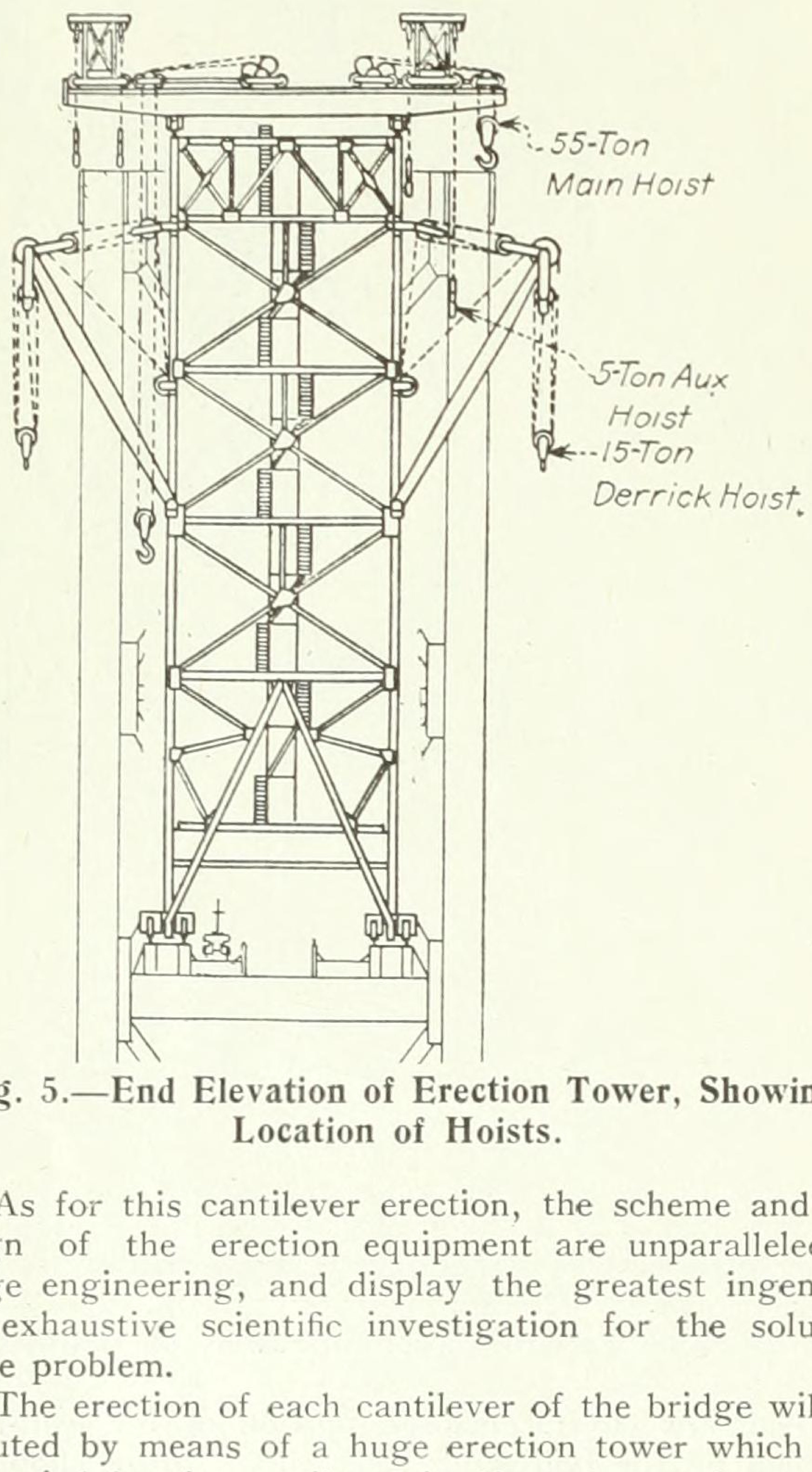


Fig. 5.—End Elevation of Erection Tower, Showing Location of Hoists.

As for this cantilever erection, the scheme and the design of the erection equipment are unparalleled in bridge engineering, and display the greatest ingenuity and exhaustive scientific investigation for the solution of the problem.

The erection of each cantilever of the bridge will be executed by means of a huge erection tower which will be carried by the cantilever itself, and moved outward along the bridge structure as its length extends from shore. These towers are of heavy steel construction with a height of 200 ft. from the carriage to the summit. Each travels by four trucks of six wheels each, spanning a double-track railway spur for the bringing in of bridge material. Each tower weighs approximately 840 tons. At this the weight is a minimum, careful experiment having been carried out to secure requisite strength without undue weight. The crane girders which project over the travellers are of nickel steel.

Each erection tower is equipped with a 90-ft. 15-ton derrick hoist on each of its four corners. Two traveling cranes, each of which carries two 55-ton main hoists and two auxiliary gantry cranes, operate at the top of the tower. Each of these gantry cranes is equipped with two 5-ton hoists, making eight 5-ton hoists for each tower.

With the exception of the travel of the four auxiliary gantry cranes all operations are electrically driven. The motor equipment of each tower is shown in Table I.

Table I.—Motor Equipment for Each Erection Tower.

Crane.	Service.	No. of motors.	Motor h.p.
15-ton derrick hoist	Hoist	4	50
	Swing	4	5
55-ton main traveler	Hoist	4	80
	Bridge	2	16
	Trolley	4	5
5-ton auxiliary gantry	Hoist	8	20
Total		26	752

This does not include, however, the motive drive of the main erection towers themselves along the cantilevers, this movement being accomplished by two of the 50-h.p. motors, which form the hoisting power for the 15-ton derrick hoists.

The electrical energy for these motors is brought to the site on each side of the river by high-tension transmission, where it is stepped down and converted by motor-generator sets to 250-volt d.c. Each sub-station receives its supply from separate systems and they are joined by submerged cables. Each is of sufficient capacity to supply the requirements of all the machinery as well as the air compressors which, in themselves, require in the neighborhood of 1,600 h.p. The object in converting from a.c. to d.c. is to afford better control and to permit the use of dynamic braking, which is necessary in the lowering of such enormous loads into position. The different speeds required during the placing of material are secured by resistances in series with the motor, which, during the period of retardation acts as a generator. The resistances are in the form of cast grids located at the base of the tower where their weight and size do not interfere with operations. Over 5,000 grids are required for this method of regulation.

The dynamic braking action is available for use only in retarding motion, while the motor armature is still rotating. When motion ceases the load is held stationary by magnetic brake. Safety devices on the important hoists prevent the load to over-travel when it nears its position.

Fig. 4 shows part of an uncompleted cantilever carrying one of these erection towers. Fig. 5 is an end view of the tower alone. These views are reproduced from the *Engineering Magazine* for December, 1913, containing an article by H. F. Stratton, descriptive of the erection equipment for the Quebec Bridge. The method of procedure, as described by Mr. Stratton is as follows:

It is planned to erect the north anchor arm over staging by what might be designated, purely for convenience, the first erection tower. When the north anchor arm has been erected, work will start on the south anchor arm by the use of the second erection tower. While the south anchor arm is being erected, the first erection tower will be at work on the north cantilever arm, and this will be finished substantially when the south anchor arm is completed. The first erection tower will then be taken down and reassembled at a point two miles below the bridge site, where it will be again set up for assembling the suspended centre span on barges. During the building of the suspended span, the second erection tower will be assembling the south cantilever arm, and these processes will be completed at substantially the same time. There then re-

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The Canadian Engineer

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CONSTRUCTION OF THE NEW QUEBEC BRIDGE

EVENTS LEADING UP TO THE PRESENT UNDERTAKING—NOTES ON THE COMPLETED MASONRY—ERECTION DETAILS AND POINTS OF SPECIAL INTEREST IN THE SUPERSTRUCTURE.

At a meeting on February 25th, 1914, the Toronto branch of the Canadian Society of Civil Engineers was addressed by Mr. C. N. Monsarrat, Chairman and Chief Engineer, Board of Engineers, Quebec Bridge. On March 2nd, Mr. Monsarrat delivered a somewhat similar address before the Canadian Club of Montreal. His subject at each meeting was a description of the reconstruction of the new Quebec Bridge, and from his remarks the following synopsis is presented:

As early as 1852 a project for a bridge over the St. Lawrence River at Quebec was considered, and again in 1884 a design was prepared and submitted to the Quebec Board of Trade for a bridge at about the present site, but nothing actually was done until about 1900, when the Quebec Bridge and Railway Company located a site near Cap Rouge and took definite steps towards the erection of such a structure. This location is at the narrowest point on the St. Lawrence River between Montreal and Quebec, the width at mean water level being about 2,000 feet. The water at this point has a maximum depth of about 200 feet and a current at ebb tide of about 7 miles per hour. The Bridge and Railway Company awarded contracts in 1900 for a bridge of the cantilever type having a main span of 1,800 feet. Work was started and proceeded until the year 1907, when about half the superstructure, then erected, collapsed. Soon after this lamentable disaster the Dominion Government undertook to reconstruct the bridge, and in 1908 appointed a board of three engineers for that purpose. This board made very exhaustive studies of various designs, including suspension and cantilever bridges, and finally decided, for good and sufficient reasons, that the cantilever type of bridge was the most satisfactory and economical kind of structure for such a crossing. It also decided that the bridge should be much wider and designed for heavier loading than the former bridge, that the same length of main span should be retained and that it should be built at the same site. Several changes were made in the personnel of this Board during the progress of the work, and since the contracts were let the Board has been composed of Mr. Ralph Modjeski, Mr. C. C. Schneider and Mr. Monsarrat, who is chairman and chief engineer.

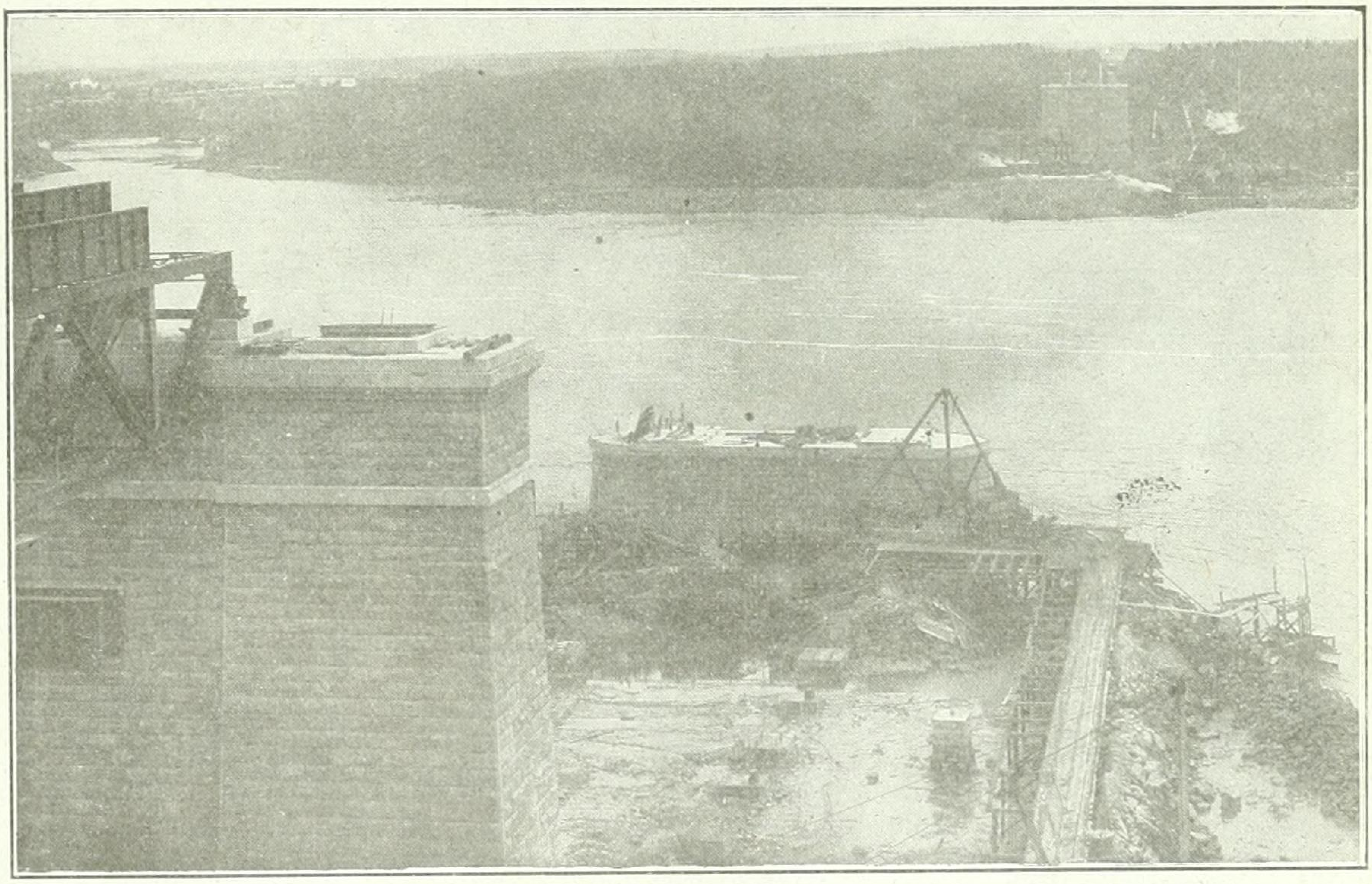

Fig. 1.—General view of the bridge site from the north shore, showing the completed masonry on both sides of the river.

Among the first things to be done in connection with the reconstruction was to take an extensive series of borings to ascertain the nature of the bottom and locate bed rock. The latter was found to exist about 100 feet below high-water. It was also decided that the old masonry was not large enough to suit the new structure and it was therefore demolished and entirely new piers built.

The clearing away of the debris of the fallen structure was a somewhat difficult task, but it was finally accomplished by the aid of the oxy-acetylene torch and dynamite. At the present time there is little or no evidence to show that this accident had ever happened. There still remains, however, about 10,000 tons of the old bridge at the bottom of the river extending out from the shore over 800 feet. Tied down by this wreckage are the remains of some 60 or 70 men who lost their lives when the accident took place. As the water at this point is very deep and the wreckage is far below the requirements of navigation, this steel will probably remain for all time in its present location, as there is no known method of salvage at the depth at which it lies.

The most serious problem in the construction of the masonry was the sinking of the pneumatic caissons for the two main piers. On the south side a single caisson 180 ft. x 55 ft. in area was used. On the north side two caissons each 80 ft. x 60 ft. were sunk with a 10-ft. space between them, the pier being bridged over this opening. No serious difficulty was met with in the sinking of these caissons although the material on the north shore was very much harder to penetrate than that of the south.

The completed main piers at the present time, extending as they do about 25 ft. above the water, do not give evidence of the enormous amount of labor expended in their construction. As the north pier was driven 60 ft. and the south pier 100 ft. below the bed of the river, at a cost of approximately $1,000,000 each, some idea of their enormous proportions may be obtained.

The anchor piers show up more prominently, being entirely above high-water. These piers are 136 ft. long and 29 ft. wide and extend about 140 ft. above the surface of the ground, or higher than a 10-story office building.

The span of the Quebec Bridge is 1,800 ft. between main piers—the longest of any bridge in the world—being 100 ft. longer than that of the famous Forth Bridge in Scotland. The length of the suspended span is 640 ft., and the total length between abutments, 3,239 ft. The bridge has a clear height of 150 ft. above extreme high-water for a distance of 700 ft. at the centre of the bridge, in order to allow passage of ocean ships beneath. The bridge is 88 ft. wide centre to centre of trusses, or 21 ft. wider than the old bridge. The height of the main posts over the main pier is 310 ft., with an unsupported length of 145 ft. These posts weigh 1,500 tons each, the four of them costing in the neighborhood of $1,000,000. The height of the bridge above the floor at the main piers is about 180 ft. Some idea of the enormous proportions of this bridge may be gathered from the fact that a 16-story building could rest on the floor at this point and hardly extend above the tops of the main posts.

The steel shoe or pedestal carrying the main posts and other members on the main pier has a base with an area of approximately 22 ft. x 26 ft. It is 19 ft. high and weighs about 400 tons. The total reaction on each of these shoes amounts to 55,000,000 lbs. Some idea of this enormous force may be gathered from the fact that it represents the weight of 150 standard locomotives. If these locomotives were placed one upon the other they would extend to a height 15 times that of an ordinary 10-story building.

The bottom chord of the bridge weighs approximately 400 tons between main panel points. This has to be shipped in four pieces for shipment and handling during erection. The outside dimension of this chord near the shoe is approximately 7 ft. x 10 ft. 6 in. If it were not for the interior diaphragms and bracings, it would be possible for six or seven men to walk abreast throughout the length of this member.

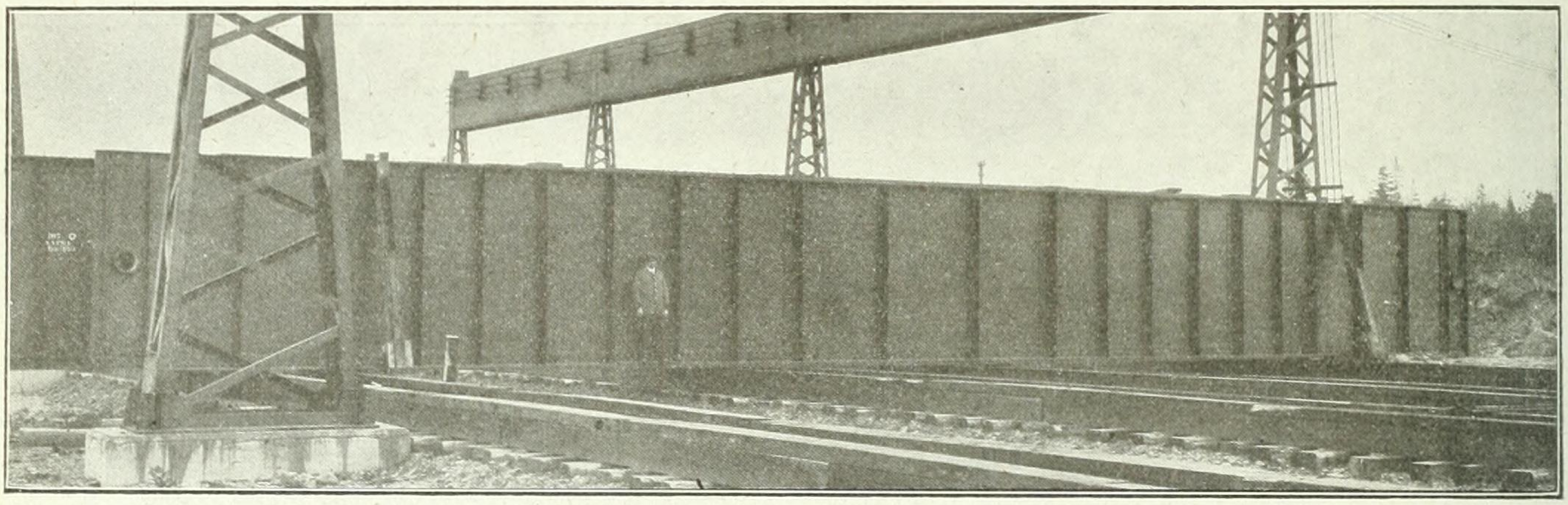

Fig. 2.—View showing one web of double floor beam at the bridge site storage yard. These girders are 10 ft. high and 88 ft. c. to c. 11-inch pins are used to connect the 60-ton floor beams to the post.

The main post, as stated before, is 310 ft. high. It is approximately 9 ft. x 10 ft. in outside dimensions, and has an area of 1,902 sq. in. It is composed of four columns laced together, and requires to be shipped in 27 pieces and connected together in the field. The weight of the bridge will amount to about 65,000 tons, which weight exceeds that of the 200 bridges constructed on the National Transcontinental Railway. These bridges, if placed end to end, would extend over a distance of 11 miles. This weight is also about five times that of the new double-track C.P.R. bridge over the St. Lawrence at Lachine.

A proportion of the steel used in the bridge will be nickel steel, 40 per cent. stronger than the ordinary carbon steel used in other bridges. This nickel steel is used principally near the centre of the bridge where the weight is the greatest factor in deciding the size of the members.

The bridge is designed to carry two railway tracks, capable of carrying two trains weighing approximately 5,000 lbs. per lineal foot each. There are also two sidewalks for foot passengers. No provision has been made for highway traffic.

New shops have been constructed by the St. Lawrence Bridge Company, exclusively for the manufacture of this bridge, with special equipment and handling machinery, the whole costing in the neighborhood of a million dollars.* Up to the present some 9,000 tons of material have been manufactured and shipped to the site.

During the past season the contractor for the superstructure has got his plant in shape and has already erected the two north approach spans from the abutments out to the anchor pier. It is expected that during the coming season practically the whole of the north anchor arm will be erected.

The erection of this bridge is probably one of the greatest problems, calling for more engineering skill than any other structure of its kind in the world. Every feature of erection from the placing of the members to the driving of the rivets is worked out in detail, and is supplied in printed form in a bound book to the erecting superintendent. All engineering problems are therefore solved for the erection force before they start, their duty being simply to carry out the mechanical end of the work in accordance with positive instructions. To handle the huge members on the bridge itself during erection, enormous steel travellers will be used, one on each side of the river, each of which, with its machinery, will weigh over 1,000 tons. One steel traveller is at the present time nearing completion on the north shore. All the cranes and derricks on this traveller are operated by electricity. The traveller runs on trucks and is moved from point to point on the floor of the bridge as the work progresses. This derrick is capable of lifting 55 tons on a boom 50 feet long. Everything about the mechanism and machinery has been made as nearly foolproof as possible.

In order that there may be no possibility of these heavy members being dropped and doing damage to the bridge or endangering lives, it is necessary to operate the hoisting engines against an electric resistance which means that the engines have to work just as hard to lower a piece as is necessary to raise it. Some idea of the size of the tackle used may be gained from the fact that the large blocks employed are about 5 feet in height, and weigh approximately 5,000 lbs. each.

One of the features of the erection which will probably be unique in the annals of bridge engineering will be the floating in of the centre or suspended span. This span will weigh about 5,000 tons and will be erected on trestles at some point near the bridge. When it is ready to be floated, very large pontoons will be floated under the span at low tide and when the tide rises will lift the entire span off the blocks. It will then be floated into position under the two ends of the cantilever arms at a low level and be connected up to these arms with long steel links. During this operation all navigation will be stopped in the river. When the connection has been made at the four corners at extreme high tide, the barges will settle with the tide and leave the span suspended. Powerful jacks of 2,000 tons capacity, situated at each corner of the cantilever arm, will then be brought into play and this span lifted slowly into place. It is estimated that the connecting up of the span should not take over an hour under good conditions and the span itself should be lifted into its proper position in about 48 hours.

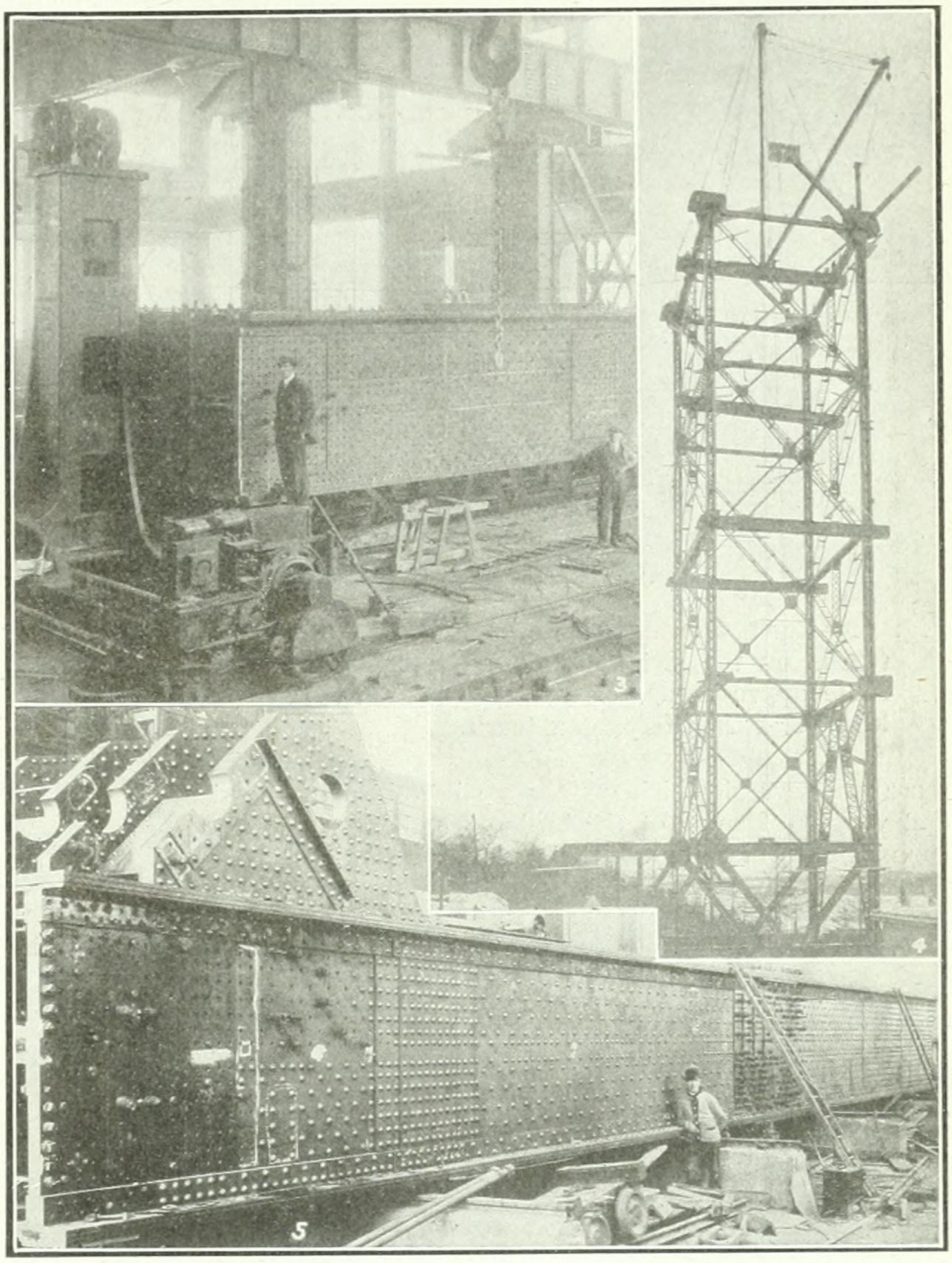

Fig. 3.—View of one end of main bottom chord in twin vertical facing machine which faces both ends simultaneously. This chord is a ½-panel length and is shipped in two pieces. Fig. 4.—North shore traveller in course of erection. It is 200 ft. high and will weigh over 1,000 tons. Fig. 5.—One full panel length connected up for the reaming of the splice plates. The member, as it stands, weighs 400 tons. The heavy gusset plates taking a vertical tension and diagonal compression member is shown at one end.

The erection of the suspended span in this manner will save about one year in the time required for the complete erection of the bridge.

It is expected that the bridge will be sufficiently completed to allow traffic to proceed over it by the end of 1917.

*For full description of these shops see *The Canadian Engineer* for January 22nd, 1914.

There are many interesting features worthy of note in the shops of the St. Lawrence Bridge Company, mentioned elsewhere. Among the accompanying illustrations

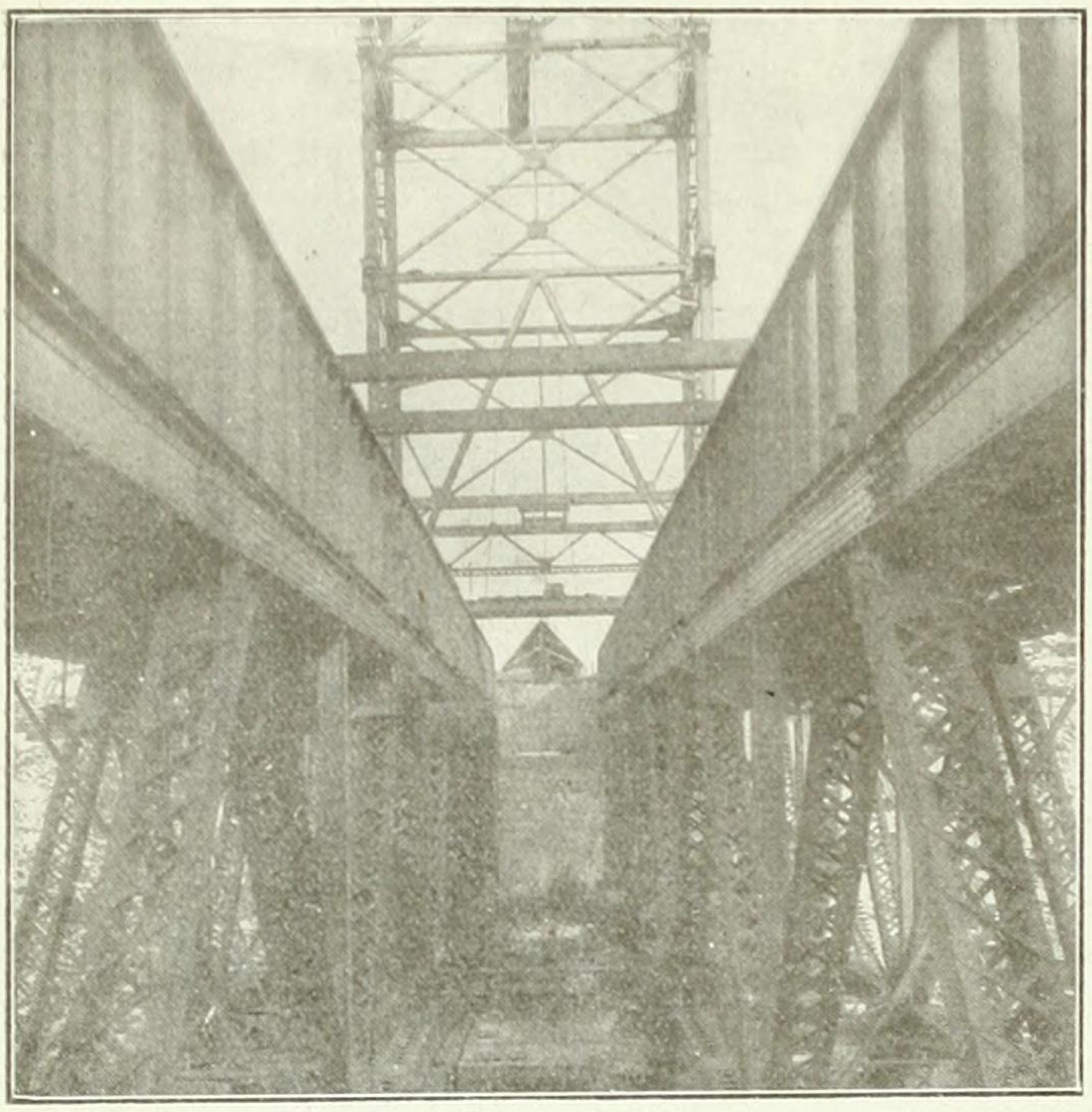

Fig. 6.—North approach span erected. As the railway tracks on the bridge are 32 ft. centre to centre, these approach spans are erected as two separate bridges, each carrying a track.

there are several which convey a slight idea of the size and weight of some of the bridge members which these shops are turning out. Their proportions greatly excel

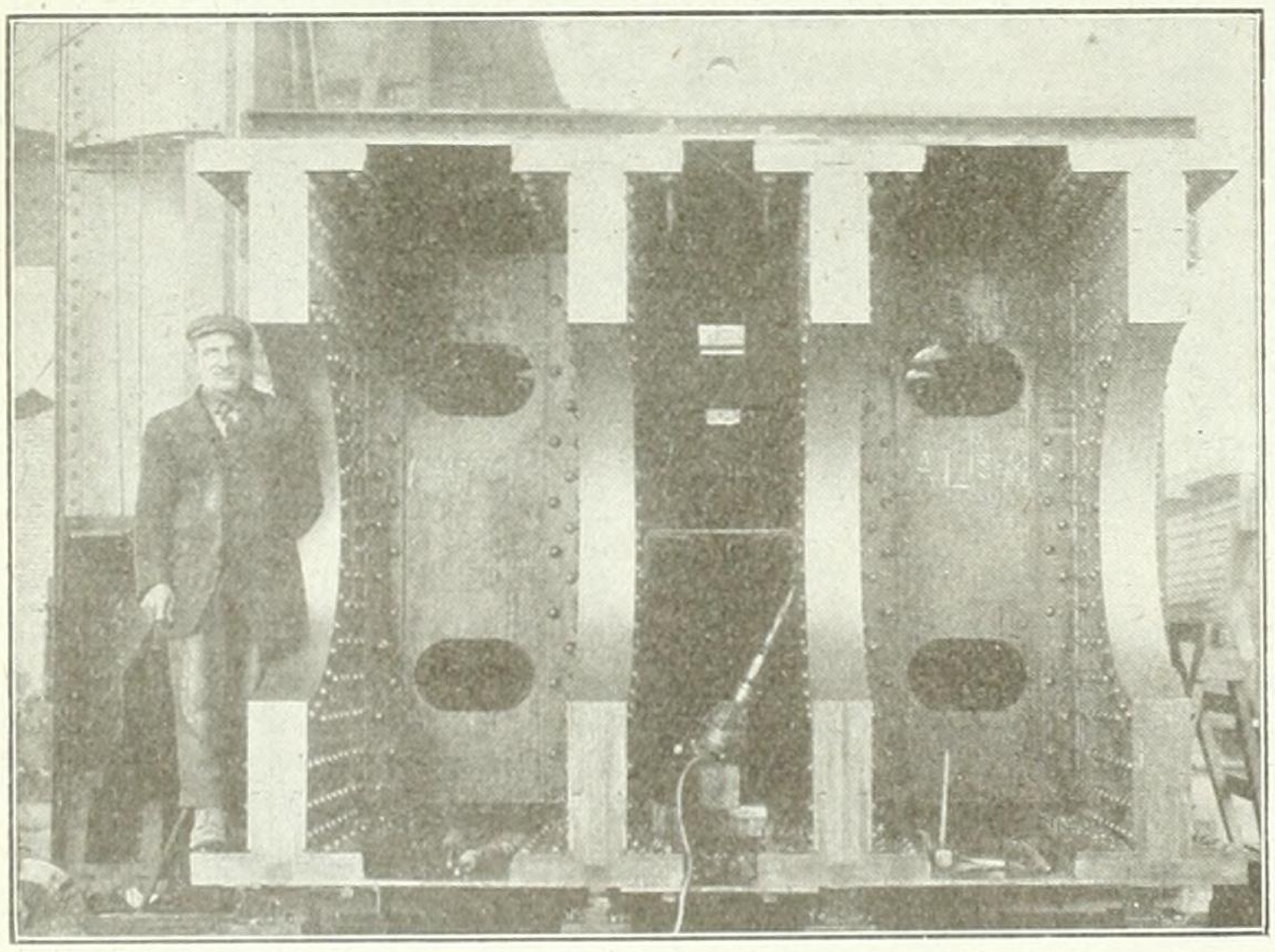

Fig. 7.—End view of member shown in facing machine. This end is bored for a 45-inch pin sleeve, which takes a 30-inch pin weighing 12 tons. Each of the webs are 7 inches thick at the pin. Manholes are provided at all diaphragms to allow contractors, painters, etc., to reach every portion of each member.

those of the product of any other shop removed any distance from the site. Moreover, the special machinery with which the plant is equipped for the rapid and accurate machining of special designs is in itself remarkable in its massiveness and adjustments. Among these various machines are the two planing machines, manufactured by James Bennie and Sons, Glasgow, with a capacity for plates up to 46 ft. in length. In them the heavy sheared plates have their edges finished, the cutting tools operating on both forward and return strokes.

The drilling and reaming are carried out on 16 stationary 7-foot radial drills, made by the Canadian Machinery Company, and 24 portable drills, transferred by cranes from one place to another. Shop rivetting is done for the most part by pneumatic yoke machines of 100 tons capacity.

A vertical boring mill manufactured by John Bertram and Sons Company, is used for boring large pin-holes and oval manholes. These large pin-holes, up to 4 ft. in diameter, are then finished in a horizontal boring machine with horizontal and vertical motions sufficient to permit the finishing of five of these pin-holes without resetting.

GRAND RIVER IMPROVEMENT.

SINCE the publication of the preliminary report of the Hydro-Electric Power Commission of Ontario on a proposed scheme or artificial storage and flood control on the Grand River, an exhaustive study of the flow characteristics of the river and its tributaries has been under way. The preliminary report appeared in *The Canadian Engineer* for April 17th, 1913. According to the 6th annual report of the Commission the investigation was begun in June, 1913, and at the present time gauging stations are established on the Grand River, and gauge recorders employed at each station to take readings of water level twice a day. This work has now been carried through one low-water season and some valuable information obtained. There has so far been a reasonably close relationship between gauge height and discharge. This satisfactory relationship has been mainly the result of low-water conditions, and there is unfortunately no likelihood that similar conditions will obtain during high stages of flow, when the gauges will be unavoidably affected by back-water.

In anticipation of the effect of back-water upon the gauges, a line of levels was run up the Grand River valley as far as Bellwood, and for several miles up each of the main tributaries. The work was started at Dunnville, using the U.S. Lake Survey level of Lake Erie as a datum. Permanent bench marks referred to sea level were established at convenient intervals on the main stream and tributaries.

During the course of the work all accessible Geodetic Survey bench marks were picked up, and in every case a very satisfactory check was obtained. A reasonable check was also obtained on various railway elevations.

All the gauges from which water level readings are being taken on the Grand River and tributaries are set from these bench marks, consequently all gauges are set to the same datum throughout the watershed, and slope data can be taken directly from the gauge readers' records. With the help of this slope data it is hoped that it may be possible to apply corrections to the gauge readings during high stages of flow, and thus eliminate to a large extent the effect of back-water.

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The Canadian Engineer

A weekly paper for engineers and engineering-contractors

SUBSTRUCTURE OF THE QUEBEC BRIDGE.

COMPLETE RÉSUMÉ OF THE CONSTRUCTION OF THE PIERS AND ABUTMENTS—SOME INTERESTING CAISSON SINKING FOR THE SOUTH MAIN PIER—PLANT OPERATION.

By H. P. BORDEN,

Assistant to Chief Engineer, Quebec Bridge Commission.

NOTE :—The construction of the new Quebec Bridge is a most illustrative piece of engineering, and has been closely followed, since its beginning, in the columns of THE CANADIAN ENGINEER. *The substructure, now complete with the exception of a few finishing details mentioned in the first paragraph below, is a vital part of the world renowned undertaking, and engineers of all countries have been interested in its progress. In the following article Mr. Borden has reviewed for us its entire construction. For greater detail respecting the piers and abutments the reader is referred to previous issues of* THE CANADIAN ENGINEER *as follows : July 14, and Oct. 6, 1910 ; June 13, 1911 ; Oct. 31, 1912 ; Feb. 13, 1913, and April 9, 1914. These deal with their design and constructional progress. Other articles appearing in various issues refer similarly to the superstructure.*
—EDITOR.

THE contract for the construction of the piers for the Quebec Bridge was awarded to Messrs. M. P. and J. T. Davis, of Quebec, in February, 1910. This work has been continued constantly since that date, and is now practically completed with the exception of pointing and cleaning the masonry and dressing the bridge seats.

This contract, as finally completed, is divided into the following units: North abutment (alterations), 404.5 cu. yds. ; north intermediate pier, 1,665.6 cu. yds. ; north anchor pier, 17,736.0 cu. yds. ; north main pier, 31,870.4 cu. yds. ; south main pier, 38,279.4 cu. yds. ; south anchor pier, 16,073.0 cu. yds. ; south abutment (alterations), 61.1 cu. yds. Total, 106,090 cu. yds.

At the start, a careful study was made by the board appointed by the government, to determine whether it was possible to use the old masonry. After a thorough investigation it was found that, owing to the increased weight of the steelwork, all the old masonry, with the exception of the abutments, would have to be taken down and new piers constructed. It was, therefore, decided to move the whole bridge to the south about 65 ft., retaining the original longitudinal centre line. This brought the north main pier further into the water and the south main pier the same distance towards shore, the same centre to centre length of span of 1,800 ft. being retained. It was impossible to place the south main pier nearer the river on account of the wreckage which lies in the water at that point.

Before the contract was awarded, a series of borings were made at and about the location of the two main and anchor piers. Nineteen borings in all were taken, each boring penetrating at least 15 ft. into solid rock in order to make sure that it was bed rock rather than a boulder that had been struck. These borings showed that bed rock would be encountered approximately at El. 0.0 on the location of both north and south main piers, which elevation was about 101 ft. below extreme high water and 70 and 85 ft. below the bed of the river on the north and south sides respectively. The formation of the bed of the river on the two sides, however, was found to be totally different. On the north side heavy boulder formation was encountered for the entire depth, the boulders being closely packed together with coarse sand and gravel. On the south side the borings showed sand formation for the entire depth with only a sprinkling of boulders at various points. The bed rock was a hard sand-stone, called "Sillery grit," overlaid with a red and gray shale. On the south side 2 ft. of hardpan overlaid this shale.

The caisson for the north main pier was started first and was constructed at Sillery, about 3 miles down the river. This caisson was 180 ft. long and 55 ft. wide. It was constructed of 12 x 12-in. southern pine with a cutting edge of the same material 30 in. square. This cutting edge was shod with a 6 x 12-in. oak timber instead of the steel shoe, as usually used. It was claimed in this case that if any distortion of the caisson took place the steel shoe would tend to prevent the caisson from readily readjusting itself—as would be the case with a wooden shoe—and that the wooden shoe gave sufficient service during the process of sinking. The caisson had a working chamber 8 ft. high in the clear, divided by longitudinal and transverse bulkheads into 18 compartments. It was built in the winter under a construction shed, thus enabling the men to work without interruption from the weather. The caisson was built over launchways with a 10% grade which led out into deep water. The walls of the caisson were built up about 40 ft. before it was launched. When ready for launching, the caisson was lowered down to its inclined position on the launchways by means of heavy jacks. When everything was ready an impetus was given by jacks placed at the rear horizontally, and launching was effected without mishap.

It was towed to the bridge June 14, 1910, and placed in position over the site which had been previously dredged to an average depth of about 20 ft. in order to push ahead the work of sinking as fast as possible.

The work of filling it with concrete was started immediately and some 2,000 yds. of concrete had been deposited before the caisson began to touch bottom as its corners. The caisson was leaking to a certain extent, but could be readily kept dry by means of two pumps. At this time, however, an accident happened to the boiler equipment and before it could be repaired the caisson had been filled with water to such an extent that it grounded on an uneven bottom. The result was that the caisson was seriously strained and the seams opened up to such an extent that it was found impossible to keep air in the working chamber. It was decided to remove the concrete from the caisson and tow it to St. Joseph de Levis and have permanent repairs made there during the coming winter.

In view of this accident a re-consideration of the masonry design was made by the board, with the result that it was decided, in consequence of the difficult sinking on the north side, to use two caissons for the north main pier and to use the reconstructed larger caisson for the south side, where the sinking operations would be much simpler and the material to be penetrated would be, as shown by the borings, composed mostly of sand. This entailed the abandonment of the enlargement of the south main pier and meant the sinking of a caisson south of the old pier and entirely distinct from it. It was, therefore, decided to sink this new large caisson, or caisson No. 1 as it has been designated, 65 ft. nearer the shore, or south of the existing main pier, and to sink the caissons for the north main pier the same distance towards the river, or south of the existing north main pier, thus making the span 1,800 ft.—the same as that of the original bridge. This change in the plans allowed the board to keep the centre line of the bridge coincident with that of the old structure which was a very important item, as it would avoid the large expense of changing the location of the railroads approaching both ends of the bridge.

It was found that caisson No. 1 could be satisfactorily repaired in dry-dock, and on May 28, 1911, it was floated out and towed up the river about nine miles to the site on the south side which, being exposed at low water, had been carefully levelled off. At extreme high water there is about 15 ft. of water over this prepared bed. As the caisson from its construction had a pretty deep draught, a false bottom was constructed with a view to decreasing this draught before floating into position. The result was that the caisson floated with a draught of 11 ft. and was placed in its exact position for sinking without serious difficulty.

The openings in the various shafts were then left unobstructed in order that the rise and fall of the tide would not lift the caisson from its permanent bed. This caisson was left in this position throughout the season of 1910, the work of the contractor being directed towards the sinking of the caissons on the north side of the river.

Caissons Nos. 2 and 3, for the north main pier, were constructed at Sillery on the same location as caisson No. 1, the same details of construction being followed throughout. Each of these caissons were 85 ft. long by 60 ft. wide. No. 2 was started June 15, and No. 3 on June 29th, 1911. Both these caissons reached their permanent location at El. 20.0 about October 20th, 1911.

The average rate of progress of sinking the westerly caisson (No. 2) was 0.37 ft. per day, and that of the easterly caisson (No. 3) 0.47 ft. per day. It was the original intention to sink these caissons to rock, but as the work progressed the sinking became more difficult, and finally, when the caissons had reached El. 20.0, it was considered that the foundations at this point were quite satisfactory for many times the load that the piers would be called upon to carry.

Bearing tests were made at this point to determine the supporting value of the foundation. A cube of granite 2 ft. square was placed on an average section of the bottom and over this was placed a lever composed of 2 I-beams supported on pin bearings. The short end of the I-beams was supported against the roof of the caisson. A hydraulic jack was placed to exercise a definite load at the end of the longer lever arm. A load of 59 tons per sq. ft. showed a settlement of only ⅛ in., practically no settlement at all being noticed at 20 to 30 tons. As the average working load at the foot of this pier was only 8 tons per sq. ft., it was considered that the board would not be justified in carrying the foundations to a lower level.

In the operation of sinking these caissons, the contractor met with considerable difficulty owing to large bounders fouling the cutting edge, and in several places this cutting edge was forced inward from 6 to 10 in., and, as it was feared that if the sinking was continued in the same manner this cutting edge would be further distorted and sinking operations endangered, the method of sinking was then changed so as to avoid any such contingency.

Timber blocking was placed beneath the bulkheads and at the centre of the chambers. A trench was then excavated all around and below the cutting edge and for several inches outside the exterior surface of the caisson. This trench was excavated to a depth of about 2 ft., after which it was filled with blue clay in bags and when all was ready the blocking was under-scoured with water jets and the caisson lowered on a cushion of clay. The clay tended to act as a lubricant and also prevented considerable air leakage, and as all boulders were removed from beneath the cutting edge before the caisson was lowered, all further damage to the cutting edge was prevented, and it was found that the sinking was carried on even more rapidly.

After the caisson had reached its final location the working chamber was filled with concrete composed of one part of cement, two parts of sand, and four parts of small crushed stone. This concrete was made much drier than the concrete used in the main caisson, it being found that concrete deposited under compressed air gave better results when very dry than in a more or less liquid state.

Concrete was deposited in terraces, the men working towards the centre from the sides and ends. Great care was taken to ram the concrete thoroughly round the roof timbers so that a bearing would be assured under the roof of the working chamber. After the working chamber was filled as carefully as possible by hand the shafts were filled with concrete. As a still further precaution, a rich grout was forced in through 4-in. blow pipes by compressed air under a pressure of 100 pounds per sq. in. One hundred and fifty-four bags of cement were used in grouting caisson No. 2, and 274 for caisson No. 3.

Caissons Nos. 2 and 3 were sunk with 10 ft. space between the two ends, thus making the overall length of the two caissons 180 ft., the same as No. 1. After they had been filled with concrete, the space between them was dredged by a clam-shell bucket to a depth of 25 ft. below high water, the boulders and hard sand being excavated with considerable difficulty. Shutters 40 ft. high, made of 12 x 12-in. timbers, were placed vertically against the outside walls of the adjacent caissons so as to close each end of the space between the caissons and overlap about 12 in. on their sides. The bottoms of the caissons were banked up on the outside with clay dumped in the river and covered with heavy rip-rap. The shutters were securely bolted to the caisson walls down to low-water level, and thus formed coffer dam walls enclosing this space between the caissons. This space was then filled with concrete deposited under water up to an elevation of 7 ft. below low-water mark. After the concrete was deposited the water was pumped out and the space between the caissons was then bridged by six old steel girders, 6 ft. deep, resting in pockets left in the concrete in the adjacent ends of the caisson, the wooden walls of the caisson having been cut away to allow this to be done. Afterwards the concrete was deposited in a continuous mass in and between both coffer dams and caisson, thus forming a monolith upon which the masonry shaft of the pier could be carried. The masonry of the pier was then built up inside of the crib work, which was kept in place until the mason work had extended above high water.

The sinking of the large caisson for the south main pier was started July 28, 1912, and was completed October 24, 1912, or at the rate of 0.75 ft. per day during the entire period. The material encountered at this point was, as indicated by the borings, chiefly sand, and required that the pier be carried down to rock, which was reached at El. 0.0, 101 ft. below high water, and 86 ft. below the bed of the river. The difficulty experienced on the north side in keeping the cutting edge intact, and also on account of the fact that the caisson had previously been overstrained, and the fear that it might yet be weak, led the contractors to take unusual precautions to prevent the possibility of any accident happening to the caisson during the sinking operations. For this reason, special appliances were devised for relieving the cutting edge from carrying all the load, and by the use of sand-jacks the total weight of the caisson was distributed over the entire bottom area. The manner of using these sand-jacks was one of the most interesting features connected with the sinking of this caisson, and possibly merits especial description.

The jacks themselves were of very simple construction. The cylinders of the sand jacks had an internal diameter of 31 in., and were 36 in. long, constructed of ¼-in. steel plate with 4-in. lap joint; two angles 1½ x 1½ x ¼-in. reinforced the cylinder at top and bottom. The piston was a block of yellow pine 2½ ft. square and 5 ft. long. Four feet at one end was round with a diameter of 29 in., thereby allowing 1 in. play in the cylinder. The lower end of the piston was reinforced by a 2½ x ⅜-in. welded iron band. During operation the piston was attached rigidly to the roof of the working chamber by long screw bolts, and remained there permanently during the entire period of sinking.

In preparing for a drop, the first step was to excavate a hole under the piston. The cylinder was filled about ⅔ full of sand, placed in position under the piston, and blocked up hard against it by means of timbers. While this was being done the caisson was supported on timber blocking under the bulkheads and other points. At the bottom of the sand-jack was a 2-in. iron pipe extending entirely across the cylinder, the centre of which was split and opened up to allow the sand to escape. This type had no bottom to the cylinder, the timbers acting as a support for the sand. Another type used had a steel bottom and two 3-in. holes with sliding cover at each side at the foot of the cylinder. The operation in both cases was the same.

When everything was ready for a drop, the timber blocking supporting the caisson was undermined by a water jet and the full load taken by the sand jacks. A man was stationed at every jack, and at a given signal, afforded by the flashing of electric lights, each man turned a hydraulic jet with 60 lbs. pressure into the hole at the bottom of the cylinder, thus washing the sand out. The sand was caught in canvas bags of uniform size. When the canvas bag was full the lights flashed again and the water jet was turned off. Another bag was then obtained, and at the signal the jet was again turned on and the bags filled. Each cylinder contained in the neighborhood of 16 bags of sand. This operation was continued until the required settlement was obtained. By adopting the signal system and emptying the sand into bags, it was possible to guarantee that the whole caisson was being sunk at a uniform rate, and that there was no reasonable possibility of any part of the caisson being strained by being sunk more rapidly than another portion. As a rule, a drop of from 1½ to 2 ft. could be effected at each operation, the recurrence of the operations depending entirely on the nature of the material to be removed. When the drop had been finished the blocking was again placed under the bulkheads to take the load of the caisson, and the holes under the sand-jacks deepened in order that the operation might be repeated. The greater part of the material excavated in this caisson, being sand, was forced out through blow pipes.

Practically no problems were encountered in the construction of the north and south anchor piers and the north intermediate pier. Both anchor piers were constructed on a location south of the existing anchor piers. For the north anchor pier a coffer dam had to be constructed around the foundations since the foot of the pier was below high-water mark. The south anchor pier was well above high-water mark, so that all excavation was in the dry.

The anchorage girders were embedded in concrete and the first length of anchorage eyebars set in place, two shafts being left in each anchor pier for connecting up the anchor eyebars of the main anchorage. It is the intention ultimately to embed the bottom section of eyebars in concrete, but this will be deferred until they receive the full dead load stress.

The concrete used in the caisson and backing of the piers was 1:2½:5 by volume, except the concrete in the working chamber, which was 1:2½:4. The cement was required to pass a tensile test for neat cement of 450 and 540 lbs., for 7 and 28 days respectively; and for 1 part of cement and 3 parts of sand, 140 and 220 lbs. respectively. For the main piers entirely new quarry cut stone was used. For the anchor and intermediate pier the specification allowed the use of stone from the old masonry. The greater portion of the old stone demolished from the old masonry was consequently used in the construction of these piers. The abutments were not radically changed, it being only necessary to raise the ballast walls and make minor alterations to suit the new design.

The masonry in the pier shafts consists of grey granite rock faced ashlar, laid with alternate headers and stretchers and backed with concrete, in which were embedded displacer stones usually about 1 cu. yd. in size. Headers were required to have a length of at least 2½ times their build, with a minimum length of 7 ft. Bed joints were ½ in. throughout and vertical joints ⅜ in. for 12 in. back from the face and not exceeding 4 in. wide at any point.

All stones in rounded ends of main piers were clamped together and connected vertically by dowels. The upper 18 ft. of these piers were built with cut granite backing. About 40% of the stones in these backing courses were made to project up through the course above, in this way giving a very strong vertical bond. The bridge seats proper are built 2 ft. higher than the surrounding upper coping course, and are 4 ft. deep, extending to the bottom of this coping, thus providing heavy stones under the main bearings.

The anchor piers are in plan about 136 ft. long by 29 ft. wide at the bottom, with a batter of 1 in 24, and reduced in section for 41 ft. at the centre to a vertical wall 18 ft. thick, thus forming pilasters at the ends, through which the anchor wells are built.

Owing to the importance of the work, the contractor spared no effort or expense to provide a plant up-to-date in every respect.

On the north side a large wooden trestle was built around the four sides of the caissons, all supported on piles and cribs. As the current here reaches 7 miles per hour and there is an average tide of 16 ft. and a maximum of 20 ft. it was necessary to have this trestle very strongly built. Platforms extended to the shore from the up- and down-stream ends of the pier carrying standard gauge double tracks which formed loops around the caisson and connected with the concrete plant 600 ft. inshore and located at the foot of the cliff.

The power plant, dining-room for "sand-hogs," and two-story bunk house were also located at the water's edge—just upstream from the pier. All supplies and material required were received by rail or team at the top of the cliff, some 160 ft. above high-water level and were delivered by gravity to the concrete plant and service tracks at the foot. A service elevator was operated by cable and hoisting engine at the top of the cliff which was an angle of about 45° at this point connected the tracks at the top with those at the bottom. A stairway provided means for the men to reach the upper and lower levels. The board of engineers' office was located at the top of the cliff.

At the foot of the cliff were situated the mechanical plants which furnished the power for the various operations. To supply compressed air, five Ingersoll-Sargeant compressors were employed. Four had a capacity of 1,250 cu. ft. and one 2,500 cu. ft. per min. These compressors discharged into a 12-in. main from which 7-in. branches led into the two caissons. Each branch was fitted with a gate valve so that the air could be cut out of either caisson at will. The main pipe was carried in a sluice of running water about 400 ft. long, which kept the temperature of the air down to about 75° F. As a consequence, the temperature of the working chamber rarely exceeded 90° F., although the service shaft, on account of the heat generated by the setting of the concrete around it, generally exceeded 100° F. For this same reason the temperature of the working chamber reached as high as 110° F. when being finally filled with concrete.

The compressors were at first supplied with power from six 100-h.p. horizontal boilers. As the work proceeded it was found that the demand on the compressors was greater than was anticipated. As a consequence, an extra 100-h.p. boiler was installed, together with one 500-h.p., one 75-h.p. and one 250-h.p. boilers, making a battery of 10 boilers, aggregating 1,075 h.p. These boilers were all coupled up, and in addition to the compressor plant, supplied power to the power-house, rock crusher and concrete mixing plant. There were also one 100-h.p. vertical and two 50-h.p. horizontal boilers on the platform near the caissons, and were used to furnish power to six 15-ton stiff-leg derricks which were used for handling stone, concrete, etc., during the sinking operations. They also furnished power to one 8-in. high-pressure pump used for washing material in the working chamber and to two 4-in. pumps which supplied water to the high-level tank on the top of the hill, thus furnishing the water supply for the whole plant.

The plant was supplied with electric light from its own power set situated near the boiler-house. It was equipped with a 30-kw. C.G.E. generator, capable of operating 16 arc lights and 100 incandescent lights (16 c.p.). There was also a blacksmith and machine shop in connection, so that all minor repairs to plant and equipment could be made on the job.

The concrete mixing plant was placed just at the foot of the cliff. Half-way up the slope was the rock crushing plant. The rock used for the concrete was obtained from an adjoining cut and was brought to the brow of the hill in cars which dumped into a chute leading to the crusher plant. The stone was fed into 2 gyratory crushers which were capable of dealing with about 500 cu. yd. in 12 hours. After passing through the crushers the stone was led over an inclined screen of 2-in. mesh, and thence into a storage hopper bin of about 200 yds. capacity. These chutes led from this to the concrete mixing platform below, the mouth of each chute being directly over a mixer. From this platform the sand, stone, cement and water, were fed in the proper proportions to the mixers underneath the platform, which in turn dumped into self-discharging buckets on trucks, which were hauled to the caissons by horses. Three Ransome mixers were used on the work, two having a capacity of 2/3 cu. yd. and the other 1 1/3 cu. yds. Owing to the conditions under which the work was carried on the mixers never had a chance to work to their full capacity; their best day's work being 450 cu. yds. for the 24 hours.

The sand used in the concrete was conveyed to the concrete mixing platform in the same manner as the stone, i.e., by means of a chute from the upper level, where it was unloaded from hopper bottom cars. The chute was 8 ft. wide by 6 ft. high and was kept practically full all the time, the sand being taken from the lower end as required. The coal for the boilers was also delivered from the upper level through a chute, which emptied into 2-yard side-dump cars at the boiler-house level. By means of a track these cars delivered the coal to each boiler-house as required. On the top of the coal chute was a double line of rails with balanced trucks, which conveyed the cement from cars at the upper level to the storage shed at the level of the concrete mixing platform. The cars could, therefore, be unloaded as they arrived and the cement placed where required for use with the minimum amount of handling.

For the convenience of the "sand hogs," who were compelled to work on shifts through the whole 24 hours, the contractor erected both sleeping and dining quarters for a large number of his men. On the lower level a bunk-house had been provided to accommodate about 100 men, and a dining room that would seat as many more. On the upper level was a similar house with bunks for about 60 men and dining quarters of about the same capacity. On the dock the contractor erected a number of buildings, which included an office and bath accommodation for the inspectors, a hospital with a doctor in continual attendance, where first aid might be administered in case of serious accidents, or regular treatment in case of minor troubles. There was also provided a coffee-house, kept at a high temperature, where the "sand hogs" could change their clothes and receive hot coffee at the end of their shift in the working chamber. In addition to the above were the usual stores, offices, etc., for the contractor's own use. In connection with the hospital arrangements there was also provided a steel hospital tank connected with the compressed air system, to which men suffering from the "bends" could be immediately transferred and treated.

For serving each caisson four 30-in. shafts for material and two 30-in. ladder shafts were employed. For ejecting the sand and smaller stones four 4-in. blow pipes were used. The larger boulders were broken up and hoisted through the material shaft in buckets having a capacity of ⅔ cu. yd. Four 7-in. compressed air pipes supplied air to the working chamber and served the blow pipes. Two 6-in. pipes supplied the water for "washing" the sand. One 2-in. pipe supplied high-pressure air for drilling, etc., and a second 2-in. pipe carried the wires for the electric lighting of the working chamber and ladder shaft.

As soon as the sinking was completed on the north shore as much of the plant as could be spared was moved to the south side. The men's dining-rooms and sleeping quarters were placed on skids, launched into the river, floated across, and placed in position on the other side. The layout for the mixing plant, sand chute, coal chute, etc., was practically the same as on the north side of the river, all the materials being led to the lower level by gravity. The stone for the crushers was quarried directly from the top of the cliff so that one derrick could pick up the stone in the quarry and deposit it in the hopper leading to the crushing plant half-way down the cliff. While the boiler and compressor plants used on the south side were drawn as much as possible from the north side, yet they had to be materially increased. The steam plant included three 125- and one 250-h.p. Heine boilers, twelve 100-h.p. locomotive boilers, and seven Ingersoll-Rand and Ingersoll-Sergeant air compressors delivering to 2 coupled receivers from which a pair of 12-in. mains led to the caisson and were carried for about 200 ft. in a wooden flume constantly filled by water. This reduced the high temperature developed at the compressors to about 80° in the working chamber of the caisson. There were also two 12-in. Worthington high-pressure pumps which delivered water to the caisson for the hydraulic jets used for excavation.

On account of the very high tide which prevailed at the site, the air pressure in the caissons constantly varied and was controlled by an operator in the compressor house who adjusted it to correspond with the indications of an automatic register showing a continuous tide pressure.

The stone from the quarry on the top of the cliff was delivered by derricks into a No. 8 McCully rotary crusher near the top of the bank, which broke the larger pieces and delivered them through a chute to a No. 5 Allis-Chalmers crusher about 25 ft. below it. The second crusher reduced the stone to a diameter of 2 in. and delivered it through another chute to a storage bin adjacent to the sand bin. Both stone and sand bins delivered by gravity through gates to measured compartments in a triple charging hopper just below the floor of the working platform. This hopper was lined with steel and had a compartment into which the requisite number of bags of cement were poured by hand. The hopper gate was operated from the charging platform and delivered all of the aggregate for one batch of concrete to one of the two Ransome mixers under the platform, which discharged into 1½-yd. bottom-dump Stuebner steel buckets which were set in pairs on 2 coupled cars drawn by one horse on a 600-ft. service track to the main pier caisson, or to the anchor pier, where they were unloaded and emptied by the derricks installed there.

The compressed air, with a maximum pressure of 40 lbs. per sq. in., was delivered to the working chamber of the south caisson through two 12-in. pipes, as stated above, which in turn was distributed into four 7-in. mains.

Water at 100-lb. pressure was distributed around all four sides of the working chamber in a horizontal main from 4 to 6 in. in diameter, provided each of the 18 compartments with a valved outlet and jet pipe with 1-in. nozzle used to loosen the sand and excavate the earth and gravel. Each chamber was also provided with a 6-in. vertical blow-out pipe and with electric lights. The caisson was fitted with six 3-ft. material shafts, each having a Moran air lock with four 3-ft. ladder shafts having simple air-locks composed of short upper sections with top and bottom diaphragms, and with one large man-lock. The latter was a 6-ft. horizontal steel cylinder about 30 ft. long, located on the deck of the caisson, and was built permanently into the solid concrete of the pier, being approached through a 4 x 4-ft. vertical stair shaft. The lock was large enough to accommodate many "sand hogs" at once, thus greatly expediting the entrance and exit of each successive shift, effecting an economy of air consumption and considerably reducing the waste of lock air.

A hospital lock was also established on the shore near the "sand hog" house. Under moderate pressures, 100 men worked 8 hours in each shift. As the pressure increased the lengths of the shifts were diminished to a minimum of 1 hour. As many more sand hogs were required to carry on the work, great difficulty was experienced in securing enough men, so that eventually the number of men in each shift was considerably reduced. Some of the men lived in an adjacent boarding house provided by the contractors, but the majority of them lived in local villages up to five miles distant.

At the present time the contractor is at work pointing the joints in the masonry and cleaning these piers thoroughly by sand blast. There is also some work still to be done on the dressing of the bridge seats. This work is very important and has proved a very difficult operation. These bridge seats are about 32 ft. x 26½ ft. and it is necessary that they should be absolutely level to distribute the load from the main steel pedestal, the base of which is shipped in four pieces. It requires about six weeks to complete the dressing on one of these beds, and it has been found that the work can be done with such accuracy that not more than a variation of 2/100 of an inch is possible.

This work is under the supervision of the Board of Engineers, Quebec Bridge, which is composed of C. N. Monsarrat (chairman and chief engineer), Ralph Modjeski and C. C. Schneider.

RESERVING WATER POWER SITES.

Consistent with the policy of the Dominion government to preserve the water powers for the people, the department of the interior is placing under reservation all vacant Dominion land that the superintendent of water powers may recommend to be valuable for the development of water power, says Conservation.

Six whole sections of land, in township 108, range 6, west of the 5th meridian, have recently been reserved from disposition of any kind until the engineers of the water power branch have had an opportunity to make a complete survey of the famous power site at Vermilion falls, on the Peace River in northern Alberta.

Similar reservations have been made on the various rivers in the provinces of Manitoba, Saskatchewan, Alberta, and in the railway belt of British Columbia. Particular mention might be made of reservations covering land contiguous to Grand Rapids on the Athabasca River, the various power sites on the Elbow and the Bow Rivers, in the province of Alberta; for land required for the development of power at Grand Rapids on the Saskatchewan River, and all unoccupied land along the Winnipeg River, in the province of Manitoba.

Other reservations will be made from time to time upon the receipt of sufficient information to enable the superintendent of water powers to make a definite recommendation covering a description of the land that might be required for power purposes.

MAIN PEDESTALS, QUEBEC BRIDGE

NOTES ON THE DESIGN OF THE FOUR 400-TON SHOES TO TRANSFER THE LOAD FROM THE CANTILEVER AND ANCHOR ARMS TO THE MAIN PIERS—METHOD OF FABRICATION AND ASSEMBLAGE.

By H. P. BORDEN,
Assistant to Chief Engineer, Quebec Bridge.

Each of the four main shoes of the new Quebec Bridge are designed to transfer the following loads:

Main vertical post	26,600,000 lbs.
Cantilever arm chord	29,600,000 lbs.
Anchor arm chord	24,100,000 lbs.
Cantilever arm Compression diagonal	7,820,000 lbs.
Anchor arm compression diagonal	7,810,000 lbs.

Resolving the above, this pedestal supports a maximum vertical and horizontal reaction of 55,000,000 and 32,000,000 lbs. respectively. Owing to the unprecedented size of the members required to transfer these loads to the shoe and the necessarily unusual proportions of the shoe itself which is required to distribute these loads to the masonry, the design of this member probably entailed more investigation and study than any other single detail in connection with the bridge.

The shoe is 26 ft. 4 in. x 20 ft. 10 in. at the base and 19 ft. high. To facilitate fabrication, shipping and erection, it is constructed in three stories. The lower story, or base, is 4 ft. high and is composed of 4 steel castings. These castings probably constitute a record for weight and size of steel castings in Canada, weighing over 40 tons each. These members have webs and flanges ranging from 2½ in. to 3 in. in thickness, the webs being supported by cross diaphragm walls of the same thickness, at frequent intervals. These castings are planed on a machine designed especially for this purpose, great care being taken to get a uniform depth for each of the 4 castings. When erected in place they are bolted together with 2½-in. bolts through exterior flanges, thus forming a base through which the vertical and horizontal reactions from the upper portions of the shore are transmitted to the masonry. The horizontal reactions at the

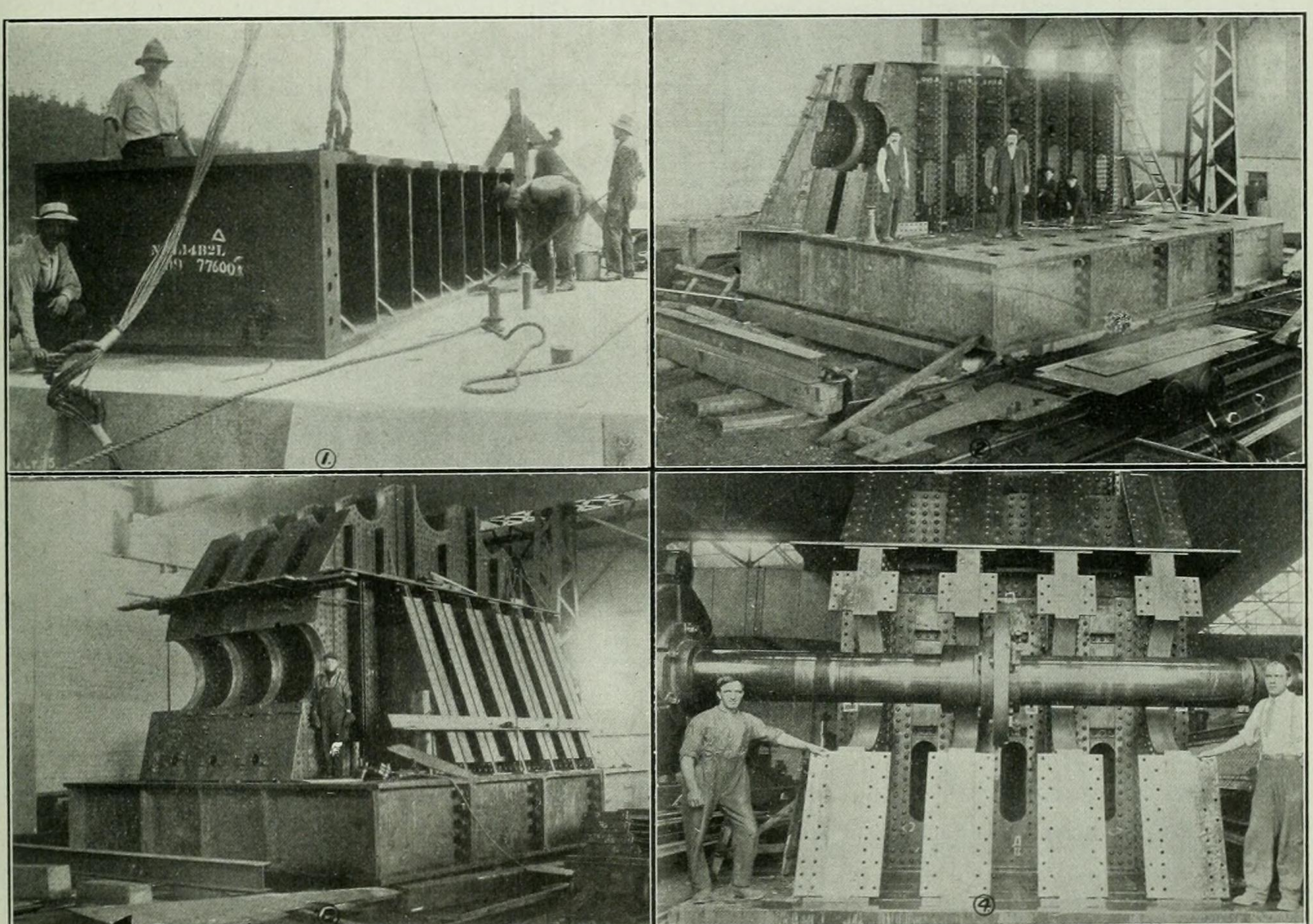


Fig. 1.—One of the 4 Castings Being Placed on the Pier. Fig. 2.—Casting Assembled (shop) and Second Story Under Construction. Fig. 3.—Second and Third Stories Nearing Completion. Fig. 4.—Method of Boring 45-inch Pin-hole.

pier can in every case be taken care of by the 30% coefficient of friction assumed between steel and masonry, but an additional factor of safety is provided by 44 3-in. anchor bolts and dowels. The dowels in the interior of the castings are grouted into the masonry and embedded in concrete with which the casting will be filled. The anchor bolts through the exterior lower flanges of the castings are grouted into the masonry with cement, that portion of bolt passing through the steel flange being grouted with molten zinc.

The middle section of the shoe is of built-up construction and is field-riveted to the lower section. This portion of the member is 10 ft. high and is composed mainly of 4 heavy webs which correspond to the webs of the bottom chords. The chord stresses are transmitted direct to this section of the shoe through 30-in. pins with 45-in. bushings. In addition to the chord stresses, this section of the shoe is required to transmit the stresses from the other web members which is transferred from the upper section and as a consequence the webs of the middle section become very heavy, the maximum thickness at the pin being 9¼ in., requiring a 1⅛-in. rivet 12 in. long. The loads distributed upon these webs are transferred uniformly to the base by means of 7 heavy brackets on each side, field riveted to both webs and castings. It was found when designing the connections between brackets and webs that the largest angles rolled would not provide sufficient rivet area to transmit the vertical shear. As a result, special connection-angles with 12-in. legs were manufactured from 1-in. plates. While it is expected that this design will undoubtedly to a large extent distribute the loads uniformly over the lower section, yet the contingencies of fabrication and erection are such that the actual results might not correspond to the theoretical expectations. To provide against the possibility of the load on the centre webs not distributing as expected, the steel castings on the base have been made sufficiently strong to distribute any such concentrated loading. The connection plates for the main bottom laterals are field riveted to the top and bottom of this section. When it is understood that these laterals have an inclination in both the vertical and horizontal plane and the face of the shoe to which they are connected is sloped at another angle in the vertical plane, it speaks well for the accuracy of the shop work that the connection holes in all these parts matched exactly when the shoe came to be assembled.

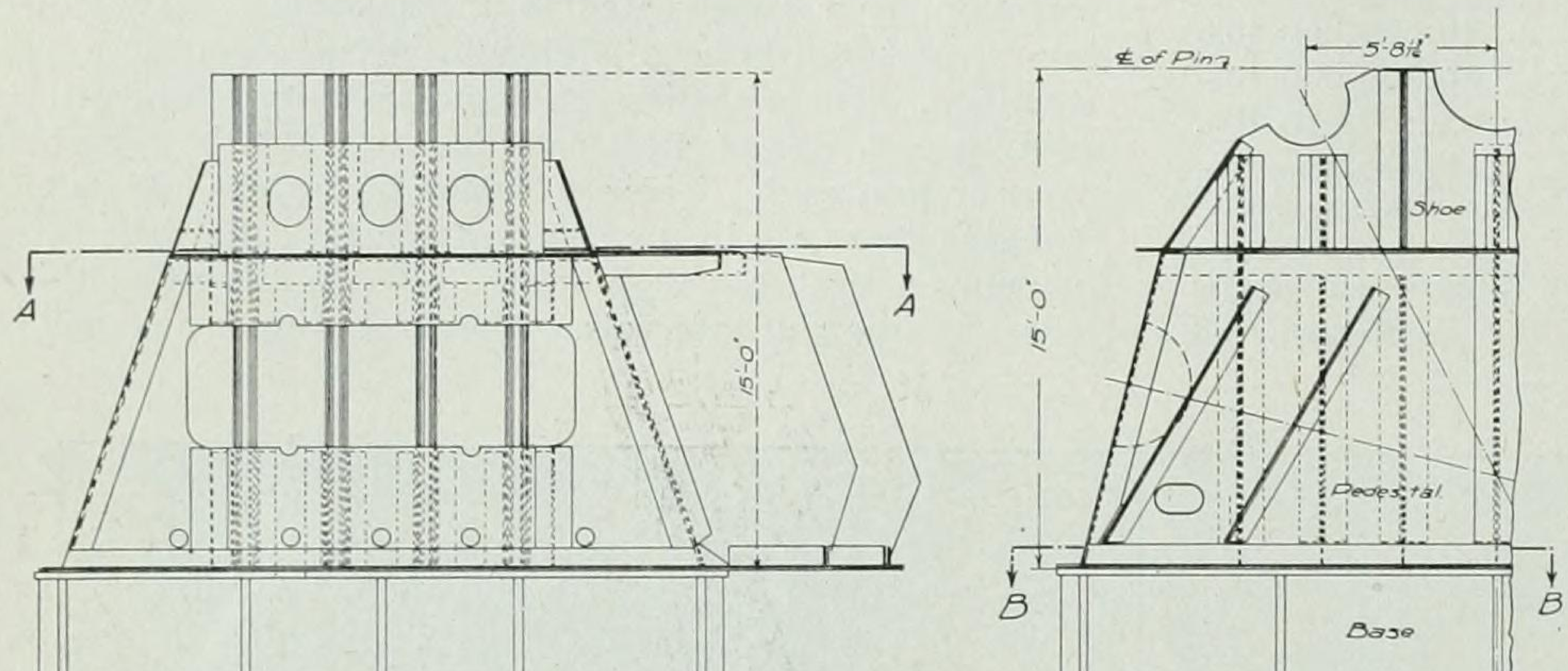
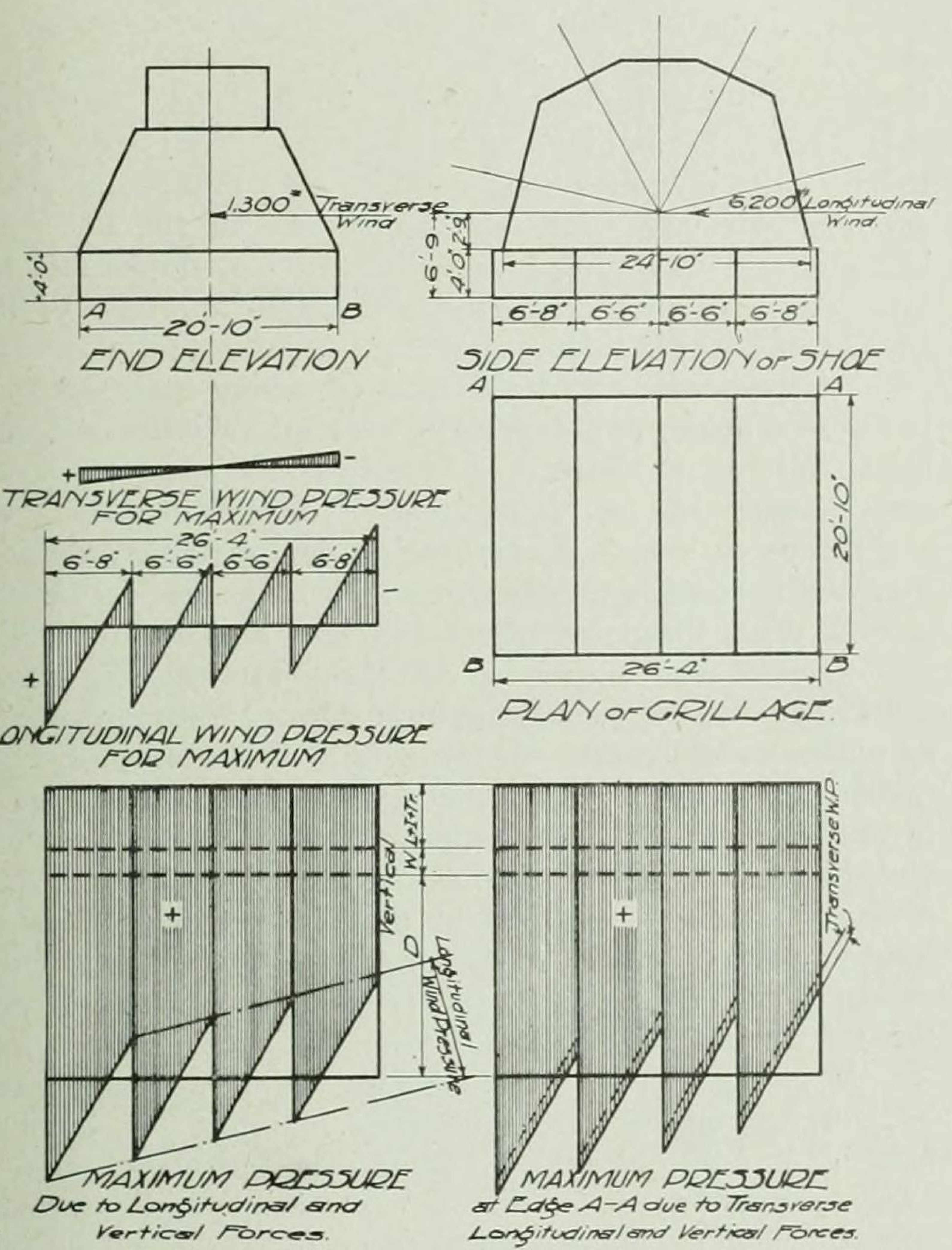


Fig. 5.—Elevations and Sections of Shoe for Main Pier Bearing.

The top or third section contains one 45-in. and two 30-in. half-pin holes which take the bushing for the 30- and 20-in. pins of the main post and diagonal compression members respectively. This section has 4 main webs which correspond to the 4 webs of the web members and post as well as the webs of the second section immediately below. In order to uniformly distribute the reaction, brackets are connected to the sides of the outer webs, spaced to correspond to the lower brackets. This top section is braced by very heavy brackets and diaphragms so that, assuming the whole shoe to act as a girder, transversely, the top and bottom stories will act as the flanges and the middle story as the web.

The maximum vertical loads on the shoe result in a uniform bearing of 660 lbs. per sq. in. on the granite masonry of the pier. This reaction comes from dead load, live load, impact, traction and vertical wind. In addition to the above there are transverse and longitudinal wind loads of 1,300,000 and 6,200,000 lbs. respectively. The transverse force is the horizontal component of the wind forces carried to the shoe by the lateral bracing and chords, and results in an increased toe pressure at the leeward edge. The longitudinal wind force is due to a torque at the main pier, due to normal wind pressure on the longer cantilever arm and half the suspended span resisted by the shorter anchor arm. This action results in equal and opposite reaction on the windward and leeward shoes on the main pier in a direction parallel to the longitudinal axis of the bridge. This longitudinal reaction is resisted by the friction between the steel castings and the masonry. As these castings are narrow in this direction, there is an overturning moment which is assumed to act on each casting individually and not on the entire base as a whole, which results in a very short lever arm as compared with that used in determining the toe pressure from the transverse wind force acting at right angles. Certain allowances are made for the fact that the castings are riveted to the middle section, but even with this allowance there is a very appreciable increase in the pressure at the edges of the castings. Under such maximum conditions and assumptions, it is found that the maximum toe pressure amounts to 915 lbs. per sq. in. for all loads.

In all these calculations the following wind loads have been assumed: A wind load of 30 lbs. per sq. ft. of exposed surface of two trusses and 1½ times the elevation of the floor and 300 lbs. per lin. ft. on the exposed surface of a train covering the whole bridge applied 9 ft. above base of rail.



FORCES FOR MAXIMUM PRESSURE

	Vertical	Longit'l.	Transverse
D	36,000		
L	9,804		
I	1,960		
W	4,500	6,200	1,300
Tr.	140		
Maximum Pressure 915#/□"			
Average Pressure 660#/□"			

NOTE.

Grillage section considered as Fixed at Top & Bottom.

Abbreviations:—
D—Dead Load L—Live Load
I—Impact W—Wind
Tr—Traction.

Fig. 6.—Diagram of Pressure Between Shoe and Masonry.

After the various parts of the shoe have been fabricated in the shop it is entirely assembled on concrete and steel skids and all field connections are reamed out in place or to a steel template. All loose parts are matchmarked with stencil and steel dies and all important centre lines chisel-marked on abutting faces. It is then taken down and the main sections re-assembled on the bed of the boring mill, and after having been accurately lined up with field level, transit and other special mechanical appliances, the five holes are bored at one setting. When this operation has been completed the shoe is again taken apart for shipment, the lower base being shipped in four sections, the middle in two main sections, and the top in one. When completed, each shoe weighs about 440 tons. The exterior faces of the middle section are covered with facia plates to give a finished appearance. These plates, as well as all diaphragms and top flange of castings, are provided with manholes, thus providing access to all parts of the shoe for riveting, inspection and painting. In order to prevent rain water settling in the interior, the shoe is partially filled with concrete which is sloped from the centre towards the sides, thus allowing all water to drain out through the holes in the facia plates.

In Fig. 1 is shown one of the four steel castings forming the lower story. It is being placed on the main pier. A thin grout is brushed over the masonry rest before the casting is put in place. The castings are assembled as shown in Fig. 2, which is a shop view showing erection on skids, and a start made on the erection of the middle section of the shoe. In Fig. 3 the second and third stories are shown nearing completion, the side brackets on the middle section being put in place for reaming. Fig. 4 shows an end view of the middle section and illustrates the method of boring the 45-inch pin-holes.

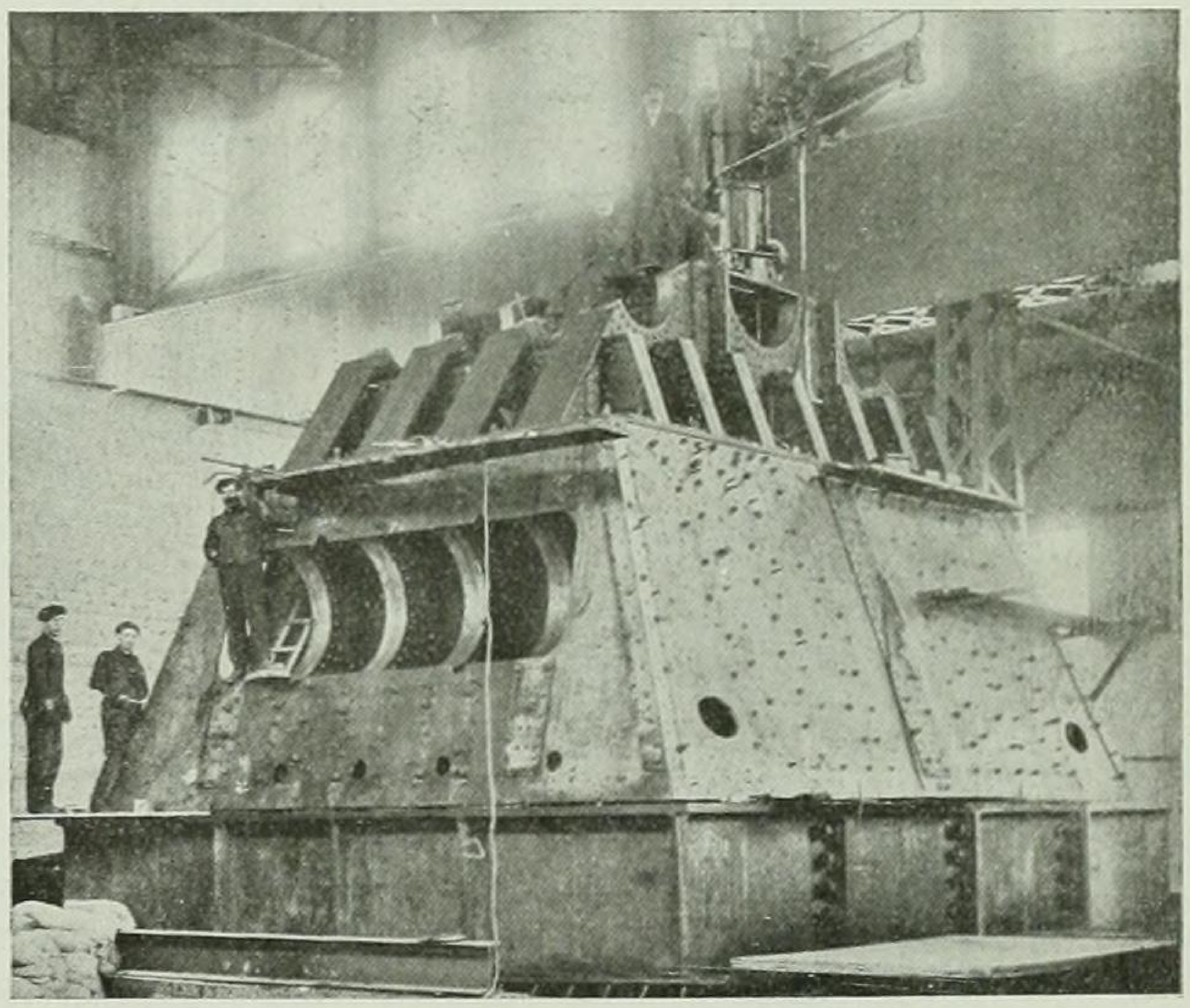


Fig. 7.—View of a Pedestal, Completely Assembled.

A general view of the completely assembled shoe is given in Fig. 7. The second story has its covering of facia plates. Every hole is reamed or drilled from the solid before being taken apart. It takes about 2 months to assemble, ream and bore this shoe in the shop, not including the time required for fabrication.

TORONTO HARBOR COMMISSIONERS TO CONTINUE WORK.

Although the early formation of ice on the bay will seriously interfere with their work along the waterfront, the Toronto Harbor Commissioners have made a careful survey of the territory under construction and are picking out the portions of the work that can be continued during the winter, in order to give employment to as many men as possible. A considerable portion of this work will consist of grading operations along the waterfront.

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The Canadian Engineer

A weekly paper for engineers and engineering-contractors

PROGRESS ON THE NEW QUEBEC BRIDGE

SUPERSTRUCTURE ERECTION REVIEWED TO DATE—PROGRAM OF ERECTION—OFFSETTING DIFFICULTIES IN PIN CONNECTIONS ARISING OUT OF ALLOWANCES FOR DEFORMATION OF MEMBERS UNDER FULL LOAD.

By H. P. BORDEN,
Assistant to Chief Engineer.

WITH the close of the present season considerable progress is to be noted towards the erection of the new Quebec Bridge. During the summer of 1913 the approach spans on the north shore from the abutment to the anchor pier were fully erected. These spans were erected by derrick cars on heavy wooden and steel falsework. As these spans would have to carry the 1,000-ton erection traveler, and as the concentrated wheel loads from this traveler were considerably greater than the live loads for which the spans were designed, this falsework was made sufficiently strong to take care of these reactions.

During the winter of 1914 the traveler was erected on the shore, just north of the abutment and it was ready to move out early in May. This traveler was carried on two double lines of tracks, spaced 54 ft. centre to centre. The two inner rails were carried on the top flanges of the outside bridge track girders, the outer rails being carried on special erection girders resting on the falsework and thoroughly braced to the track girders themselves. The traveler was moved out over the approach spans to the anchor pier on May 18th, and proceeded to erect the inside falsework carrying the floor of the anchor arm on which the traveler runs.

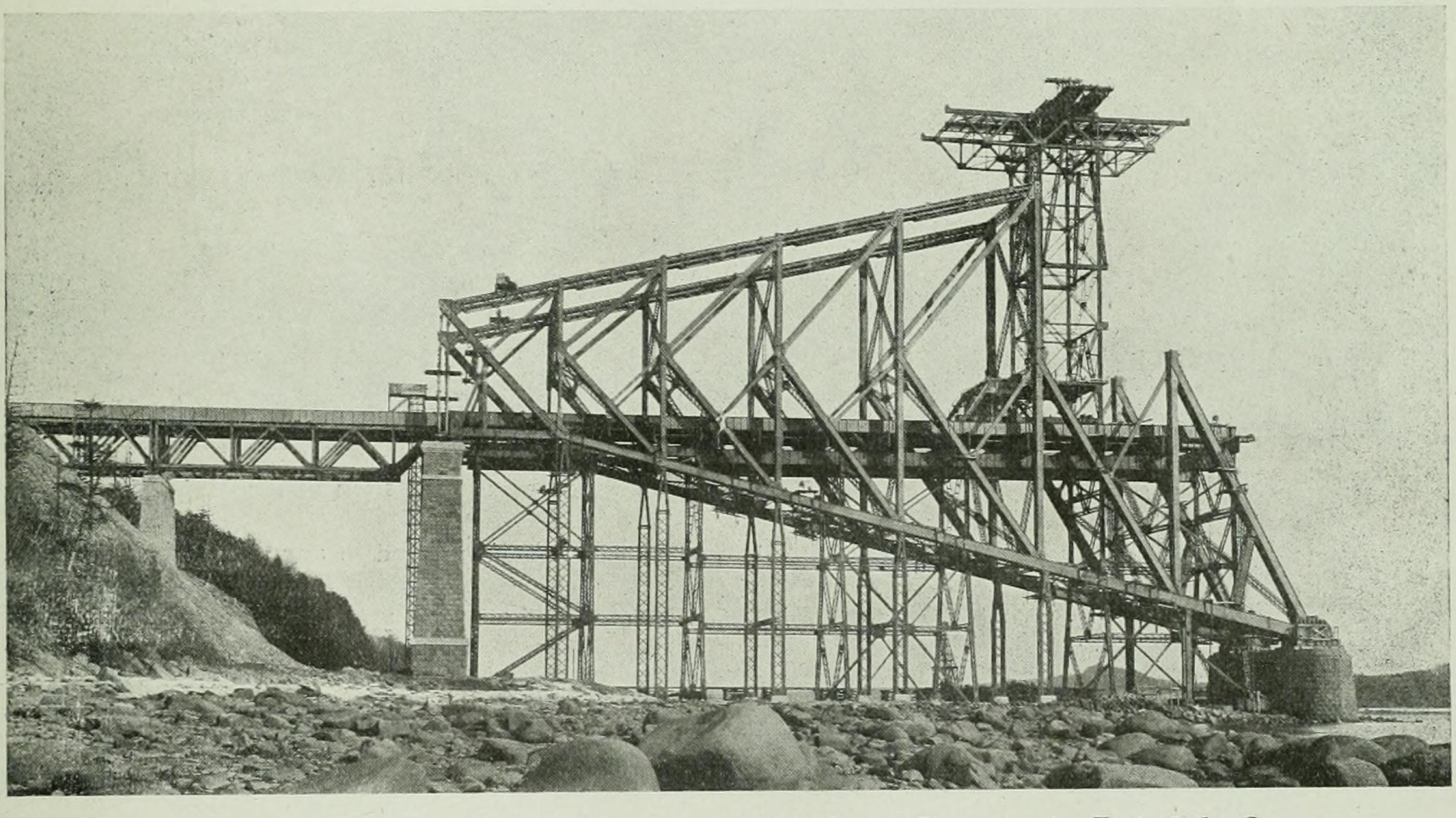


Fig. 1.—View Showing North Anchor Arm when Work Closed Down at the End of the Season.

The main floor beams of this floor were supported on special erection girders supported by this falsework and were located in approximately their correct positions. The main track girders, sub-floor beams and stringers were then erected in place and special girders erected outside the track stringers for the erection traveler.

When this falsework had been completed out to the north main pier the main shoes were erected, and the bases for these shoes were accurately placed and the entire shoe erected. An elaborate series of triangulations and measurements, extending over several months, were made to locate the longitudinal and transverse centre lines of these shoes. Once the bases had been placed in their proper position the rest of the shoe went forward rapidly, and a start on the erection of the bottom chords was made.

According to the program of erection, it was proposed to lay the bottom chords complete with their lateral bracing from the main shoe to the anchor pier, the main traveler moving back as the work progressed. When this had been done the traveler moved ahead again to the main pier and started the erection of the web members up to their middle intersection above the floor. This was carried back to the north anchor pier, after which the erection of the upper half of the web members in the top chord was effected, the traveler moving forward as the work progressed.

Work stopped for the season with the anchor pier completely erected with the exception of two upper panels near the main pier.

Owing to the deformation of all members under full load, it has been necessary to manufacture the compression members slightly longer and the tension members slightly shorter than their actual geometric length. On account of this fact there would naturally be difficulties in making the pin connections between the various members of the anchor arm in view of the fact that all these members are erected on falsework and consequently under no load except from their own weight. To offset this difficulty, the bottom chord was given a camber which would correspond to the deformations indicated by the Williot's or deformation diagram. In other words, after the bottom chord had been entirely riveted up from end to end, it was lowered a certain amount at each panel point by means of jacks at the foot of the steel falsework to correspond to this deformation. The final displacement, including deformation of falsework posts, amounted to zero at the main shoe, seven inches at the middle point, and five inches at the north anchor pier, varying practically uniformly between these points.

Owing to the length of this bottom chord, it was able to obtain this deformation without any difficulty.

To offset the effect of deformation of the web members from their own weight, and to enable pins to be driven without any difficulty, elongated holes were bored in the upper end of the upper tension diagonals and in all the eyebars in the top chord. The holes in the diagonals were elongated 2 inches and each eyebar ½ inch at each end, the elongation being made in the side of the hole nearest the centre of the member. By this means it was possible to drive these pins without any difficulty, the play in the holes being taken up as the cantilever arm is erected and stresses applied to the members of the anchor arm.

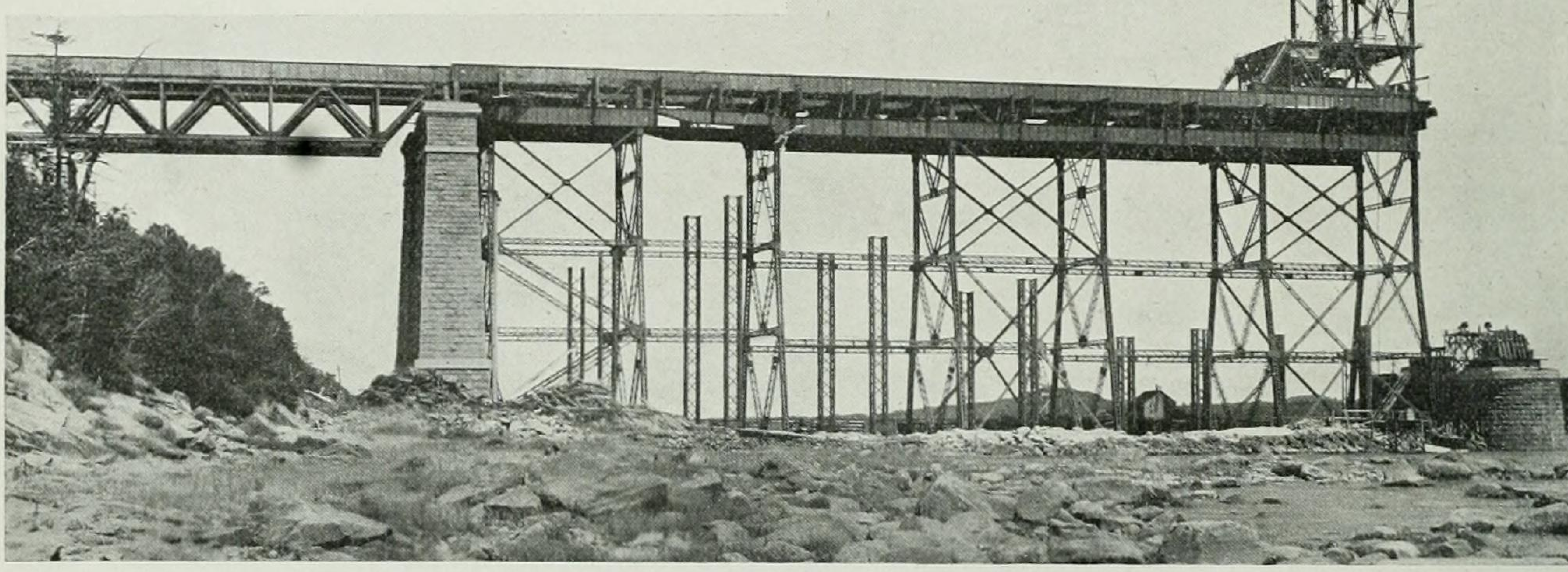


Fig. 2.—Falsework and Floor Erected, and a Start Being Made on the Erection of the Main Shoes.

The driving of pins was materially facilitated by the fact that these pins are in duplicate, each pin going through two webs only of the 4-web members. This also applies to the top chords. In designing the driving rams for these pins it was estimated that heavy rams, weighing in the neighborhood of two or three tons, would be required. It was found in actual practice, however, that these were not necessary, and after the first one or two pins had been driven a steel rail 10 feet long, weighing 80 lbs. per yard, was used and pins in practically every case were driven home in from one to two minutes.

The maximum clearance allowed in all pin holes is 1/32 inch + 1/100 inch.

The amount of steel erected during the season just passed is about 15,000 tons, and this was practically erected in four months, from August 1st to December 1st.

A duplicate traveler is now being erected on the south side of the river and will be in commission the first thing in the spring. If the work is carried on according to programme, it is expected that the remainder of the anchor arm and the whole of the north cantilever arm as well as the south anchor arm, should be erected next season.

The St. Lawrence Bridge Company, Montreal, are the contractors for the superstructure. The work is being carried out under the supervision of the Board of Engineers, Quebec Bridge, composed of Mr. C. N. Monsarrat (Chairman and Chief Engineer), Mr. Ralph Modjeski and Mr. C. C. Schneider.

ECONOMIC FEATURES OF THE ROGER'S PASS TUNNEL.

FROM time to time articles and notes of engineering interest have appeared in this journal on the five-mile, double-track tunnel which Messrs. Foley Bros., Welch and Stewart are driving through the Selkirk Range, in the vicinity of Roger's Pass, for the Canadian Pacific Railway Company. For a description of the engineering features of the undertaking the reader is referred to *The Canadian Engineer* for April 23, 1914, page 621. Maps and profiles of the old and proposed lines are illustrated therein to good advantage, and a reference to them will be of assistance in the following portrayal of the problem in economics which the revision of railway location has presented.

The following abstract from a paper by J. G. Sullivan, C.E., chief engineer of the western lines of the C.P.R., presents the factors involved in a study of the cost of operation via the present and proposed routes. We are indebted to the "Cornell Civil Engineer" for the information. (Mr. Sullivan is a graduate of Cornell University, Class '88.)

The data to be taken into account is as follows: Present location, total distance 23.1 miles, revised location 18.68 miles; grades consist, on the present location of 16.65 miles up hill for westbound traffic on maximum grade of 2.2%, 6.45 miles down grade same maximum with a total rise of 1,726 ft. and a drop of 692.1 ft. with 1,860 degrees of curvature on the up hill and 1,288 degrees on the down hill portion of the line. The revised location consists of 16.77 miles up hill with about 5 miles of 2.2% pusher grade, the balance 1% and a down hill run of 1.91 miles with a maximum 2.2% grade; a total rise of 1,178.2 ft. and a drop of 144.3 ft., with 635 degrees of curvature on the up hill grade and 66 degrees on the down hill. The average traffic for the years 1912 and 1913, which is made the basis of calculations, was 1,342½ passenger trains in each direction; the average weight of the passenger trains, exclusive of locomotives, was 443 tons; 980 of the passenger trains required pusher engines; the weight of the passenger and pusher engines for passenger trains was 175 tons each; there were 173½ freight trains in each direction per year; the average weight of the freight trains eastbound, exclusive of locomotives, was 950 tons; the average weight of freight trains westbound was 898 tons; all freight trains had to be pushed in both directions; weight of freight locomotives and pushers, 181 tons each. The tonnage eastbound and westbound was as follows:—

Eastbound.

1,342½	trains @ 443 tons each	594,727.5	tons
2,322	locomotives @ 175 tons each	406,350.0	"
1,738½	freight trains @ 950 tons each	1,651,575.0	"
3,477	locomotives @ 181 tons each	629,237.0	"
	Total	3,281,889.5	tons

Westbound.

1,342½	trains @ 443 tons each	594,727.5	tons
2,322	locomotives @ 175 tons each	406,350.0	"
1,738½	freight trains @ 898 tons each	1,561,173.0	"
3,477	locomotives @ 181 tons each	629,237.0	"
	Total	3,191,487.5	tons

Comparison of Comparable Factors Affecting the Cost of Operating Over Roger's Pass, via Present Line and via Tunnel Line, Now Under Construction, Average Traffic for the Years 1912 and 1913.

E. B. tonnage per year, including weight of engines, 3,281,890 tons.

Resistance to overcome, on present line.

Actual rise, 692.1 ft.	692.1 ft.	
Curve resistance, 1,288° × .04′	51.5 ft.	
Friction resistance, 6.45 mls. × 15′	96.7 ft.	
Total		840.3 ft.

Resistance to overcome, tunnel line.

Actual rise, 144.3 ft.	144.3 ft.	
Curve resistance, 66° × .04′	2.6 ft.	
Friction resistance, 1.91 mls. × 15′	28.6 ft.	
Total		175.5 ft.
Difference		664.8 ft.

3,281,890 tons × 664.8 ft. equals 2,181,800,472 foot tons.

W. B. tonnage per year, including weight of engines, 3,191,488 tons.

Resistance to overcome, present line.

Actual rise, 1,726 ft.	1,726.0 ft.	
Curve resistance, 1,860° × .04′	74.4 ft.	
Friction resistance, 16.65 mls. × 15′	249.7 ft.	
Total		2,050.1 ft.

Resistance to overcome, tunnel line.

Actual rise, 1,178.2 ft.	1,178.2 ft.	
Curve resistance, 635° × .04′	25.4 ft.	
Friction resistance, 16.77 mls. × 15′	251.5 ft.	
Total		1,455.1 ft.
Difference		595.0 ft.

3,191,488 tons × 595 ft. equals 1,898,935,360 foot tons.

Total work done (extra)	2,181,800,472 foot tons.
	1,898,935,360 foot tons.
Total	4,080,735,832 foot tons.

1,000 foot tons equals approximately 1 horse-power hour. Assuming that 5 pounds of coal is consumed in doing one horse-power hour's work and that coal on locomotive costs $4.60 per ton, the saving in fuel will amount to:

$$\frac{4{,}080{,}736 \times 5 \text{ lbs.} \times \$4.60}{2{,}000 \text{ lbs. (one ton)}} = \ldots\ldots \$46{,}928.46$$

Extra Wages, Train and Engine Crews.

Present line.

6,162 trains for 23.1 miles,	142,342.2 train miles.
5,437 push. engs. for 23.1 mls.,	125,594.7 push. eng. mls.

Tunnel line.

6,162 trains for 18.68 miles	115,106.2 train miles.
5,437 push. engs. for 13 mls.,	70,681.0 push. eng. mls.

Amount saved { 27,236.0 train miles.
54,913.7 pusher engine miles.

Volume 30. Toronto, June 1, 1916. Contents of this issue on page 5.

The Canadian Engineer

A weekly paper for Canadian civil engineers and contractors

THE NEW QUEBEC BRIDGE

AN INTERESTING ACCOUNT OF THE METHOD TO BE EMPLOYED IN HOISTING THE SUSPENDED SPAN INTO PLACE—THE WEIGHT OF THE SPAN IS APPROXIMATELY FIVE THOUSAND TONS.

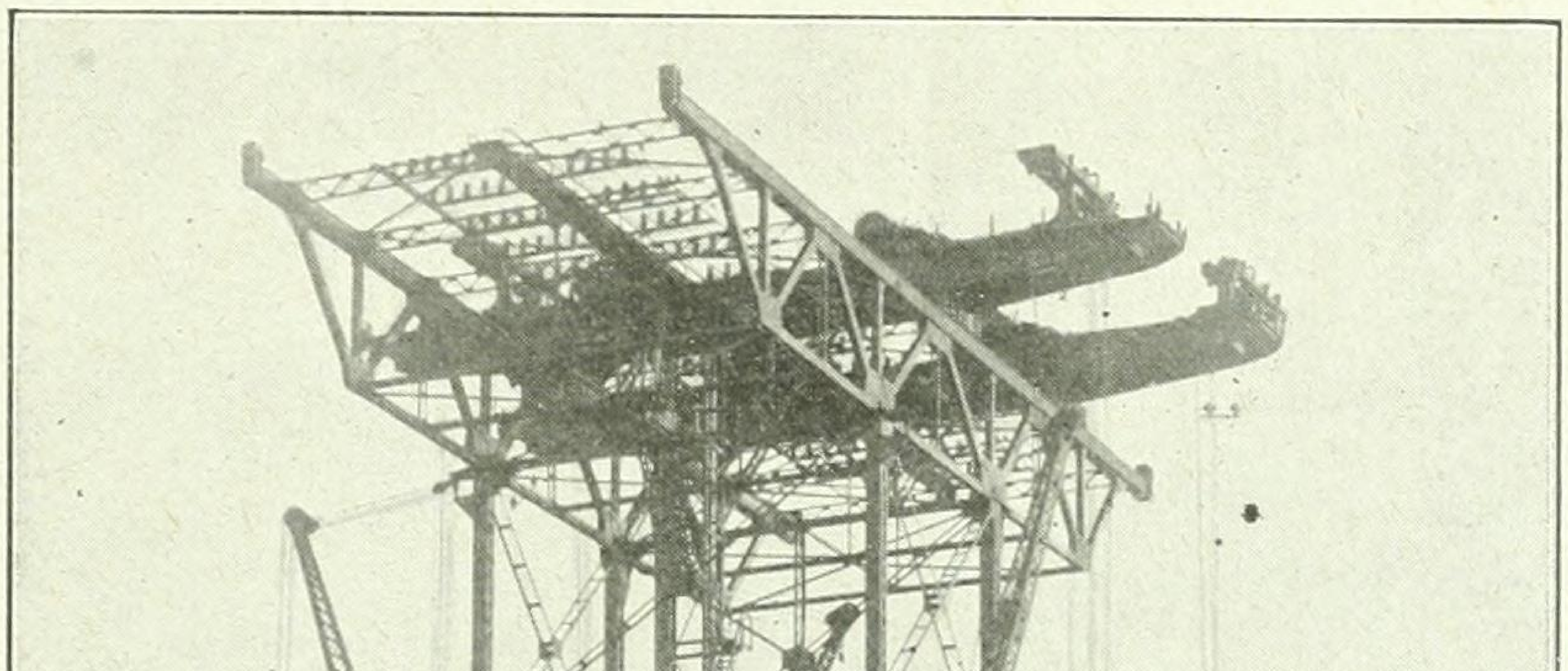
By A. J. MEYERS,
Chief Draftsman, Board of Engineers, Quebec Bridge.

THE contract for the construction of the piers for the Quebec Bridge was awarded to M. P. and J. T. Davis, of Quebec, in February, 1910. This phase of the work was very fully described in the issue of July 9th, 1914, in an article by Mr. H. P. Borden. The close of the year 1914 found considerable progress had been made.

During the season of 1915 most satisfactory progress was made, a detailed account of which was published in *The Canadian Engineer* September 23rd, 1915.

On July 8th, 1915, the erection of the main shoe on the south shore started. Work in connection with this part of the construction was greatly facilitated by the experience gained.

On November 12th, 1915, when the erection programme for the new Quebec Bridge was finished for the season, the north shore anchor and cantilever arms and the south shore anchor arm including the main post, had been completed. The total tonnage erected up to that time amounted to approximately 46,000 tons, about 30,000 tons of which had been placed during the 1915 working season of seven months, from the middle of April to the middle of November. The total quantity of steel in the bridge will weigh in the neighborhood of 65,000 tons, so that the programme for the season of 1916 calls for the erection of about 19,000 tons, a comparatively easy task, judging from the records of the past summer. Of this 19,000 tons, the south shore cantilever arm contributes 13,000 tons and the suspended span 6,000 tons.



View Showing 1,000-ton Traveler and Progress of Erection.

Work on the erection of the south shore cantilever arm was properly started about the middle of April, 1916, and at the time of writing this article, the first panel and a half, adjacent to the main pier, is practically completed. It is expected that the progress of erection of the south shore cantilever arm will be approximately as stated in the schedule on the following page.

The method of erection of the south cantilever arm is entirely the same as that followed on the north cantilever arm, and, as noted above, it is expected that this work will be finished by the end of the first week in September, 1916, when the bridge will be in readiness for the floating in and hoisting into place of the suspended span.

The suspended span is a double-track, curved top chord span, 640 feet long, 110 feet high and 88 feet wide, and weighs in the floating in condition approximately 5,000 tons. The greater part of the floor steel, being left off while the span is being floated and hoisted into place, will be placed by

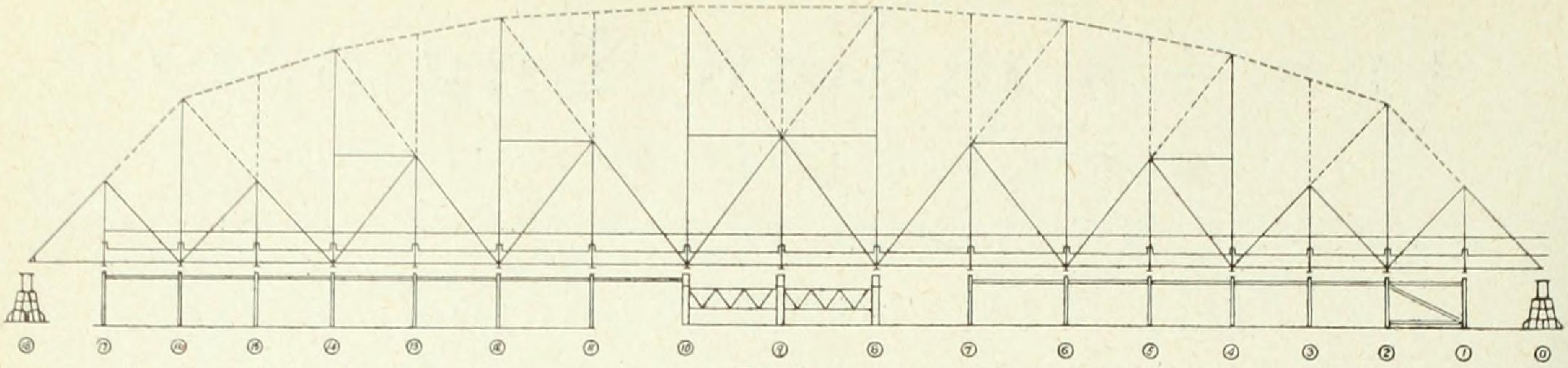


Fig. 1.

means of a derrick car after the span has been coupled up to the ends of the cantilever arms.

Schedule Showing Approximate Progress Expected in Erection of South Shore Cantilever Arm.

Main panel.	Days required.	Date of completion	Tons of steel to be erected.
16-14	40	May 10th	3,100
14-12	30	June 9th	2,650
12-10	22	July 1st	1,960
10-8	16	July 17th	1,460
8-6	12	July 29th	1,300
6-4	9	August 7th	850
4-2	14	August 21st	630
2-0	15	September 5th	650
Total....	158		12,600

This span will be erected in the shallow waters of Victoria Cove, on the north shore of the river, about three miles below the bridge site, the work of erection proceeding simultaneously with that of the south shore cantilever arm.

The foundations for the falsework bents supporting the trusses and approach track were prepared during the season of 1915 at the periods of low tide. This work was rather difficult, considerable blasting having to be done, and could not be carried on with any very great speed as the time available was only from two to four hours each day.

As shown in the accompanying Figs. 1 and 2, the span will be supported during erection on staging bents placed under each panel point. The traveler, which is the same one that erected the north shore cantilever and anchor arms, but with the top trusses and travelling cranes left off, will be first erected on bents 19 and 20, immediately adjacent to the staging of the span. The steel will be handled by means of four 70-foot 30-ton booms, placed one at each of the four corners.

With the traveler at bent 19, the staging bents 0, 1 and 2, the longitudinal bracing between bents 1 and 2, and the bridge material in panel 0-1 will be placed. The traveler will then move forward, erecting staging and

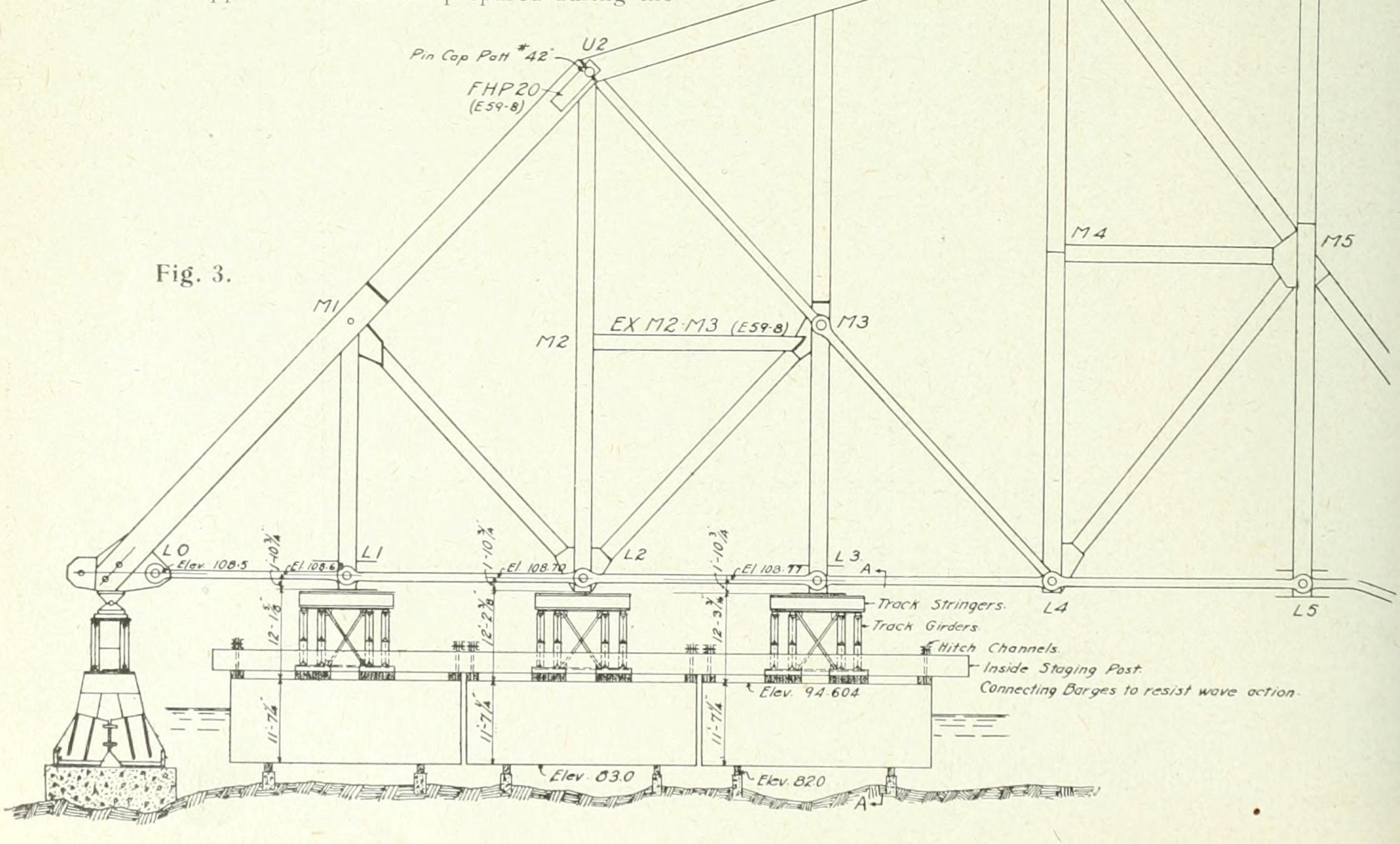


Fig. 3.

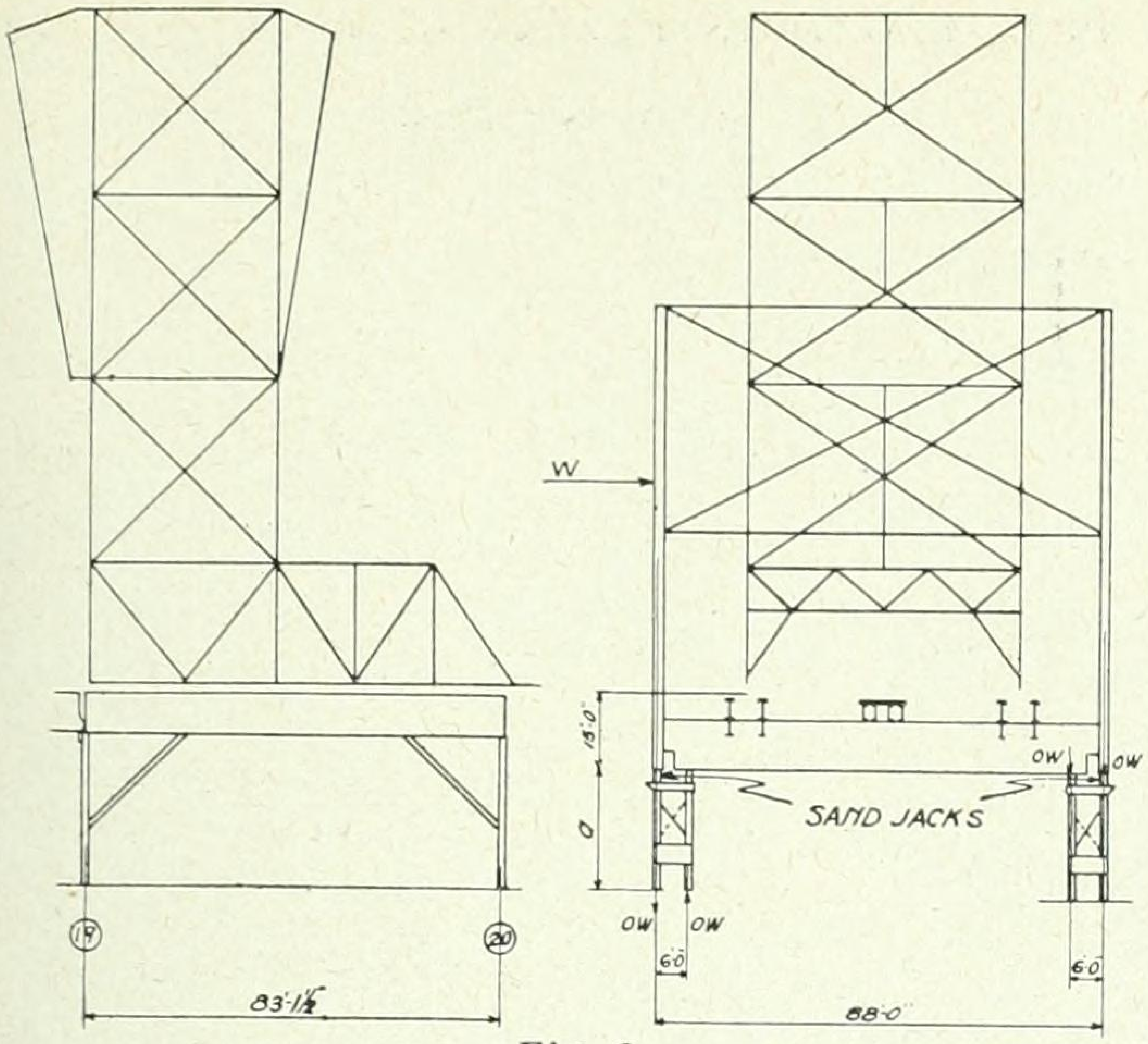


Fig. 2.

longitudinal bracing, floorbeams, bottom chords, bottom laterals and web members, except the upper half of the main diagonals and vertical sub-posts, as it advances until it reaches bent 17. It will then move backwards, completing the erection of the truss members, top laterals and sway bracing.

In Fig. 1 the members erected as the traveler advances are shown in full lines, the members placed on the return trip are shown by dotted lines.

Sand jacks will be used at the even panel points, directly under and with top bolted to the vertical posts, to transfer the load to the outer columns of the staging. Timber blocking will be used for the same purpose at the sub-panel points and also between the floorbeams and inside columns of the staging at all panel points.

The span being completely erected, the timber blocking at the intermediate staging supports will be removed, the sand jacks lowered, and the span will rest on the end bents at L_0 and L_{18}. In this condition, as shown in Figs. 3 and 4, six scows 32 feet wide, 160 feet long, and 11 feet 7 inches draft, will be floated in and placed under the panel points L_1, L_2, L_3, L_{15}, L_{16} and L_{17}. The valves in the bottom of the scows will be opened and the scows sunk until they rest on their foundation supports. The cross-girders and bracing which transfer the loads to the scows will then be placed.

To raise the span from the end supports at L_0 and L_{18}, preparatory to floating out, the scows will be drained at low tide, the bottom valves closed, and as the tide rises the span will be gradually lifted and be in readiness for proceeding on its journey to the bridge site, if the weather and tide conditions are considered favorable. If conditions are not considered favorable, arrangements will be made by means of timber crib guides, tackle running to anchorages on the shore and tugs, so that the span can be returned to its supports.

While the span is on its way to the bridge site, it will be kept under control by means of tugs of sufficient power capacity to overcome all anticipated resistances due to wind and current.

Arriving at the bridge site, the span will be anchored to the ends of the hanging trusses shown in Fig. 5, coupled up to the hanger slabs provided at each of the four corners of the cantilever arms, and raised into its final position by means of the movable jacking girders and eight 1,000-ton hydraulic jacks, two at each corner, as shown on Fig. 3.

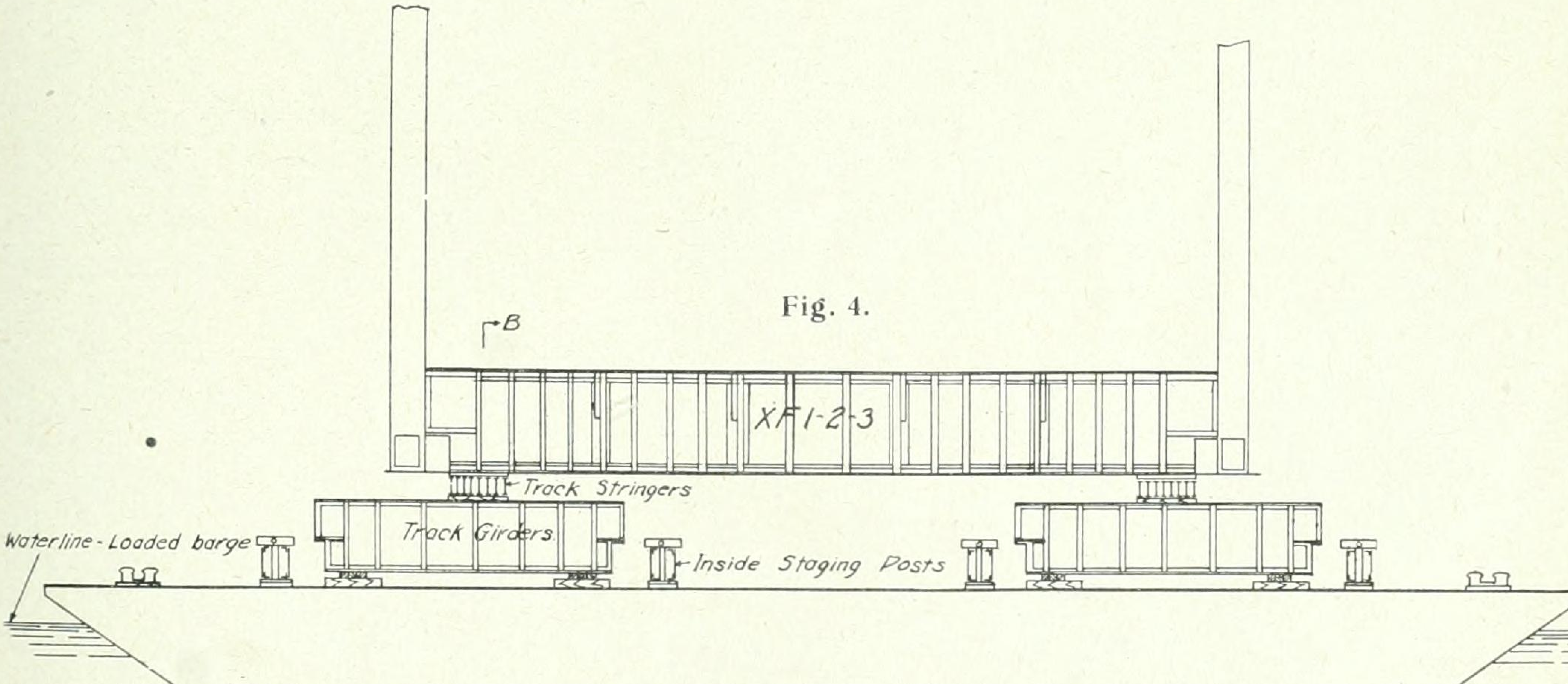
It is expected that this span will be floated into place sometime during September or October, 1916. If this programme is carried out, it will be possible to run trains over this great steel bridge, the largest in the world, and the last link in the National Transcontinental Railway system between the Atlantic and the Pacific, before the close of the year 1916.

The work is being executed under the supervision of the Board of Engineers, Quebec Bridge, composed of C. N. Monsarrat (chairman and chief engineer), Ralph Modjeski and H. P. Borden.

The St. Lawrence Bridge Company are the contractors for the superstructure, George F. Porter being engineer of construction, W. B. Fortune, superintendent, and S. P. Mitchell, consulting engineer of erection.

NOTE:—The construction of the new Quebec Bridge is replete with unique engineering methods and has been

Fig. 4.



closely followed since its beginning in the columns of *The Canadian Engineer*. Interest in this work is practically world-wide and engineers in all countries will rejoice in its successful completion. In the foregoing article Mr. Meyers gives a review of what has already been accomplished and gives some interesting information as to the methods to be employed in placing the suspended span. For further details of the substructure and superstructure of the enterprise, readers are referred to the following issues of *The Canadian Engineer*: July 14 and October 6, 1910; June 13, 1911; October 31, 1912; February 13, 1913; April 9, 1914; November 12, 1914; December 31, 1914, and September 27, 1915.—[EDITOR.]

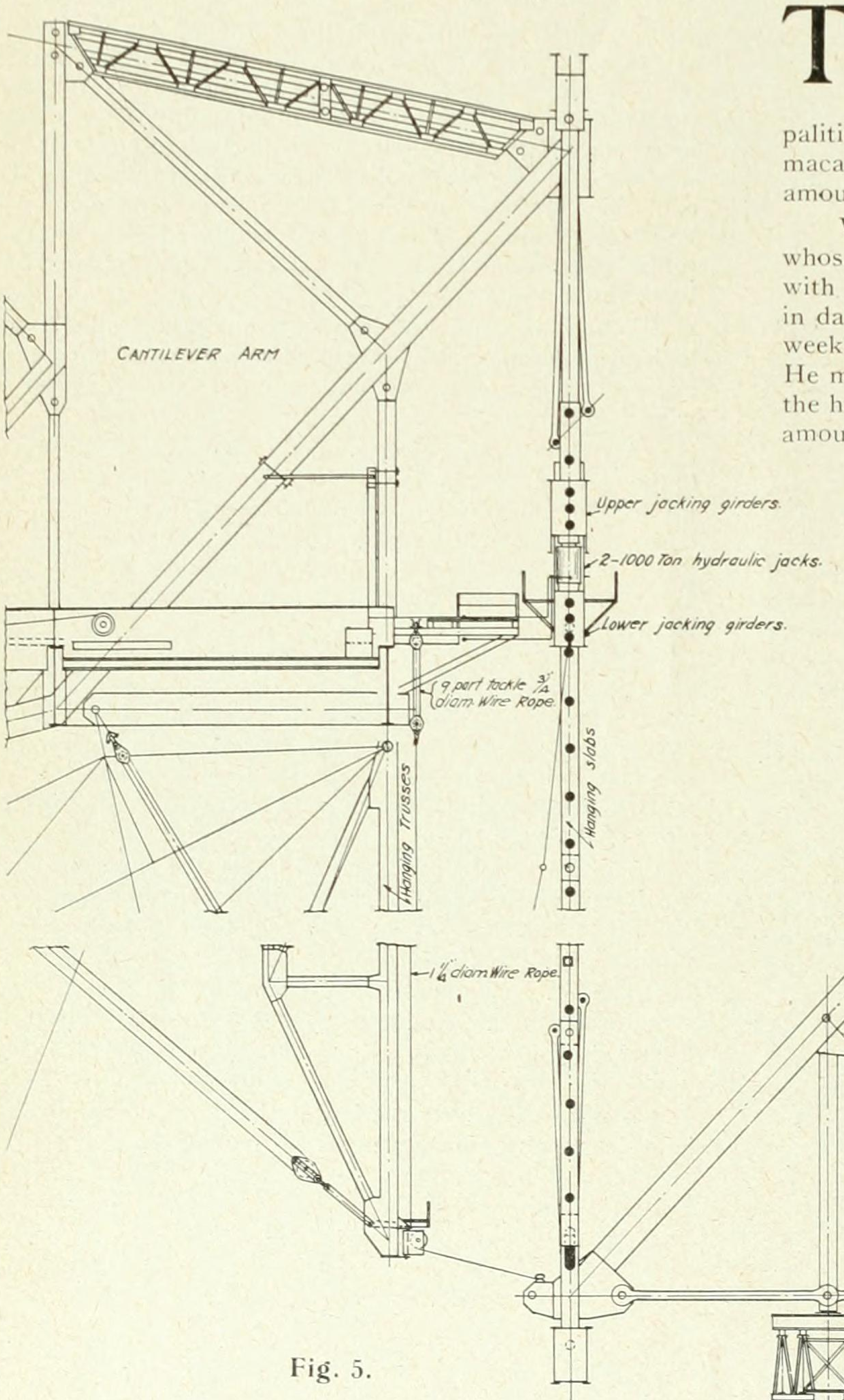
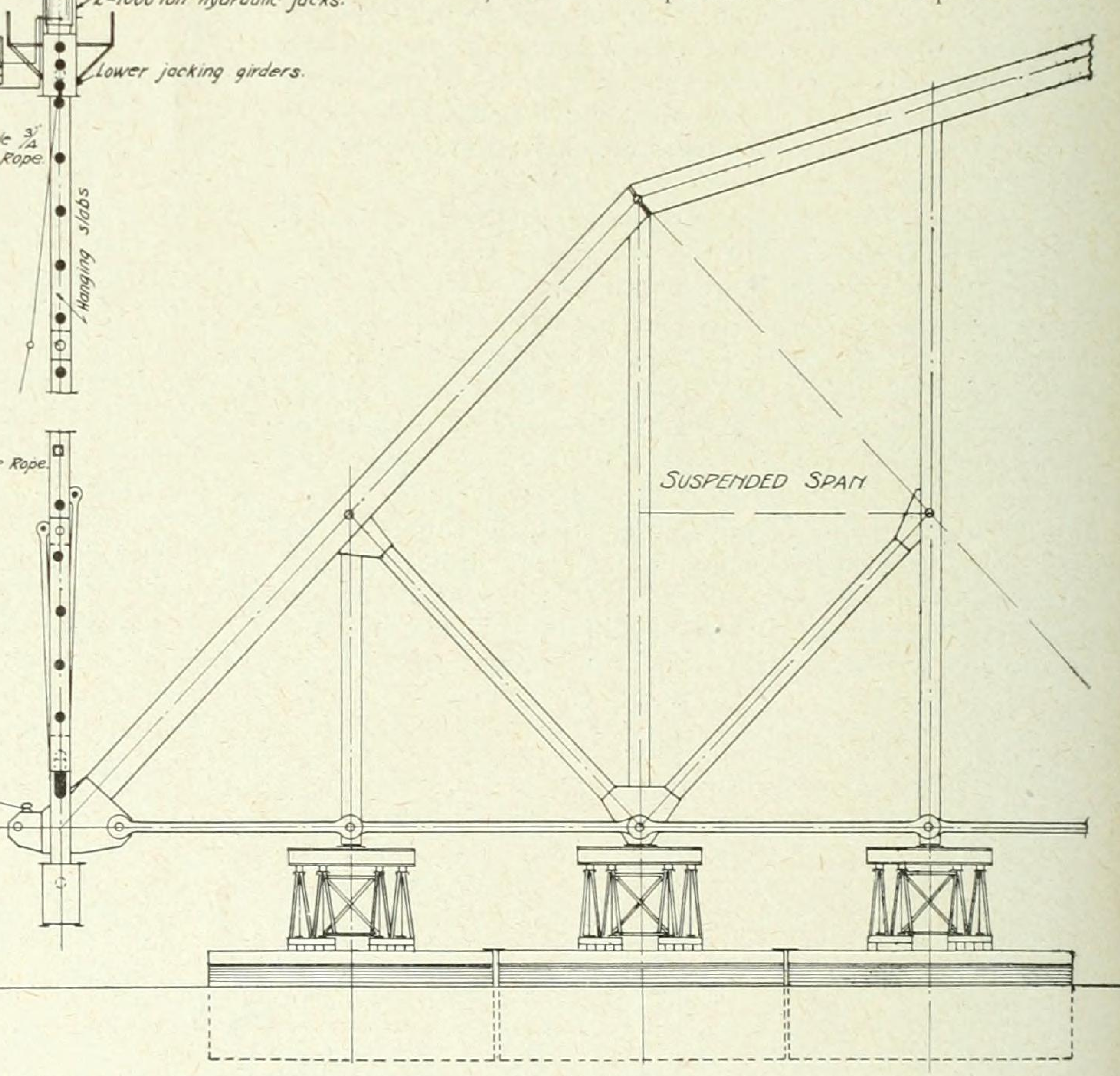



Fig. 5.

The London United Tramways Company, of London, England, last year carried 63,145,000 passengers, or 1,701,000 more than in the previous year.

PRACTICAL MAINTENANCE OF ROAD PLANTS.*

By M. E. Fafard,

Supt. of Road Plants and Construction, Province of Quebec.

THE Department of Roads of the Province of Quebec owns 57 complete macadamizing plants, besides a special plant for gravel and earth roads. These plants are placed at the disposal of municipalities, upon request. This allows municipalities to macadamize their roads without spending a considerable amount for the purchase of a road plant.

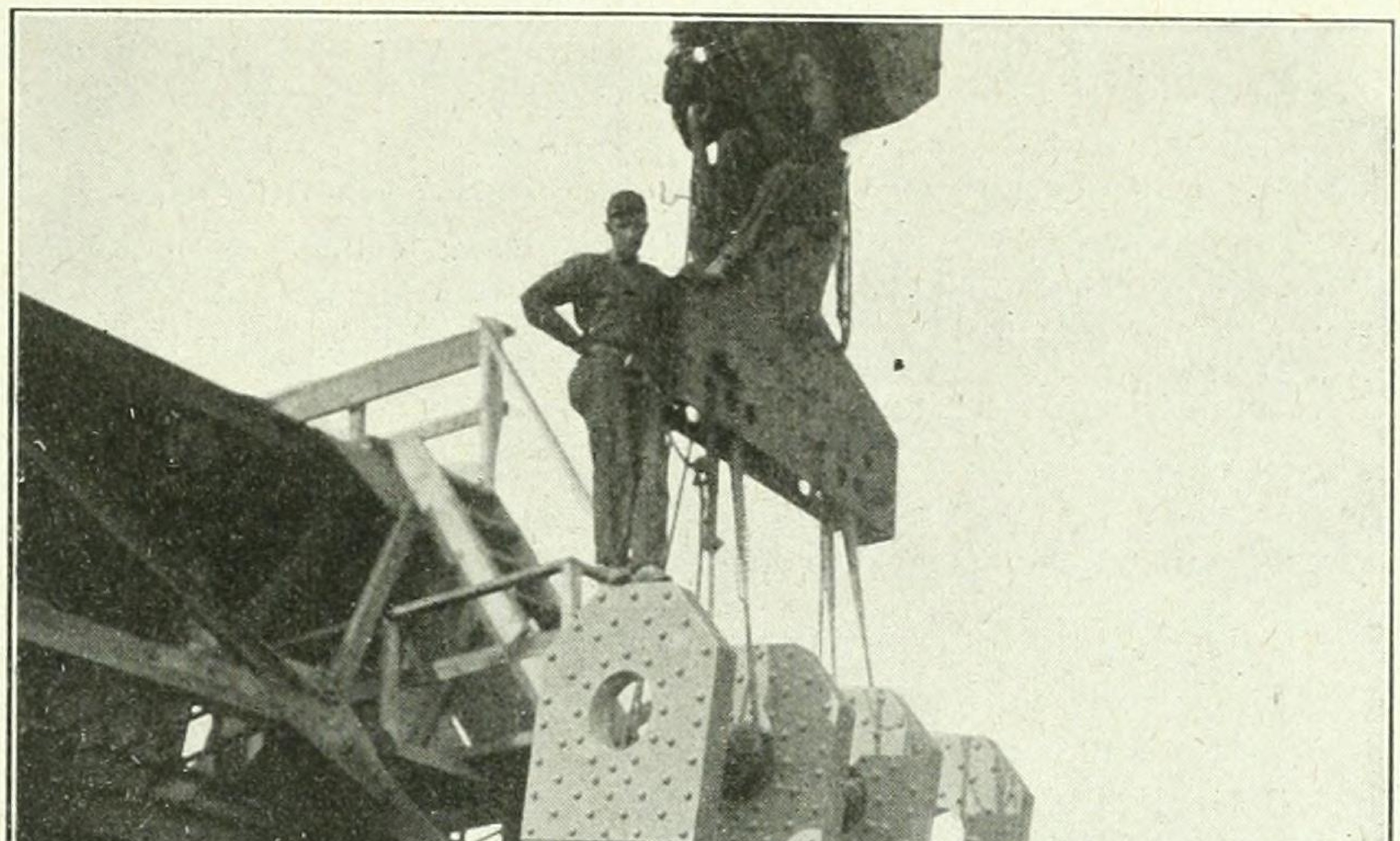
With each plant the department sends an instructor, whose duties consist in having the work done in accordance with the specifications. He must look after the plant, be in daily communication with the department, and make a weekly report, showing the work done during the week. He must show in detail what each man did, the length of the haul, the number of trips made by the carters, and the amount spent for labor for each of these operations. These reports are looked into and classified by a civil engineer. The instructor must also look after all purchases of tools and repairs to the plant. All purchases and repairs must be requisitioned on special blanks signed by him, which are given to the merchants or to those making repairs. Such requisitions must correspond with the accounts that are sent each month to the department to be audited; otherwise the accounts are refused. The instructor must also keep the department posted regarding the state of the plant and of the repairs made or to be made. The advantage given to the municipality of either renting or borrowing the government plant obliges the department

*Abstract of paper read at Third Canadian and International Good Roads Congress, Montreal.

to move many plants from one municipality to another every year.

Repairs and Maintenance.—The method followed at present has been studied and modified, and gives entire satisfaction. We have a head machine repairer, who formerly built plants and road machines, and he has with him another machine repairer of experience. They each have a tool-box containing all the necessary tools to make the repairs on the spot. They also each have a portable smith's forge, because in most cases the plants are far from villages and workshops. They also have the necessary utensils for melting metals, and casting babbitt bearings.

The large parts, which can not be repaired on the spot, are sent to the department's store of spare parts, which attends to the repairs to be made. The repairers work all the season repairing road plants, following instructions of the department. They must go only where the department orders them to go; they must report daily; every Saturday, they must, on a special form, report to the department for each day of the week, use of their time, the places where they worked, the work done each day in each place, the distance covered daily, and whether on a railroad or in a wagon; they must inform the department, by telephone, on Wednesday of each week, of the place where they are, what they have done, and what remains to be done to the plant; they must telephone to the department as soon as repairs are finished, so that they may receive instructions to go elsewhere.



Connection at Panel Point A L2—Bottom Chord, South Anchor Arm, Quebec Bridge.
—See article "The New Quebec Bridge," page 583.

At the beginning of the season before work is started, and in the fall after work is stopped, they are accompanied by four men who have experience in repairing. They are given an itinerary to repair the plants which have suffered the most damage, and to put them in good working order, because, each in their turn, all these plants have to be examined and overhauled. In the fall the head machine repairer inspects the plants which he did not see during the summer, and reports to the department the parts which will have to be repaired during the winter, and he ships to the department's store of spare parts in Quebec, all the parts which will have to be repaired. A linen tag is attached to each part, and the number of the plant from which it comes is written in ink, as well as the name of the municipality. These tags remain attached, so far as possible, to the parts while they are being repaired; thus, there is no confusion in returning the parts.

At the end of the season, the instructor must make a complete inventory, on a special form, of the machinery and spare parts which he has on hand. Moreover, he must explain in detail, for each machine, the repairs necessary. So, should the head machine repairer be unable to inspect all the machines, or should the plant be too far away, the department still knows what repairs have to be made to each machine and to each plant. The spare parts which can be repaired are sent to the store. Before they arrive a new part is shipped to the plant, and the department only charges the municipality with the cost of repairs. This is very economical and also often prevents work being stopped in the busy season. To obtain this result, we require the instructor to telephone to the department every time the plant is out of order to such an extent that he cannot repair it. It is his duty to find out, before telephoning, the exact number of the part. If it has no number, he must be able to describe it accurately, giving its size, etc., so that we can send the right part. If he is unable to give the necessary information, he has to pay for the telephone or the telegram, and is likely to be dismissed, as this would denote carelessness or incompetence.

Our store of spare parts carries a stock of the parts most in use, as we now know the parts which wear out quickest or are likely to break often. Jaws, metals, packings, fittings, oil, etc., are specially chosen. The store has over $20,000 worth of stock. Three employees receive and ship goods. By systematized accounts each part, whether sent from the store, from the shop or by a manufacturer, is charged to the plant which has asked for that part. A record is kept of everything coming in to the store, and nothing is delivered unless requisitioned by the office on a special form.

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Expansion Joints and Traction Trusses, Quebec Bridge

Special Devices Providing for Changes in Length of Superstructure and Its Parts Under Varying Conditions of Erection, Temperature and Stress—Sliding Rail Expansion Joints Allow Motion of 17½ Inches between Suspended Span and Each Cantilever Arm

By ARCHIBALD JOHN MEYERS
Chief Draftsman, Board of Engineers, Quebec Bridge

IN all steel bridges of considerable span it is necessary to consider the effects upon the structure of changes in length of its component parts or members from varying temperatures and loads. Any lengthening or shortening, great or small, of a main member of a truss has a proportionate component effect on the distance between the truss reaction points. It is the general practice to provide for a change in these distances by the use of sliding or rolling joints, in which free and unhindered motion is allowed, except for the effect of friction. If such expansion joints are not provided, the truss reaction points become fixed in position, the lines of action of the reaction forces, from the weight of the structure and its superimposed loads, are no longer vertical, the supporting piers or abutments are compelled to resist end thrusts or pulls from the deforming structure and the effect of such end thrusts or pulls would not only have to be considered with regard to the piers and abutments, but the resulting stresses induced in the truss itself would have to be calculated and provision made for them.

In the case of a short, simple or cantilever span, it is usually only necessary to provide for a change in the centre to centre distance of the truss reaction points, and a change in the overall length of the floor system, any relative motion of the intermediate panel points of the trusses with reference to the bridge floor from differences of temperature or from varying stresses in the members of the truss or floor being too small to be considered. In the case of larger spans, however, it is necessary to examine the effects of this relative motion between the intermediate points of the trusses and the floor system, and to provide intermediate expansion joints for the bridge floor, in order to relieve the severe bending stresses which might otherwise be induced in the flanges of the transverse floorbeams, which form the connecting link between trusses and the bridge floor.

In addition to the secondary bending stresses, just mentioned, in the flanges of the floorbeams, these flanges have, in small spans, usually to resist the effect of longitudinal forces from a braked train or the pull on the track of the locomotive drivers and the rolling frictional resistance of the train following. In larger spans these longitudinal forces should be resisted by special transverse traction trusses in the plane of the floor system, the duty of which is to transfer these longitudinal forces to the bridge trusses and consequently relieve, to a great extent, the floorbeam flanges from resisting bending forces for which they are not well adapted and which, if necessary, they can only resist in a very uneconomical manner.

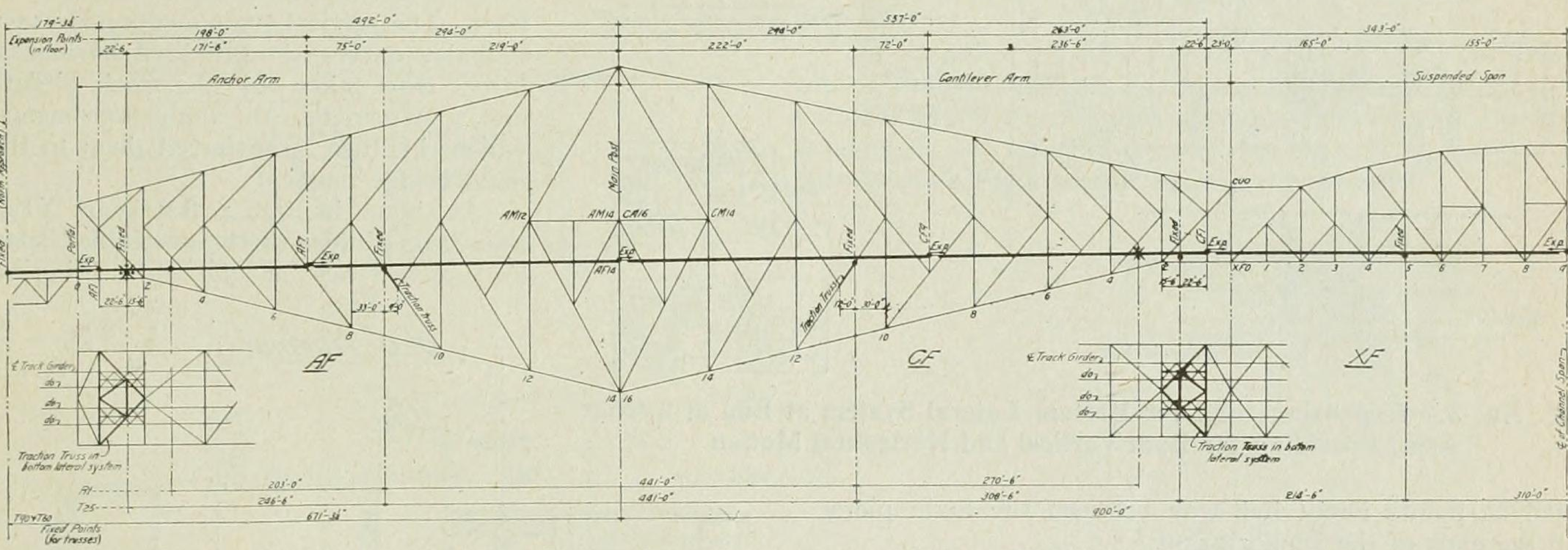


Fig. No. 1.—Elevation of Quebec Bridge Showing Location of Espansion Joints and Traction Trusses for Floor and Truss Systems

In the case of the Quebec Bridge, provision for change in length of the trusses of the main span—that is, the trusses of the cantilever arms and suspended span,—was made at the junction points between the cantilever arms and the suspended span. Provision for change in length of the floor and lateral systems of the main span was also made at the same points, but additional intermediate sliding joints, to accommodate the relative motion between the floor system and the bridge trusses, were provided in the bridge floor at the centre of the suspended span, at points directly over the main piers and at points about

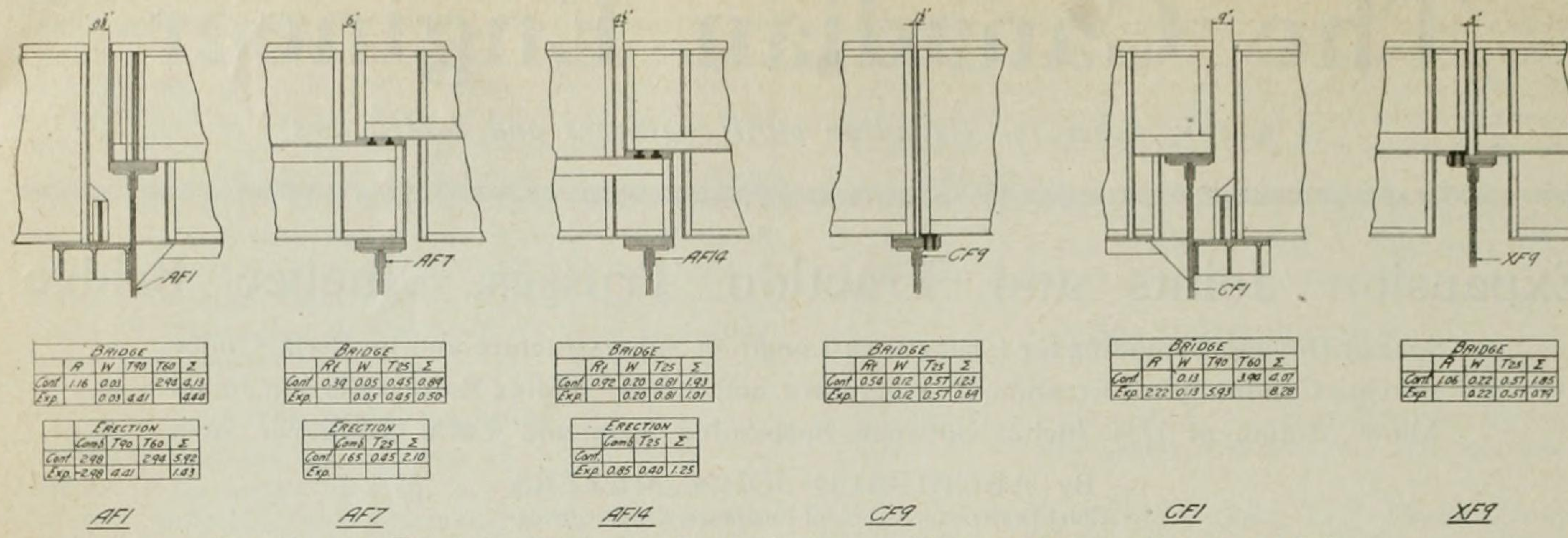


Fig. No. 2.—Expansion Joints for Track Girders at Main and Intermediate Panel Points

half-way between the main piers and the ends of the cantilever arms. For the anchor arms, provision for change in length of the anchor arm trusses and floor and lateral systems was made at the end of the anchor arms and intermediate sliding joints for the floor system were provided at points about half-way between the main piers and the ends of the anchor arms.

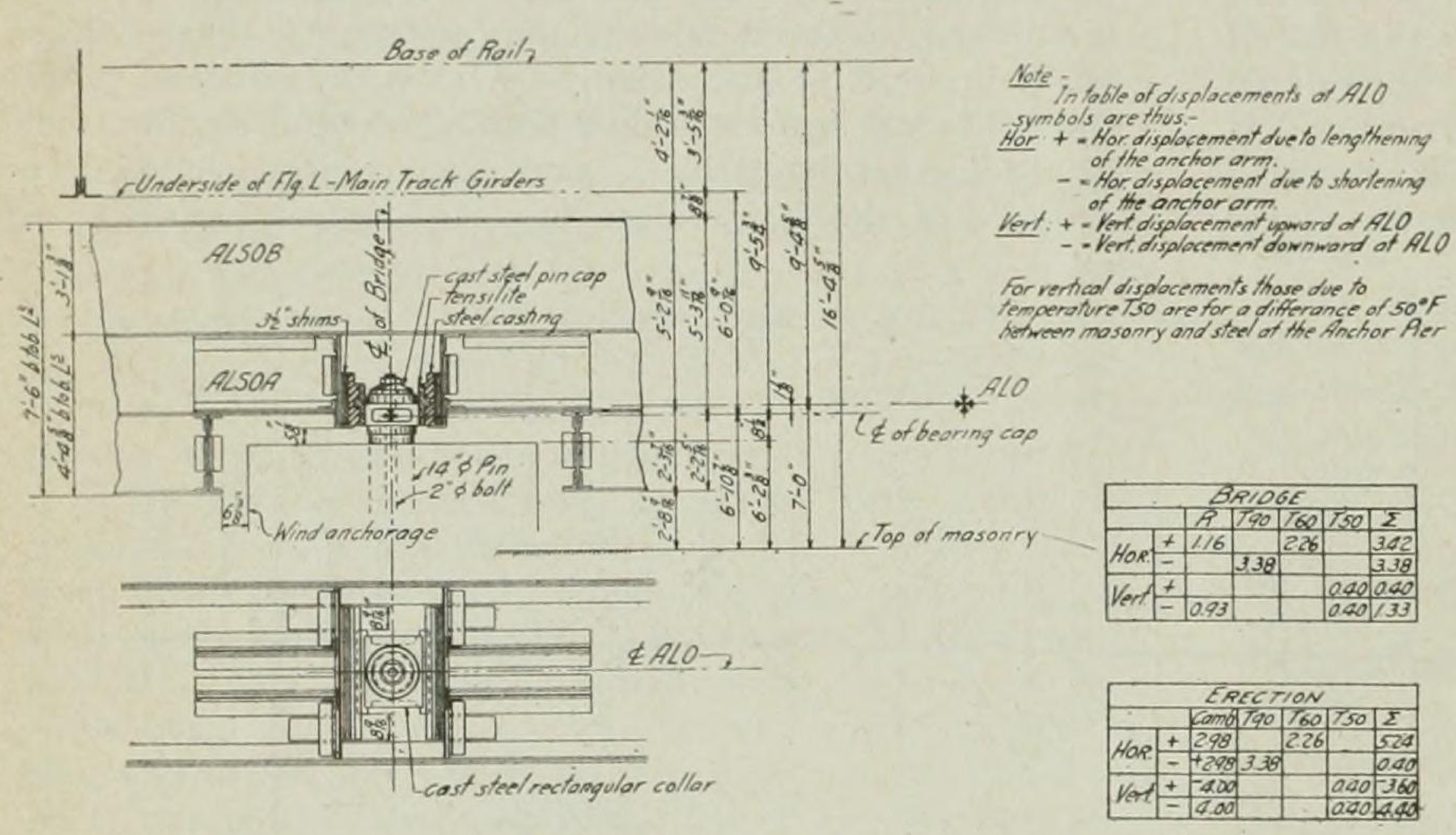
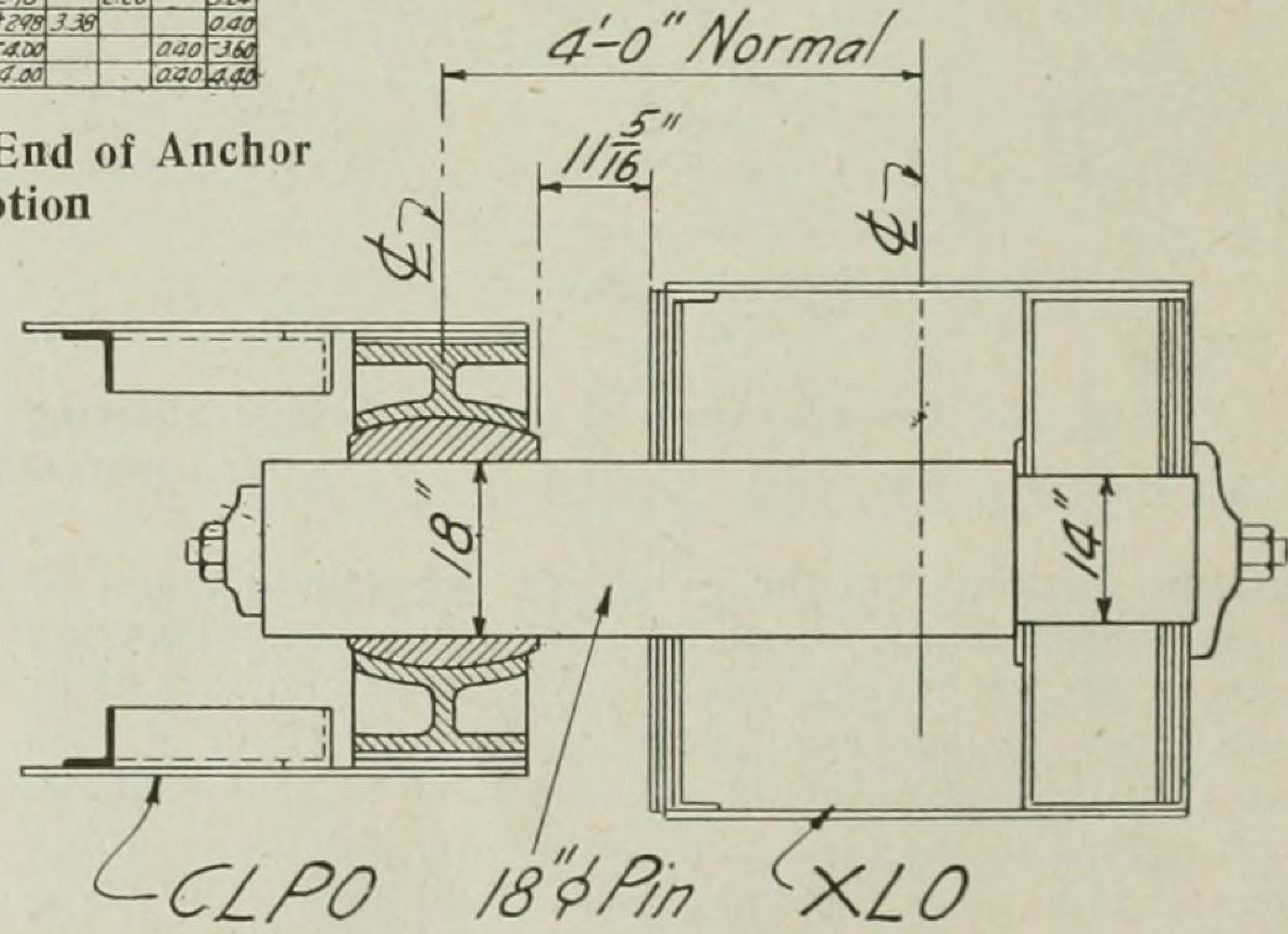


Fig. No. 3.—Expansion Joint for Bottom Lateral System at End of Anchor Arm, Providing for Both Vertical and Horizontal Motion

In order to properly transmit to the bridge trusses the longitudinal horizontal forces from moving live loads on the floor, each section of the floor, between sliding joints, was rigidly connected to the main bridge trusses by means of transverse traction trusses introduced in the sway and lateral bracing systems of the bridge. The positions of each traction truss and the adjacent sliding joints are shown in Fig. 1. They were interdependent and had to be so chosen so as to reduce as much as possible the bending stresses in the flanges of the main floorbeams. The positions of the fixed points were also governed to a large extent by the practicability of inserting a truss to connect the main bridge trusses with the floor system.

When the bridge floor was near the plane of the bottom laterals, as in the suspended span and along the horizontal bottom chords at the end of the cantilever and anchor arms, this was easily accomplished. The track girders were riveted to the bottom laterals at the points marked "fixed" in Fig. 1, and complete transverse trusses were introduced in the lateral system at these points by supplementing the bottom lateral members with additional members to form a complete truss system, designed to receive the horizontal longitudinal forces at the panel points and transmit these forces axially to the bottom chords of the main trusses. Midway between the ends of the cantilever and anchor arms and the main piers, inclined transverse trusses were introduced in the sway bracing for the compression diagonals which formed part of the sway bracing system. The track girders were riveted to the top chords of these trusses and delivered to them a diagonal component of the horizontal longitudinal forces acting on the floor. The vertical components necessary to balance these longitudinal horizontal forces were taken by the track girders and transferred to the main floorbeams, which in turn transferred them to the main bridge trusses.

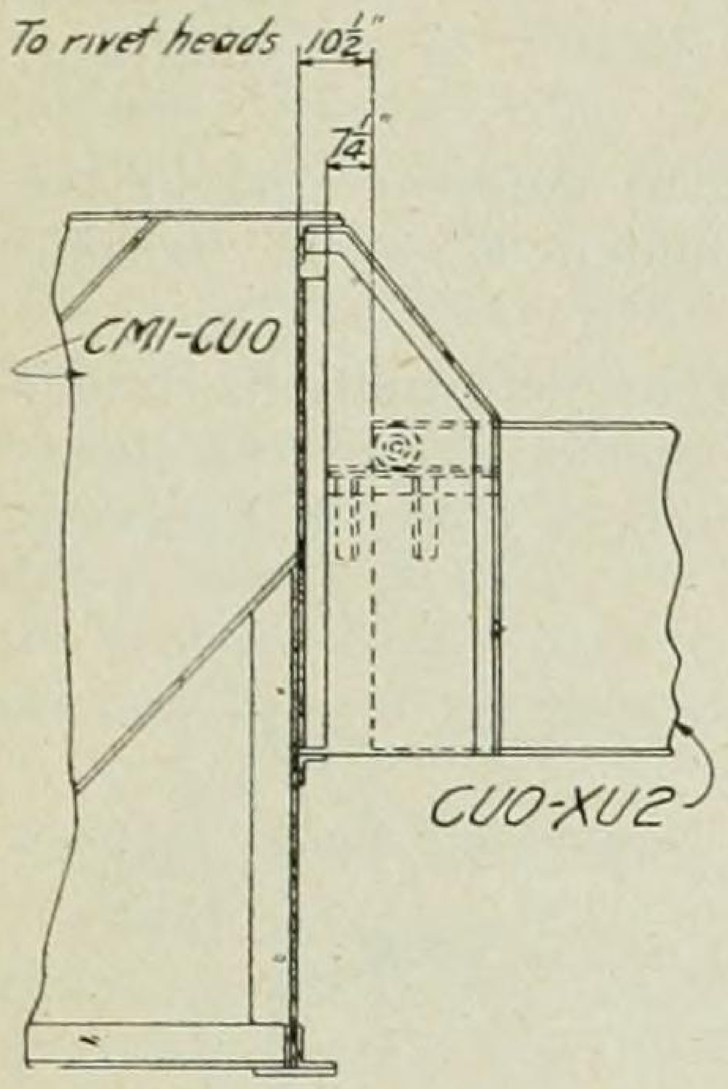
As shown in Fig. 2, floorbeam XF9, the track girders of the suspended span are notched out at the ends, bringing



BRIDGE	R	T90	T60	Σ
Cont.			3.94	3.94
Exp.	2.22	5.93		8.15

Fig. No. 4.—Expansion Joint for Bottom Lateral System at Connection Point Between Cantilever Arm and Suspended Span, Providing for Relative Motion in Any Direction

the elevation of the bearings, on the top flanges of the main bridge floorbeams, about on the line of the neutral axis of the girders. For this reason the centre to centre distance of the floorbeam top flanges does not change under live load. The bottom chord, nickel-steel eyebars of the suspended span, with large unit stresses from live load, stretches considerably and in consequence the top flanges of the floorbeams are deflected, amounts which are practically in direct proportion to the distance of the floorbeams from the fixed points of the floor system or the points of location of the transverse trusses. In order to reduce this lateral deflection of the floorbeam flanges from this relative motion of the suspended span bottom chord panel points with reference to the floor system, to a minimum, the track girders were manufactured to such a length that the floorbeam flanges would be straight when the suspended span was carrying full dead load and a uniform distributed load equal to one-half the live load. The floorbeam flanges will therefore be deflected laterally equal amounts, opposite in sign, under full live load and with no live load on the span. Inasmuch as any floorbeam receives its maximum live load stress from engines placed directly over it, it could happen that at the same time the remainder of the span might be fully covered with live load or might have no live load at all. That is, any floorbeam may receive its maximum stress from vertical loads with full live load stress in the bottom chords of the span or with practically no live load stress in these chords. Therefore, by manufacturing the track girders in the shop so that the floorbeam flanges would be straight under dead load and a uniform distributed load on the span equal to one-half the live load, the lateral bending stress, co-existing with maximum live load stress in the floorbeam flanges, was reduced to a minimum. The track girders were erected after the suspended span was hoisted into place and when placing them the floorbeam flanges were given an initial deflection corresponding to the condition of no live load on the span.

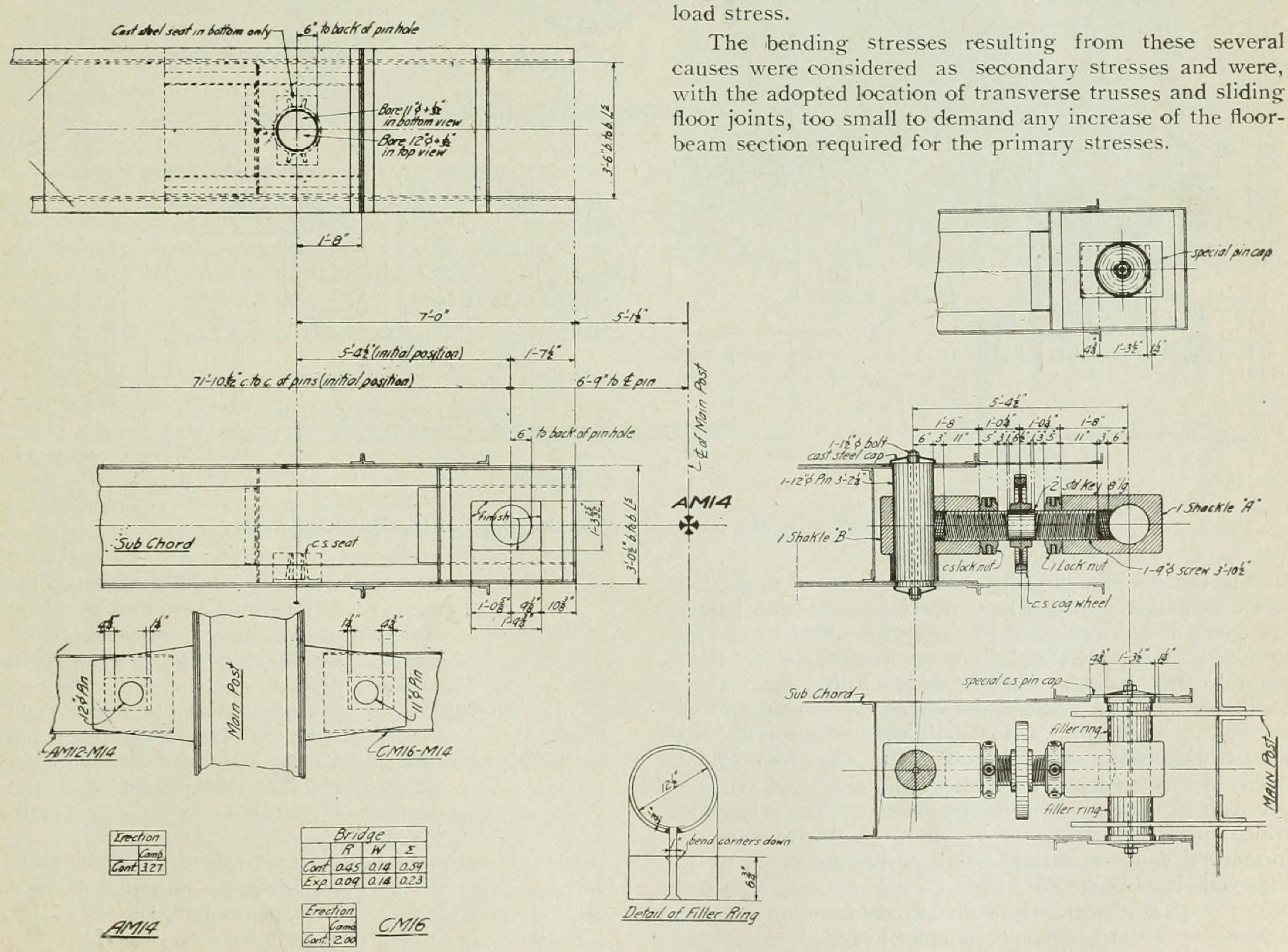


Bridge	R	W	T90	T60	Σ
Cont.		0.23		3.94	4.17
Exp.	2.46	0.23	5.93		8.62

Fig. No. 5.—Expansion Joint for Top Chords at Point of Connection Between Cantilever Arm and Suspended Span

The specification demanded that stresses arising from a difference of temperature of 25° Fahr. between the steel of the bridge trusses and the steel of the bridge floor must also be calculated and taken into consideration. The bending stresses in the flanges of the floorbeams from the relative motion of the suspended span bottom chord panel points with reference to the floor system, due to this assumed difference of temperature, was therefore calculated and considered as co-existing with maximum live load stress.

The bending stresses resulting from these several causes were considered as secondary stresses and were, with the adopted location of transverse trusses and sliding floor joints, too small to demand any increase of the floorbeam section required for the primary stresses.



Erection	
	Camb.
Cont.	3.27

Bridge	R	W	Σ
Cont.	0.45	0.14	0.59
Exp.	0.09	0.14	0.23

Erection	
	Camb.
Cont.	2.00

Fig. No. 6.—Adjustable Erection Joint Provided in Main Trusses at Panel Point AM14

Similar considerations for the cantilever and anchor arms governed the location of the sliding joints and transverse trusses to which the floor system was fixed. The floor system is there subdivided by sliding joints into sections of about equal lengths not exceeding 300 ft. and each section is provided with a transverse truss. Where the track girders are altogether above the floorbeams, with the bottom flanges riveted to the top flanges of the floorbeams, the moving load track girder flange stresses increase the centre to centre distance of the floorbeam flanges and this increase had to be taken into consideration when calculating the amount of expansion for which to provide. The relative motion of the cantilever and anchor arm truss panel points with reference to the floor system was obtained from Williot's displacement diagrams.

lower or tension flange of the main track girders while carrying live load where they rest on top of the main floorbeams. The deformations calculated on are based on an assumed average flange stress of 5,000 lbs. per square inch throughout the length indicated thus * in the diagram, Fig. 1.

W = displacements due to deformations in the truss members under a 30-lb. normal wind load.

T_{90} and T_{60} = displacements due to deformations under temperature. Expansions due to a shortening of the members under a temperature variation of 90° Fahr. Contractions due to a lengthening of the members under a temperature variation of 60° Fahr. Normal temperature is assumed to be 60° Fahr.

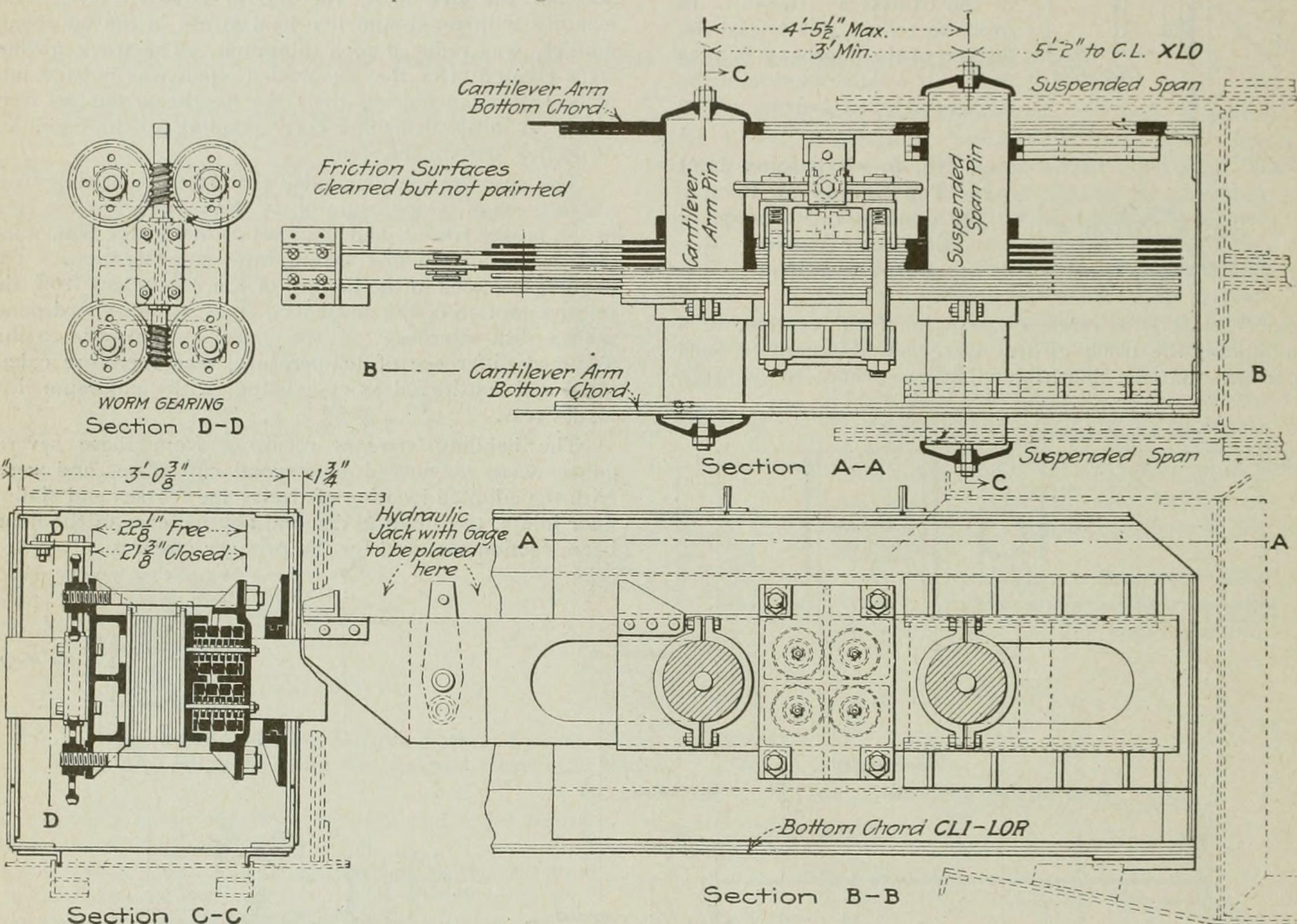


Fig. No. 7.—Traction Brake for the Suspended Span of the Quebec Bridge

The detail amounts which make up the total expansion and contraction provided at the various expansion points are given in the tables of Figs. 2 to 6, inclusive. The openings shown exist under normal conditions of temperature and loading. That is, with full live load on the cantilever arm and suspended span and a temperature of 60° Fahr. The terms "expansion" and "contraction" are used in the tables with reference to the expansion joints only. An expansion is an increase and a contraction is a decrease in the normal openings shown. The elements which appreciably affect the expansion joints are as noted in the tables for the various points and are represented by the symbols as follows:—

R = displacements due to deformations in the truss members under live load.

R_t = an allowance for the lengthening of the

T_{25} = displacements due to a temperature between the floor and truss of 25° Fahr.

Camb = displacements which occur during erection due to the initial shop camber of the members or to other erection camber adjustments.

Σ = the total displacement due to a combination of the above elements as noted at each point. The displacements are shown for both bridge and erection conditions.

(Continued on page 119)