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CABLE TOWAGE ON CANALS AND RIVERS --- THE HYDRAULIC CANAL LIFT AT LES FONTINETTES, FRANCE --- THE NAVIGATION OF THE SEINE FROM PARIS TO THE SEA --- THE PNEUMATIC FOUNDATIONS AT GENOA AND AT LA PALLICE, THE PORT OF ROCHELLE.

BY

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CABLE TOWAGE FOR BOATS ON CANALS AND RIVERS.

The principal difficulties in cable towage arise from the following circumstances:—

First. That owing to the obliquity of the towrope, the boat tends, constantly, to pull the cable out of the grooves of its guiding pulleys. Some means, therefore, must be found to confine the cable within these grooves.

Second. When the towrope comes to a pulley, it passes into the groove with the cable; while the latter should be confined to the groove, the former should immediately slip out without carrying the cable with it. These two contradictory conditions render the solution of the problem extremely difficult, especially in going around concave curves.

Third. The joint between the towrope and the cable should be such that the former cannot be twisted upon the latter by the rotation of the cable; otherwise the towrope would be wound upon it, and could not then be detached from it.

Fourth. The towrope must be easily detached from the cable at any instant,—an operation of some difficulty, as it is done by a cord 60, 80, or 150 metres long, which forms kinks by being dragged on the ground or through the water.

Fifth. Starting should be progressive, although the boat is made fast suddenly to a cable in motion.

System adopted.—The system of cable towage introduced by M. Maurice Lévy solves all these difficulties as follows:—

The first condition of success was to avoid all irregular motions of the cable. For this purpose, instead of determining the weight and tension of the cable according to the usual rules governing telodynamic transmission, he determines them by the double condition of maintaining the oscillations of the cable, whether horizontal or vertical, within certain prescribed limits, which can be made as small as may be desired. This requires that the cable should be heavy (about 3 kilogrammes per metre), and that it should be set up with an initial tension incomparably greater than that usually adopted in such cables. This tension, as well as the weight of the cable, depends on the length of circuit and the speed required for the boats.

For the system constructed between Paris and Joinville, the weight and tension were determined by the condition that the deflection caused by the oblique and irregular haul of the boat, should not exceed ten centimetres. This was accomplished by giving to the cable a weight of 3.65 kilogrammes per running metre, and a permanent tension of 5 tons.

The cable as shown by Figs. 1–3 has a breaking strength of 50 tons.

Advantages of this tension.—A boat of three hundred tons attached to the cable at any point exerts a pull of from 100 to 150 kilogrammes, which is added to the permanent tension of 5 tons; this addition produces scarcely any local deflection.

The mean force, F, required to impart to a boat at rest, the velocity, V, of the cable is found as follows: Let W be the weight of the boat, g the acceleration of gravity (9.81 metres), and l the length of the towline.

$$F = \frac{P\,V^2}{2gl}$$

If $P = 300$ tons, $V = 1$ metre per second, and $l = 100$ metres, then $F = 150$ kilogrammes (neglecting the resistance of the water as compared with the inertia of the boat).

The supporting and guiding pulleys.—The vertical supporting pulleys are 0.80 metre in diameter, and have a depth of groove of 0.20 metre. A roller on the top of the pulley prevents the cable from leaving it, but the towrope attachment would catch between the pulley and the guide roller. To obviate this, openings are made on the water side of the pulley grooves, consisting of two notches extending the whole width of the groove, and having their edges curved in the form of the involute of a circle (Figs. 8–9); other notches are added having a depth slightly exceeding the thickness of the towrope. When the towrope coupling enters the groove, it is caught by one of the notches, carried over the pulley, and escapes, as shown in the figure.

The passage around convex bends in the banks presents no difficulty; it is accomplished with the aid of horizontal pulleys turning round vertical pivots solidly fixed in metallic supports. These pulleys have no need of notches, as the cable, with its towrope coupling, passes only on the water side, and the latter thus escapes. On account of the great tension of the cable there is no danger that the towrope will pull it off.

The passage around concave angles is, on the contrary, an extremely delicate problem. In that case, the cable passing round the pulley on the land side, the towrope joint cannot clear itself unless we adopt very special and precise arrangements.

This problem has been solved in several ways. The first method is shown in Figs. 10–11.

In the elevation, the plane of the lower pulley is supposed to be revolved to coincide with that of the upper one.

Two vertical pulleys are taken, having a common tangent, to the bottom of their respective grooves, one of the pulleys being in the plane of the part coming on, and the other in that of the part going off. The cable rolls upon the first (which we may suppose to be the upper one) and descends vertically along the common tangent, and then passes on to the second.

Fig. 10.

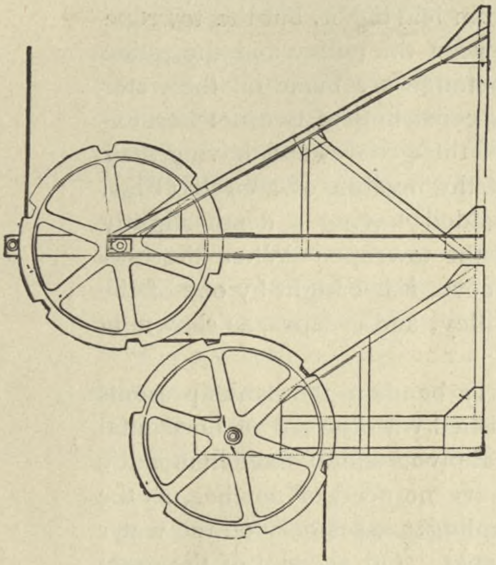


Fig. 11.

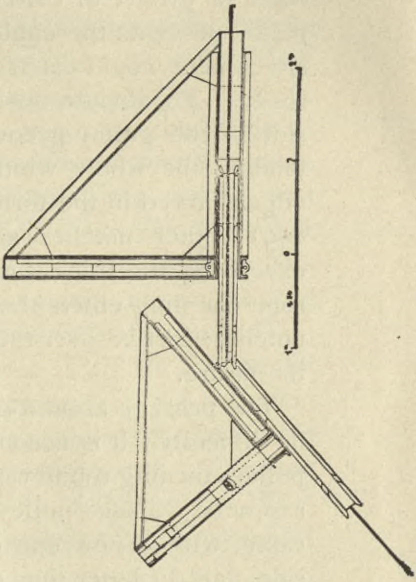


Fig. 8.

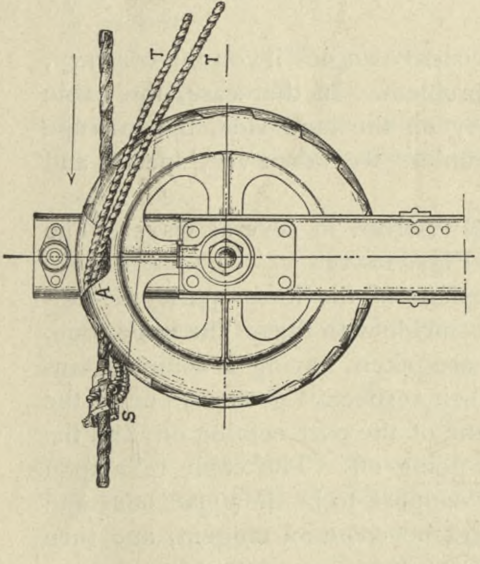
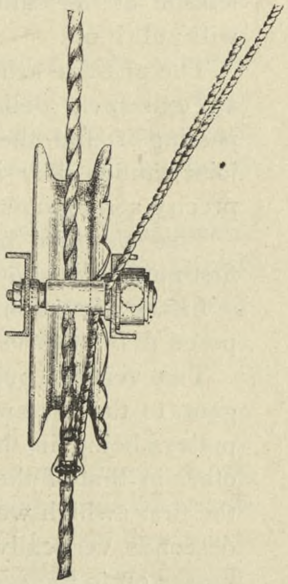


Fig. 9.



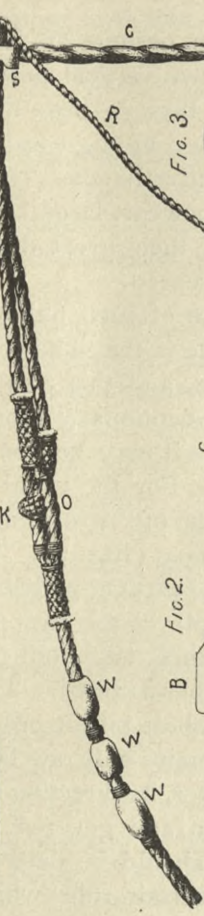
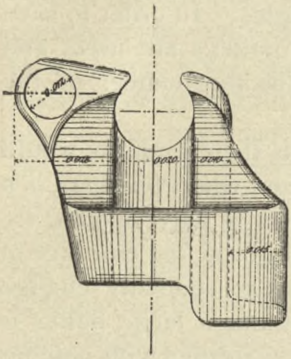


FIG. 1

FIG. 3.

Fig. 4.



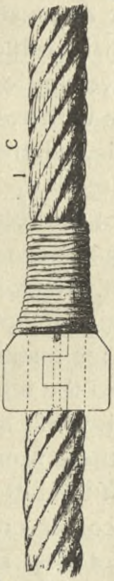


FIG. 2.

Fig. 6.

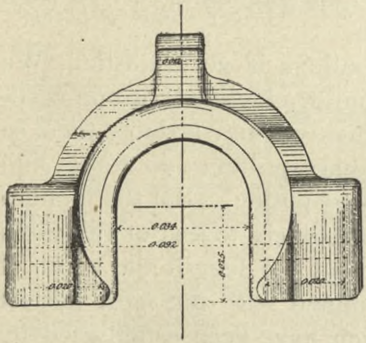


FIG. 5.

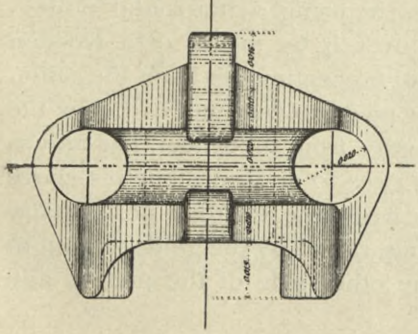
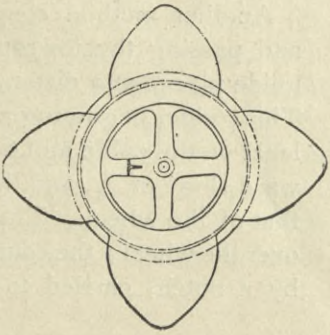


Fig. 7.



This solution permits any change of direction whatever by the aid of two vertical pulleys, and consequently it suffices to notch these pulleys like the supporting pulleys to let the towrope coupling escape. But it subjects the cable to two consecutive bends at right angles. In order to save the cable from wear, large 2-metre pulleys are used, and on account of their great dimensions the number of the notches is increased.

The expense of such pulleys with their supports would be considerable if they had to be used wherever there is a concave angle, and this arrangement is only suitable for curves with exceptionally short radii, or at the entrance of tunnels, where it may be convenient to suddenly change the direction. For the usual deviations a large pulley is used of the type of 1.40 or 2 metres, furnished with notches on the upper face (Fig. 7). This solution is derived from that of the two vertical pulleys.

The principle of the two pulleys is very elastic. We may, for instance, take both pulleys inclined, or one vertical and the other inclined. Then we may arrange them so that the first shall be an ordinary pulley 0.60 metre, and then there remains only one large pulley. But the inclination of the latter, its direction relatively to that of the cable as it comes on and goes off, and the length and width of the notches, should be determined with the most perfect precision by certain rules which have been established by theory and experiment.

Another method consists in using a horizontal pulley, and passing the towrope over it by means of a wooden guide placed at a distance of 60 centimetres from the cable. This guide, beginning at a point 20 centimetres below the level of the cable and 6 metres from the wheel, has an upward slope of $\frac{1}{10}$, and thus rises 30 or 40 centimetres above that of the wheel. This carries the towrope horizontally over the wheel; the coupling, raised by the guide, is caught by a notch, carried to the other side of the pulley, and escapes. The economy resulting from this arrangement is considerable, amounting to three hundred dollars per kilometre.

The rotation of the cable.—Towrope joint.—A cable in motion is constantly turning like a screw in its nut. This motion can be easily observed. If we stick a piece of paper to the cable, it will make a complete revolution in going a distance of from 12 to 14 metres. After passing certain angles, the direction of the rotation will be reversed, so that the cable twists in certain portions, and untwists in others, without any precise law. It follows from this that the towrope cannot be made fast directly to the cable, for if it were, the former would be completely wound upon the latter after going a distance of from one to two hundred metres. This fact renders it difficult to join the two. The joint should consist of two pieces having distinct and independent motions; one solidly attached to the cable, and the other forming a loose ring about it. The towrope is attached to the second piece and pulls it against the first, which serves as a stop; this pull keeps the ring fixed while the cable and the stop rotate together.

Details of the joint adopted.—Figs. 1–6. The towrope grip consists of a malleable iron saddle. Figs. 4–6, 60 millimetres long, formed of a demicylinder, S, 32 millimetres in diameter, and terminated by vertical tangents 14 millimetres long; the cable being 30 millimetres in diameter, there is a play of 2 millimetres between it and the saddle. The posterior portion of the saddle is hollowed for a length of 10 or 12 millimetres, so as to fit upon the corresponding part of the stop. The stop is thus boxed in for three fourths of its perimeter, and in this position the saddle cannot be lifted vertically off of it, but can only be pulled off by turning about its posterior edge. This is accomplished by pulling a cord, R, attached to the pommel P. This saddle is encircled by the tackling-rope, T, which has a "Turk's head" K, at one end, and a loop for making fast to the towline, at the other; its length is 4.50 metres. At a distance of about 3 metres from the knob there is a cut splice or buttonhole, O, to hold K. Lead beads, W, W, W, strung on the tackling rope just below O, serve as weights to draw the saddle back onto the cable after it has been pulled off by the releasing cord, R.

To hook on a boat.—After making fast the towline to the tackling loop, and seeing that the releasing cord is attached, the boatman goes on shore, saddle in hand, puts it upon the cable, buttons in the "Turk's head," and returns to the boat. He need not hasten, for the saddle will slide along the cable until it meets the first stop. If he is not ready to start, he makes fast the releasing cord to the boat, and slackens the towline before going ashore. Then each stop pulls the releasing cord, which makes the saddle jump over the stop. The saddle momentarily quits the cable, but the weights, W, W, bring it back; this prevents any friction between the tackling rope and the cable.

Hooking on, and management by a single boatman.—After hooking on to the cable, the method of starting is as follows: The boatman first sets his rudder so as to steer away from the shore, and pushes off the bow; then he loosens the releasing cord and winds the towline crosswise ∞ about the two bitts. When the stop takes hold and the boat begins to move, he slackens on his towline, slowly letting out 10 or 15 metres until the boat acquires the velocity of the cable; this done, he goes to the helm. The steering is much simplified by the uniformity of the pull. Mr. Lévy states that he has frequently seen boats carrying a party of several persons, and all of them in the cabin: the boat was taking care of itself, without any steering at all.

Automatic starting.—The bitts being well greased, the boatman takes a number of loose turns about them, and then as the towline tightens it slips on the bitts. The haulage in this way may be made automatic with the two bitts well greased, and just the proper number of turns taken about them to maintain the normal haul; the towline will then slip automatically, if the boat meets with an unexpected resistance.

Stopping en route without casting off from the cable.—If during the journey it is necessary to stop or slacken speed, it is done by making fast the releasing cord and slackening the towline. Then the pull on the releasing cord causes the saddle to jump over the stops as fast as they come along.

To cast off from the cable.—The boatman first makes the saddle jump over the stop, which is done by the haul of the boat; then pulling on the releasing cord, he draws the saddle along the cable until it is opposite to him; the towline then is perpendicular to the cable; continuing to pull, the saddle quits the cable, leaving the "Turk's head" resting upon it; then by giving a sudden jerk, the "Turk's head" is drawn out of the splice O, the saddle falls to the ground and is pulled on board. It may be noticed that the saddle does not touch the cable during the haul; it rests with its cupping on the stop, and thus does not wear the cable.

Method of circuits.—In an extended application, the circuits may cover without difficulty a distance of from 15 to 18 kilometres, and as the two machines driving two consecutive circuits may be united, it follows that the machines may be from 30 to 36 kilometres apart.

The machines thus placed, two and two in the same shed, can mutually help each other in case of accident to either. Continuous towage can go on with slightly diminished velocity, it is true, but with no stoppage.

The power used depends on the velocity desired. With a velocity of 0.70 metre per second, the velocity of horse towage, it requires only two horse power to draw a barge loaded with 350 tons, and one horse power for lighter loads.

If we adopt the velocity of one metre per second, we must multiply these figures by 2.25. One half a horse power per kilometre should be added for power consumed by the unloaded cable. Under these conditions for a traffic of 1,000,000 tons per year, with a velocity of one metre per second, two machines of from 45 to 50 horse power would be required for each distance of 30 kilometres.

The cost of the plant depends on the dimensions of the barges, their number, and velocity.

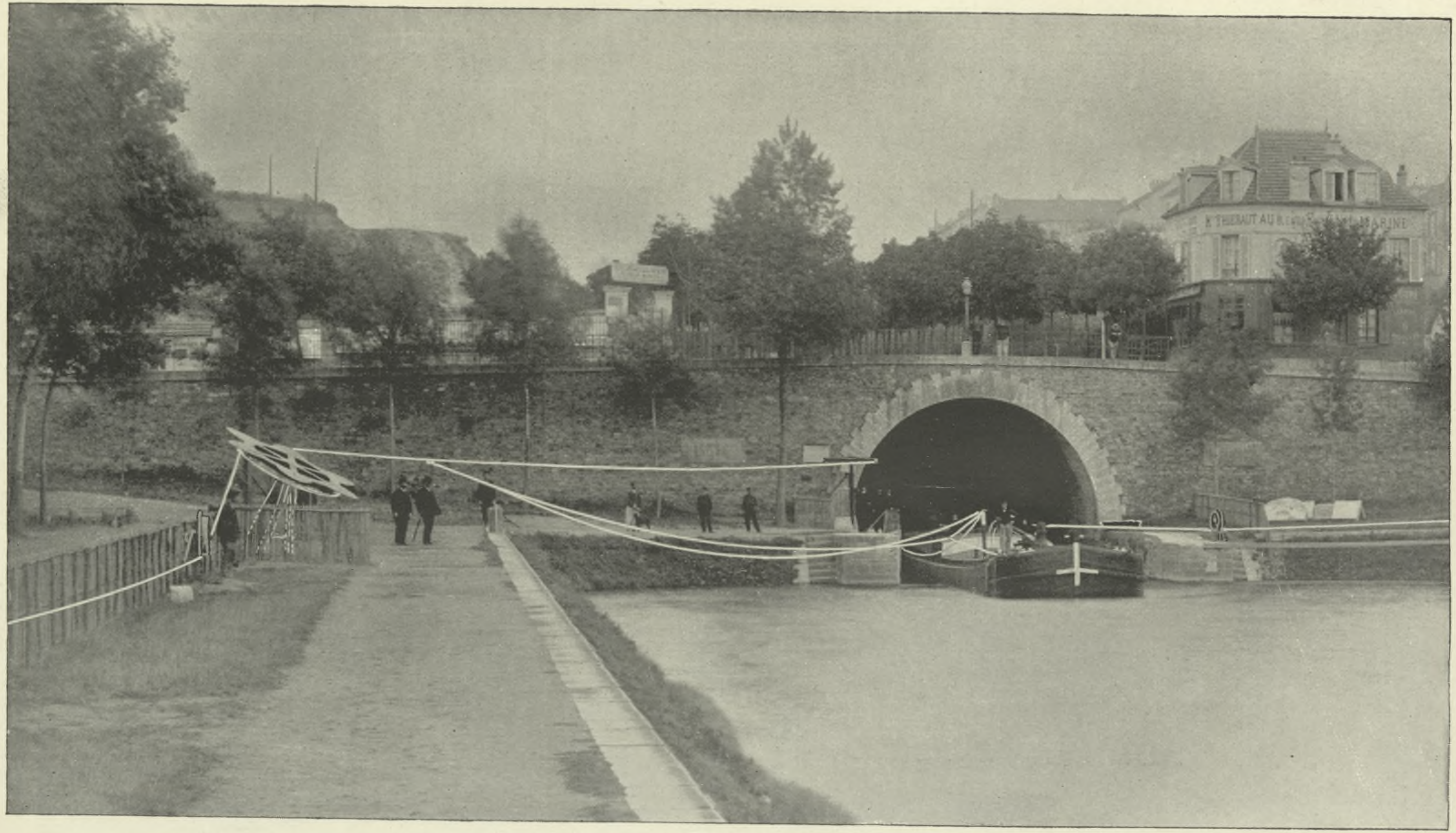
Assuming the largest, with a velocity of one metre per second, and a traffic of 1,000,000 tons per year, we may estimate the cost of the plant at 17 francs per running metre.

The cost per metre of working, under the severest conditions, and including a sinking fund for the capital, and the cost of renewing the cable not exceeding 3.18 francs, the expense of traction is 0.003 francs per ton per kilometre, if we have a traffic of 1,000,000 tons; it descends to 0.0012, if the traffic amounts to 2,500,000 or 3,000,000 tons.

This system has been devised and applied between Paris and Joinville by M. Maurice Lévy, chief engineer of roads and bridges.

The plate represents the system of cable towage near Paris. On the right is seen the cable just entering the tunnel of Joinville, from which it issues, passing around a horizontal pulley, and thence at the left around an inclined winged pulley used for concave angles; thence under a guide pulley. The boat is seen emerging from the tunnel with its towrope and releasing cord.

Cable Haulage on the St. Maur Canal — Lévy's System.



BOAT EMERGING FROM JOINVILLE TUNNEL — ST. MAUR CANAL.

THE HYDRAULIC CANAL LIFT AT LES FONTINETTES, FRANCE.

The Neufossé Canal, on which this lift is situated, connects Dunkirk, Gravelines, and Calais with the system of internal navigation, and has an annual traffic represented by 13,000 boats.

The Fontinettes locks, situated on this canal, near St. Omer, consist of a flight of five successive locks surmounting a difference of level of 43 feet.

The time consumed in passing through these locks often exceeded two hours; the system of crossing was consequently abandoned, and the locks were used for the ascending boats one day, and for those descending the next.

The traffic has so increased that the locks could not accommodate it; accordingly, the Government ordered the construction of an hydraulic lift capable of raising boats of 300 tons burden.

Principle of the lift.—The lift, properly so called, consists of two iron troughs containing the water in which the boats float. Each trough is bolted at its center to the head of a piston, or ram, which works in an hydraulic press set up in a basin. The two presses communicate by a pipe containing a valve serving to cut off, at will, communication between the cylinders.

We thus have an hydraulic balance, and it is sufficient to give a certain surcharge of water to one of the troughs when the valve is opened, in order that one trough shall descend, and in so doing raise the other. Besides, the weight of the trough does not vary, whether it contains a boat or not, provided the water in it stands at the same level in both cases.

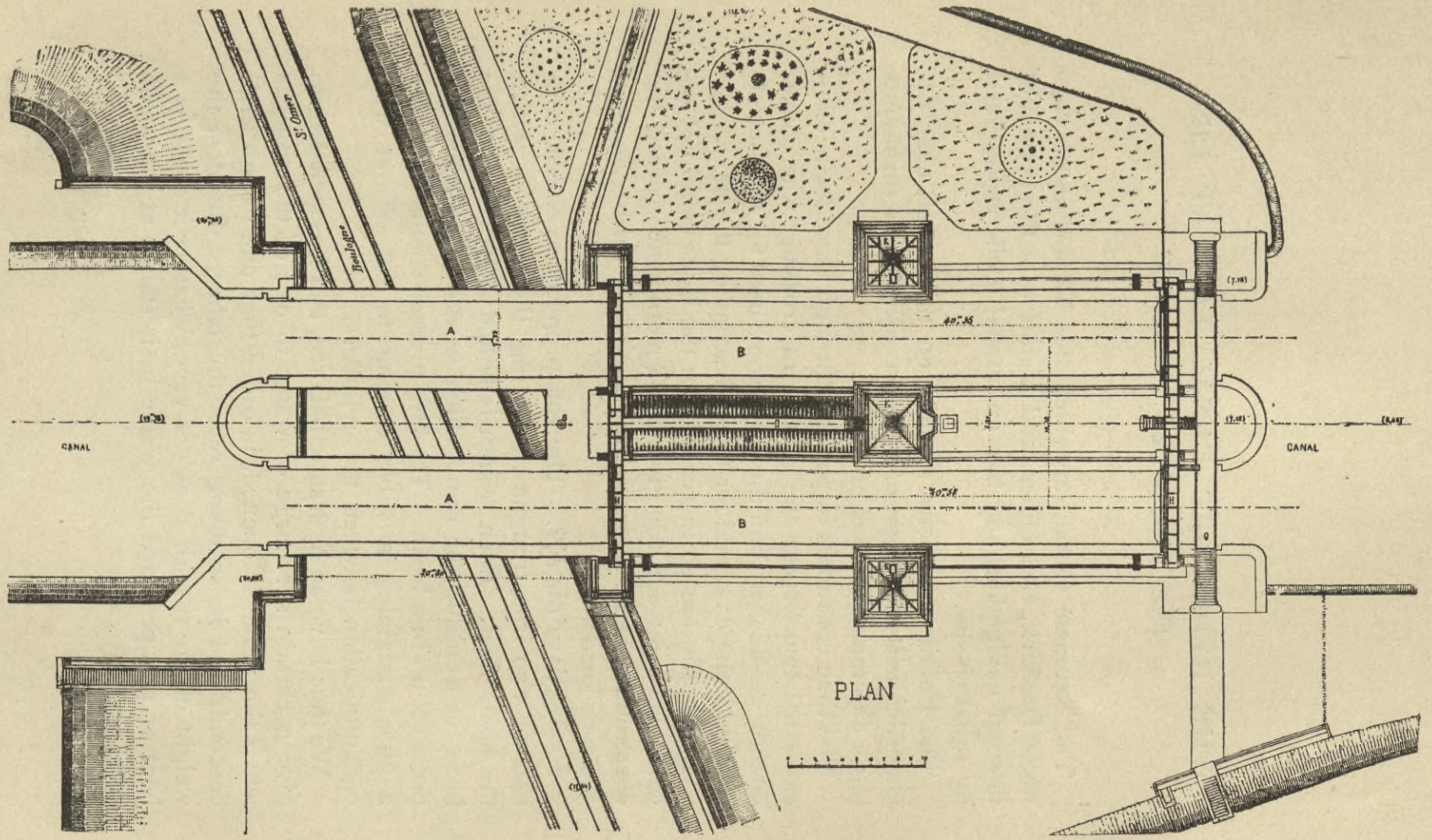


FIG. 1.—Plan of the hydraulic lift at Les Fontinettes. A A, canal bridge with two separate lines or branches crossing the railroad from Boulogne to St. Omer; B B, movable troughs; H H, frames supporting the gates; K K K, towers; L, lookout cabin; M, machine house; Q, service bridge; S, capstan.

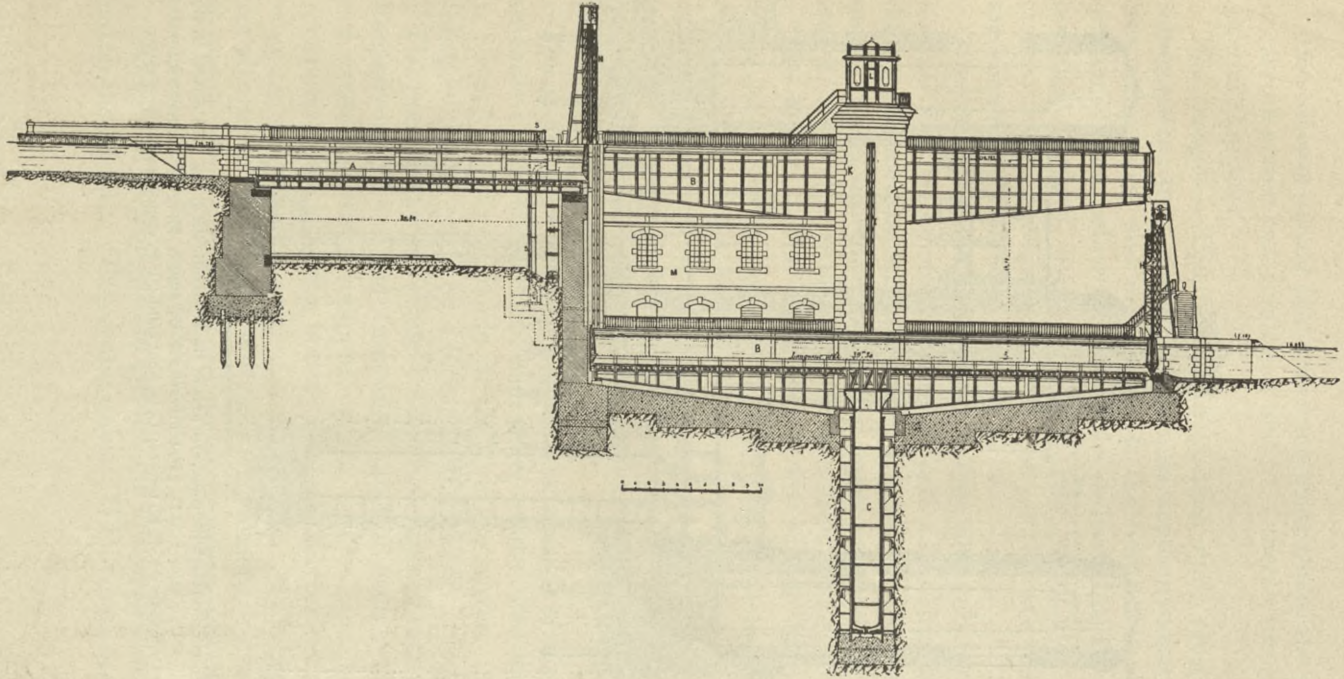


FIG. 2.—Hydraulic lift at Les Fontinettes. Longitudinal section along the axis of the trough. A, canal bridge; B, movable trough; C, pistons; D, great presses; H, frames supporting the lifting gates; I, guides; K, towers; L, lookout cabin; M, machine house; Q, service bridge; S, Capstan.

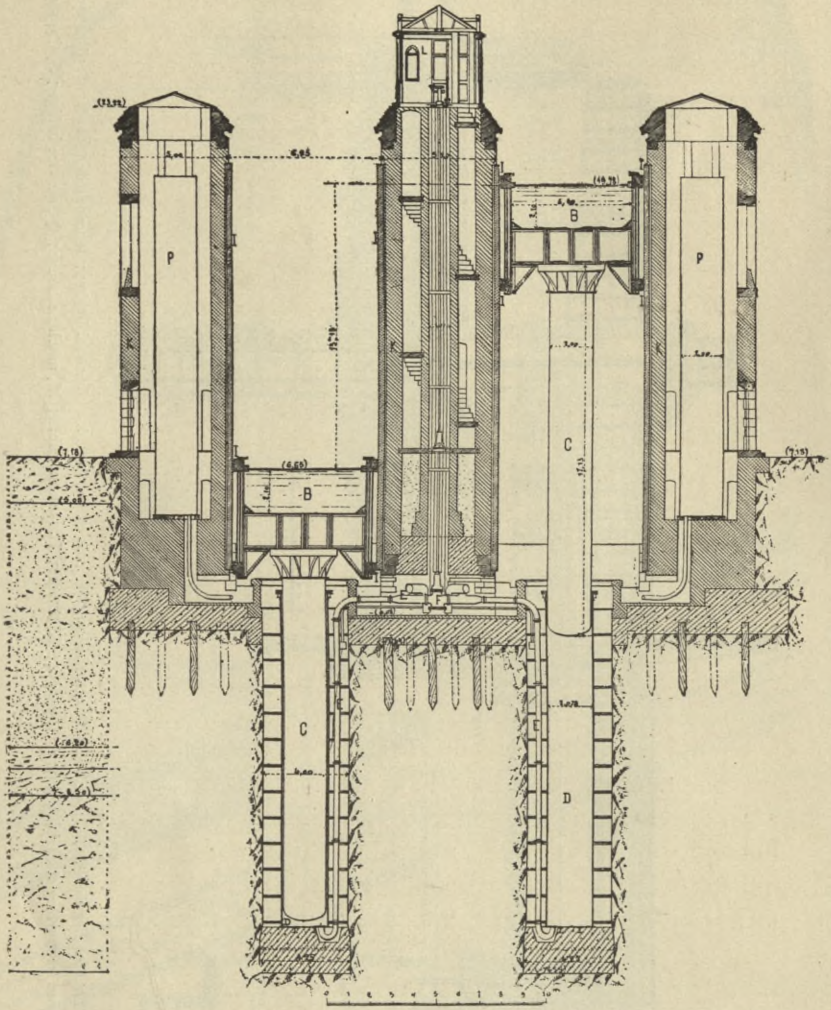


FIG. 3.—Cross section through the transverse axis of the Hydraulic lift at Les Fontinettes. B B, movable troughs; C C, pistons; D D, great presses; E E, supply pipes; F, connecting valve; I I I I, guides; K K K, towers; L, lookout cabin; P P, compensating reservoirs.

The lift was placed just below the point where the canal is carried across the Boulogne and St. Omer Railroad by an iron aqueduct.

The troughs.—The troughs have their ends closed by lifting gates; they contain a minimum depth of water of 6 feet 10⅝ inches, and are lodged at the bottom, in a dry masonry basin below the level of the lower bay. This basin is divided, by a wall 17 feet wide, into two compartments, each closed by a gate at the extremity of the connecting aqueduct.

The pistons.—The pistons are cast-iron plungers, 57 feet, long, 6 feet 6¾ inches in diameter, and 2.8 inches thick; they are formed in sections 9 feet 2 inches long, flanged on the inside, united by bolts, and made water-tight by a ring of sheet copper inserted between each flange.

The presses.—The great presses are 71 feet high and 6 feet 10 inches in diameter. They rest upon masses of cement béton at the bottom of the pits, tubbed with cast iron. The presses themselves are made up of rolled weldless steel hoops 6 inches wide, stepped into each other at half thickness, with a joint .2 of an inch high, and made water-tight by a copper lining.

The joint between the piston and the press is formed by an India-rubber band, lined with sheet copper, and lodged in an annular recess made in the cylinder cover. This lining is kept in place by a bayonet attachment.

The presses communicate by an iron pipe 9¾ inches in diameter inside, starting from the bottom of each cylinder and ascending the corresponding pit. The pipe has a horizontal branch at the bottom of the basin between the two pits, and contains a valve in the middle. This branch has also tubes connecting with two distributors, by means of which water may be forced under pressure into either press, or allowed to escape therefrom.

Guides.—The troughs are guided on the upstream end and in the middle. The center guides, D D, which are the most important, rest against three massive square towers. The engineer, in the valve house, L, at the top of the central tower, directs the whole apparatus, opens and closes the connecting valve between the presses, and the valves of the distributors. Access to this house is afforded by the tower staircase, or by a footbridge from the top of the lift wall.

The side towers contain wrought-iron cylindrical reservoirs, designed to reduce the consumption of water, but it has not been thought best to use them.

When one trough is raised to the end of its course, there is a play of about 1¾ inches between its upstream extremity and the downstream end of the aqueduct connecting with it. At the moment of raising the gates to allow a boat to enter or to pass out of a trough, the joint is made by an India-rubber hose running round the end of the aqueduct, and protected by springs. This hose is inflated with air, at a pressure of 1½ atmospheres. Little valves inserted in the gates permit this space (between the gates) to be filled with water before making the connection. The same arrangement is made for the lower bay joint.

Porticos constructed on the lift wall, and also on the tail wall, have, on their tops, hydraulic apparatus for lifting the gates. The gates, which are balanced to a great extent by counterweights, allow, when raised, a free height of 12 feet above the level of the water. Below the lift, a footbridge, Q, connects the two banks with the central masonry wall.

The machinery (Pl. III.) placed in a building, M, between the two compartments of the dry basin on the upstream side of the central tower, consists of two turbines driven by the water of the upper bay, brought into a tank between the two lines of the aqueduct. One turbine of 50 horse power drives four double-acting force pumps coupled together two and two, and supplying an accumulator of 264¼ gallons capacity. The other 15 horse power turbine drives the air compressor for the inflation of the joining

PLATE I.

GENERAL VIEW OF THE HYDRAULIC CANAL LIFT AT LES FONTINETTES.

hose, and also a centrifugal pump which serves to keep the trough basins clear of water, whether from leakage or false maneuvering.

A little steam engine works the pump when the upper bay is not in use.

The weight to be raised, including a piston, a trough, the water, and a boat floating in it, amounts to about 800 tons; the pressure in the presses is, therefore, about 25 atmospheres. But the accumulator has been loaded to 30 atmospheres to make sure of the efficient working of the presses for lifting the gates.

Method of working the lift.—The lift is worked as follows: One of the troughs being raised to the height of its course and containing a depth of water 7 feet 10½ inches, the joint is made by opening the cock admitting compressed air into the hose running around the face of the end of the aqueduct. Then the trough and aqueduct bridge are hooked together, and at the same time the space between the gates is filled by means of a little valve. The two gates are then raised together by means of a counterpoise and the hydraulic apparatus; a boat is hauled into the trough, then the gates are lowered and unhooked, the valve is closed, and the air in the rubber hose allowed to escape.

During this time similar operations have taken place below; the other trough being at the end of its course, resting on wooden blocks, and containing water 6 feet 10⅝ inches deep. The upper trough has thus a surcharge of 12 inches in depth, corresponding to about 64.6 tons.

The connecting valve between the presses is then opened, and one trough descends while the other rises. The motion is stopped by closing the connecting valve when the level in the ascending trough is 12 inches below that of the upper bay. The descending trough has also its level 12 inches above the level of the lower bay. The joints are formed, and the gates lifted, slightly at first, then completely. The upper trough takes its surcharge for the following operation while the lower one gives up its water ballast to the lower bay. The boats can then be hauled out and replaced by others.

The position of a trough may be corrected either before or after the opening of the lifting gates. It is sufficient for this purpose to move the distributor valves so as to allow water to escape from the press or to introduce water under pressure from the accumulator into it.

Also safety valves are introduced, opening automatically, and thus preventing the trough from rising too high, which might be dangerous.

At the beginning of the operation, the press of the upper trough contains 41 tons of water more than that of the lower. The force producing the descent attains about 106 tons. This force diminishes progressively, since the water in the first press passes gradually into the second, and at the end of the operation the force is only 24 tons; this is necessary to overcome the friction and passive resistances. This force would be in reality only 12 tons if the connecting pipe were entirely free, but it was thought best to reduce the section by valves and thus regulate the apparatus, in order to avoid either an excessive velocity or a premature stoppage in case of error in taking the surcharge.

As we see, the initial force diminishes and the motion slackens continuously, so that each trough comes to the end of its course with nearly no velocity.

The actual time of the ascent and descent of the troughs is 5 minutes.

The total time, including the entrance and the departure of a barge in each direction, is 20 minutes.

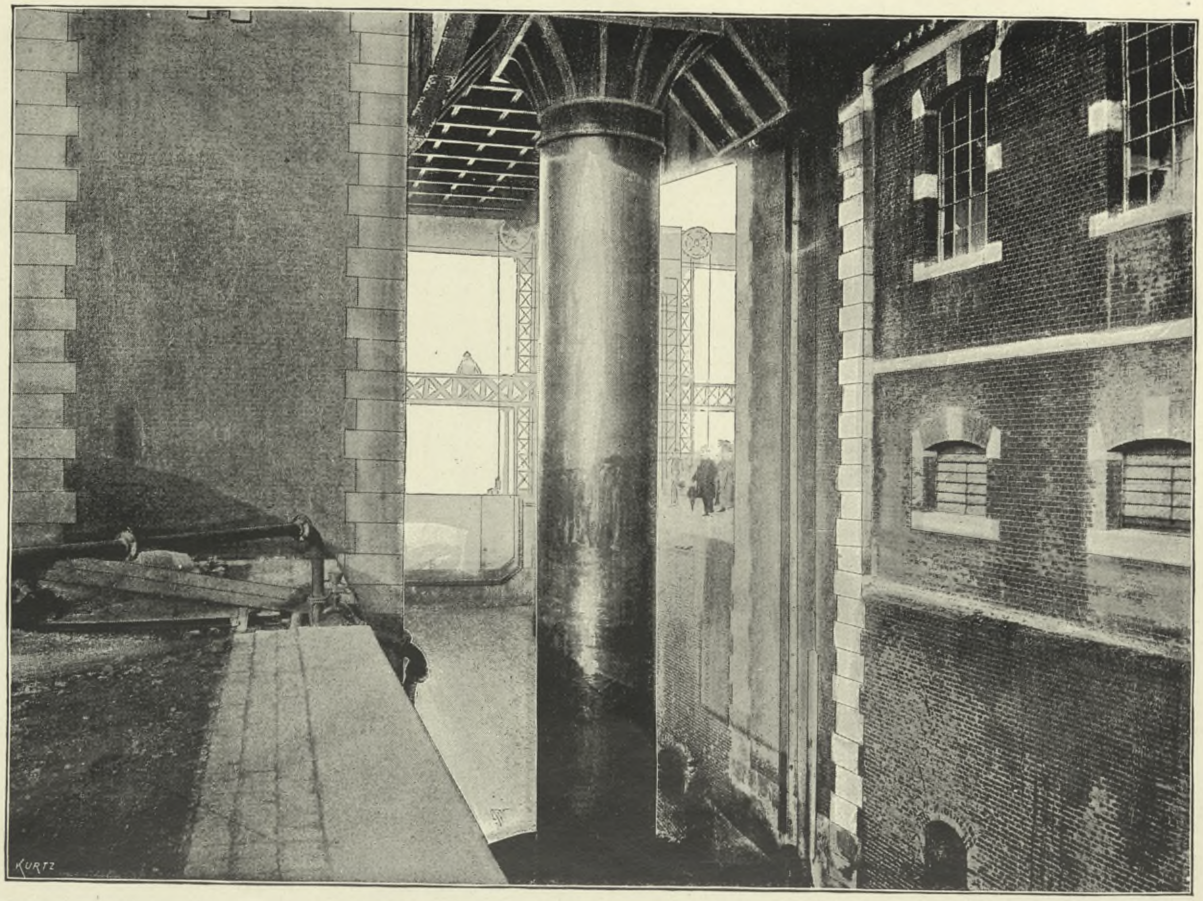
The total cost of the lift was about $374,000.

SUMMARY.

Les Fontinettes Lift, Neufossé Canal, France.

	Metres.	Feet.	Inches.
Trough :—			
Length	39.50	129	7
Breadth	5.60	18	4½
Depth of water	2.10	6	10⅝

PLATE II.



HYDRAULIC CANAL LIFT AT LES FONTINETTES. VIEW OF THE TROUGH BASIN.

	Metres.	Feet.	Inches.
Press; copper internal cylinder with exterior weldless steel hoops:—			
Thickness of copper cylinder	0.003		0.118
Thickness exterior steel hoops	0.060		2.362
Length of press	15 682	51	5.406
Length of stroke (height of lift)	13.13	43	1.
Pressure in the press, 25 atmospheres, 442 pounds per square inch.			
Ram or piston:—			
Thickness of cast iron	0.070		2.755
External diameter	2.00	6	6¾
Total weight lifted, including water, trough, and ram, 800 tons.			
Equivalent to a pressure of 25 atmospheres.			
The contents of one stroke in water, 41 tons.			
Equivalent to a surcharge on the trough of	0.20		8.
Actual surcharge used, 64.6 tons.			
Equivalent to a depth of water of	0.30		11.811
Size of boats lifted, 300 tons.			
Actual time of lift, 5 minutes.			

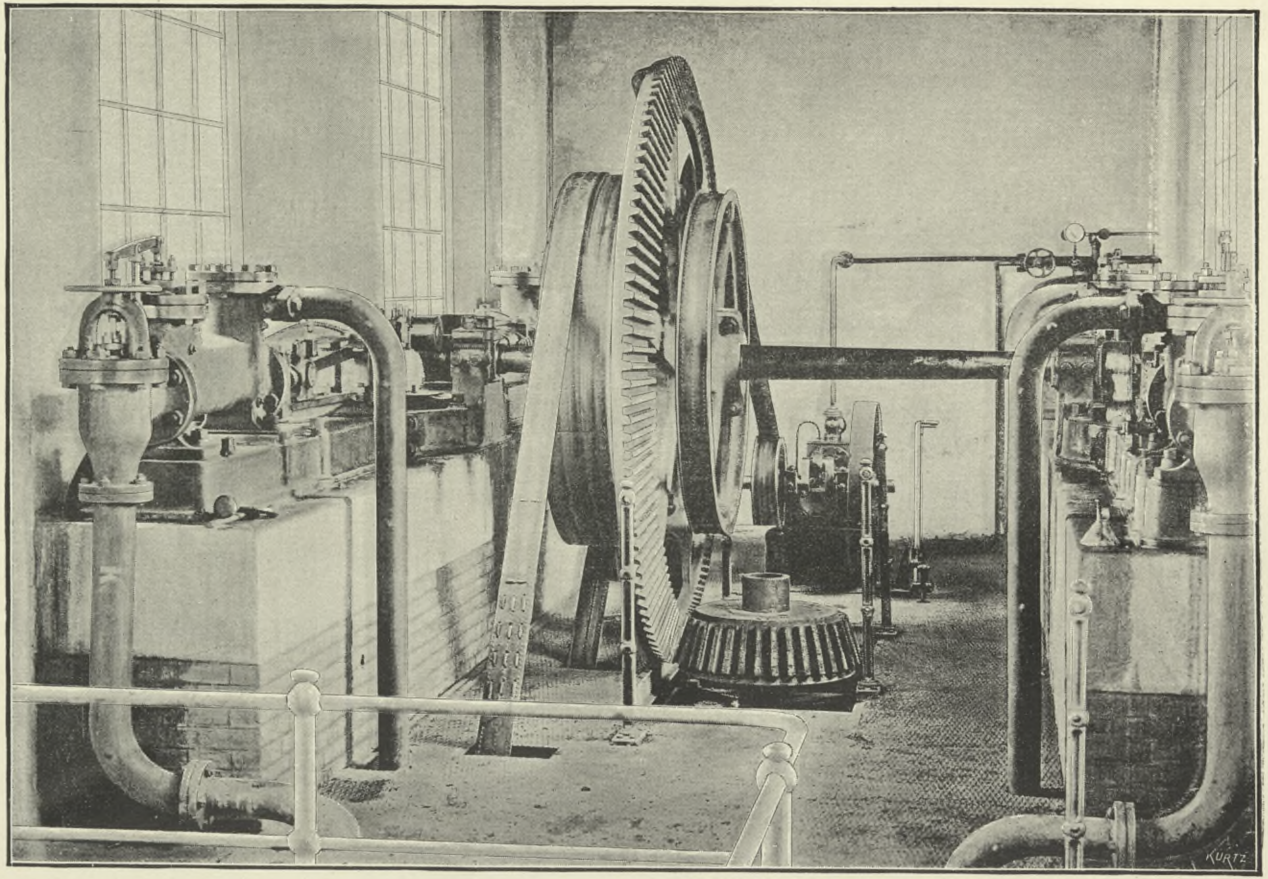
Acknowledgment.—I wish in this connection to express my indebtedness to M. Gruson, chief engineer of roads and bridges, for the information concerning this interesting subject as well as for the three figures which accompany it.

Plate I. is a general view of the lift.

In the foreground is seen the iron lattice bridge over the two branches of the canal containing the lift. Immediately behind, is the lower iron frame supporting the downstream gates; the trough on the right is raised; on the right and left are the towers with their iron guides to steady the trough in its ascent and descent. Behind the first tower, on the left, is the machine house containing the accumulator, the turbines, and the feed pumps; on the top is the lookout cabin containing the levers for opening and closing all the valves used in operating the lift. Still farther in the rear are the supports for the upstream gates, also containing the hydraulic moving apparatus. Below, in the rear, is the iron girder bridge carrying the canal over the Boulogne and St. Omer Railroad, resting on the massive abutment. At the extreme right is the original canal leading to a flight of five consecutive locks.

Plate II. shows the trough basin, giving a view of the trough as seen from beneath when it is raised, and of the parts of the structure which are then below the trough. It exhibits the junction of the square head of the ram with the trough bottom and the details of the construction of the latter. On the side of the house is seen the guide; beyond is the gate with its lifting chain and guide pulley, surmounted by the iron lattice supports. On the left side is a little centrifugal pump for draining the trough basin.

PLATE III.



HYDRAULIC CANAL LIFT AT LES FONTINETTES. VIEW OF THE PUMPING MACHINERY.

THE NAVIGATION OF THE SEINE FROM PARIS TO THE SEA.

At the beginning of the century the navigation of the Lower Seine was often interrupted by low water and by freshets. Great difficulties and even dangers were encountered in passing the bridges and dams. Ascending only by horse towage, consuming from Rouen to Paris fifteen days for ordinary freight, and four or five for accelerated freight, the boats were rarely able to be loaded to their full depth, from 6 to 6½ feet. The cost of freight was $3.20 per ton from Rouen to Paris, and the annual traffic did not exceed 77,000,000 kilometric tons.

Without undertaking to describe the improvements made in the navigation of the river before 1878, it is sufficient to say that with the works recently constructed, the river between Paris and Rouen has been divided into nine reaches by the construction of locks and dams, with a minimum draught of water of 10 feet, and no difficulties are experienced either from low water or the passage of locks. The transport is made by steam, either by freight boats or towboats, by the former in 28 hours, and by the latter, towing a convoy, in 3 days. The price of freight, which was from $2.40 to $3 per ton in 1840, is now from 80 cents to $1 ascending, and from 65 to 70 cents descending, and will diminish progressively as new boats are built to utilize more completely the improvements of the route.

Indeed, the traffic* since the completion of the canalization, has considerably augmented. The total tonnage between Paris and Rouen, including that taken on the way,

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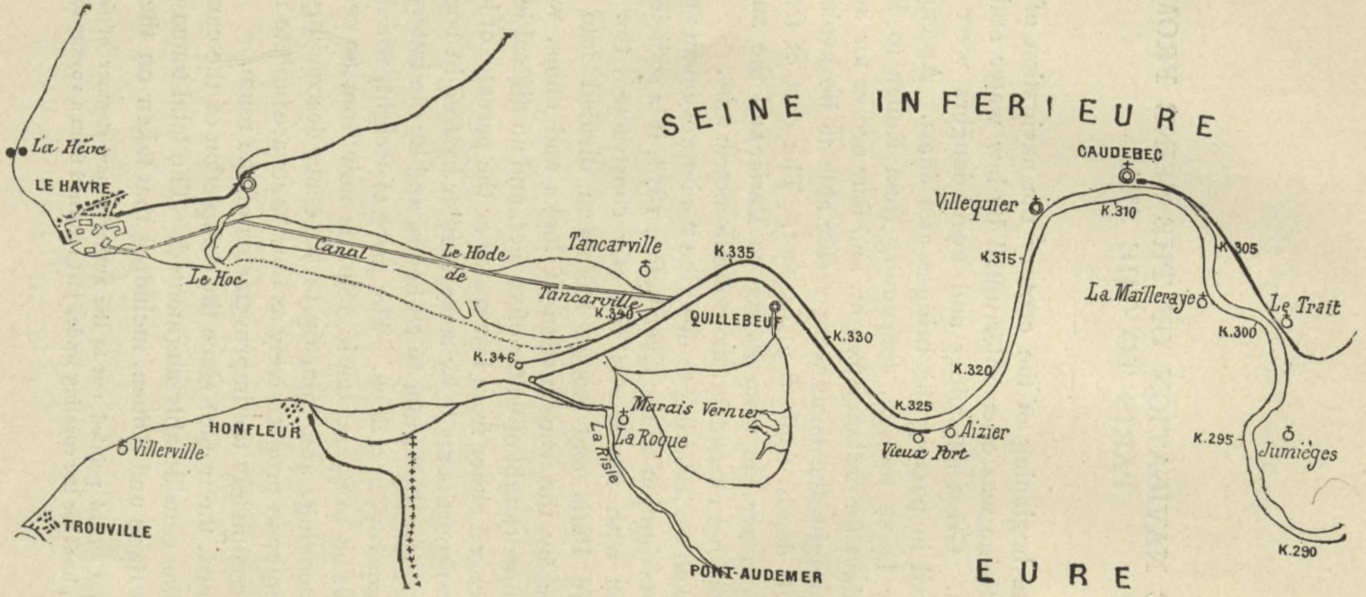
*M. Cameré pointed out to the author a new steamer of 600 tons burden, built for the coasting trade, just returned from a voyage to Spain.



Map of the tidal Seine.

was in 1881, 227,307,266 kilometric tons, and in 1888 it was 389,668,346.

Cost.—The cost of the works of canalization amounts to 88,553,000 francs ($17,210,000). If we compare this total expense with the actual traffic we find the interest at 5 per cent on the first cost, divided by the number representing this traffic to be, $\frac{5}{100} \text{ x } \frac{88,530,000}{389,568,346} = 0.011 = 2.2$ mills per kilometric ton, and it is certain that the cost of freight has diminished very much more than that.

EMBANKMENT WORKS FOR THE IMPROVEMENT OF THE TIDAL SEINE.

The object of the improvement of the tidal Seine is to facilitate the access of vessels to the port of Rouen, situated 78 miles from the sea. Of this distance, half required improvements to render it navigable, and this comprised the parts between La Mailleraye and the sea below Honfleur. The breadth of the river increased between these places from five eighths to six miles. See map.

Depth of water.—This vast extent of water was filled with banks of shifting sand, which were constantly changing place through the action of the strong currents of the ebb and flow of the tide, and it often happened that in the course of a few days the position of the channel would be shifted from one side of the river to the other. The depth was also variable and insufficient. During the highest tides there was a depth of 14 feet below Quillebeuf, and only 5 feet at high neap tides, and many dangerous rocks and shoals impeded the navigation above this point. These perils encountered at intervals of the voyage were considerably augmented by the tidal wave or bore, and vessels were stranded by its powerful action without the possibility of receiving assistance. Under these circumstances the navigation was confined to vessels of from 100 to 200 tons burden. The voyage from the sea up to Rouen occupied four days; a great number of wrecks marked the route, freights between the sea and Rouen rose to $2 per ton, and the rate of insurance was one half per cent.

Improvements.—Such was the state of things in 1848, when the improvements were begun, which consisted in building training walls, sometimes on one side, sometimes on both sides, extending from La Mailleraye to the mouth of the Risle, a distance of 26 miles. The distance between the training walls was 984 feet at La Mailleraye, and gradually increased to 1,640 feet at the Risle.

These training walls are constructed of random work built of blocks of chalk taken from the cliffs on the banks of the river; some are raised above the level of the highest tides, while others are capable of being submerged, so that they may have less influence in promoting the accumulation of deposits.

The stones from the neighboring quarries were soft, and subject to the action of frosts, currents, and particularly the tidal wave or bore, a powerful volume of water preceding the flood tide, rushing up the river, and dashing against the banks with great violence; this has undermined and sometimes destroyed the original walls. Very extensive repairs, or rather reconstructions, were necessary, which bring up the total cost of the walls to the sum of $5,300,000 since the beginning.

Alluvial land.—Behind the training walls, and in parts formerly occupied by the shifting sands, alluvial meadows were formed to an extent of over 20,000 acres in 1880.

These meadows are of excellent quality, and they are actually worth $325 per acre. When all the alluvial lands now forming are definitely constituted, the total value of the lands thus reclaimed will be $6,710,000. Finally, it should be understood that these calculations only include the lands above the actual limit of the training walls, and that the influence of these works extends a long distance beyond them into the estuary.

Results.—The results have surpassed all anticipations. The channel has become fixed and deepened between the walls more than 6 feet 7 inches, so that vessels of 2,000 tons can navigate the river, the depth being at low tide 17 feet, and at high tide 20 feet. The charge for freight between Havre and Rouen has been reduced one half, that is, to 5 francs per ton, and the insurance for Rouen is the same as for Havre. The traffic has consequently increased from 500,000 tons in 1860 to 1,600,000 tons in 1888.

The effects of the training walls have been confined to the channel between them, but their deepening influence extends little beyond their extremities. The estuary channel is constantly shifting. In M. Vautier's report he traces on the chart of the estuary twelve totally different locations of the main channel beyond the walls, from 1874 to 1880.

A prolongation of the southern bank below the Risle was carried out in 1870, but a proposed prolongation of the northern bank was refused, and the works finally stopped, for fear of endangering the approaches to Havre, the second port of France, by the silting up of the estuary.

Such was the state of things in 1886, when the idea occurred to Prof. Vernon-Harcourt, the eminent hydraulic engineer, of making the experimental investigations on the Seine estuary described in the following extracts from his paper on The Principles of Training Rivers through Tidal Estuaries.

INVESTIGATIONS ABOUT THE SEINE ESTUARY.

The training works in the lower portion of the tidal Seine are acknowledged to be incomplete; and great interest has been evinced, particularly within the last few years, in the question of their extension, so that the shifting channel between Berville and the sea may be trained and deepened, and the access to Honfleur improved, without endangering the approaches to Havre. The objects desired are distinctly defined, but the means for attaining them have formed the subject of schemes, exhibiting great varieties in their general design, and illustrating very forcibly the great uncertainty which exists, even in a special case where the conditions have been long studied, as to the principles which should be followed in designing training works. It is evident that no reasoning from analogy could prevail among such very conflicting views ; and having had the subject under consideration for a long time, the idea occurred to me in August, 1886, of attempting the solution of this very difficult problem by an experimental method, which might also throw light upon general principles for guidance in training rivers through estuaries. The estuary of the Seine is in some respects peculiarly well adapted for such an investigation, for old charts exhibit the state of the river before the training works were commenced, and recent charts indicate the changes which the training walls have produced, while the various designs for the completion of the works, proposed by experienced engineers, afford an interesting basis for experimental inquiries into the principles of training works in estuaries. If, in the first place, it should be possible to reproduce in a model the shifting channels of the Seine estuary as they formerly existed, and next, after inserting the training walls in the model as they now exist in the estuary, the effects produced by these works could be reproduced on a small scale, it appeared reasonable to assume that the introduction, successively, in the model of the various lines proposed for the extension of the training walls would produce results in the model fairly resembling the effects which the works, if carried out, would actually produce.

When the third Manchester Ship Canal bill was being considered by Parliament, in 1885, Prof. Osborne Reynolds constructed a working model of the portion of the Mersey estuary above Liverpool on behalf of the promoters of the canal, with the object of showing that no changes would be produced in the main channels of the estuary by the canal works, which have been designed to modify very slightly the line of the Chesire shore above Eastham. This model was, I believe, the first experimental investigation on an estuary by artificially producing the tidal action of flood and ebb on a small scale, and Professor Reynolds's experiment showed that a remarkably close resemblance to the main tidal channels in the inner estuary could be produced on a small scale. But the very interesting and valuable results obtained in the model of the Mersey, could afford no assurance that experiments involving essentially different and novel conditions would lead to any satisfactory results. I therefore restricted the requirements for my experiments within the smallest limits, and contented myself with the simplest means, and the limited space available in my office at Westminster.

Description of the model of the Seine estuary.—The model representing the tidal portion of the river Seine and the adjacent coast of Calvados, extending from Martot, the lowest weir on the Seine, down to about Dives, to the southwest of Trouville, was moulded in Portland cement by my assistant, Mr. Edward Blundell, to the scales $\frac{1}{40000}$ horizontal and $\frac{1}{400}$ vertical. Where the rocky bottom lies bare, near Havre and Villerville, the model was molded to the exact depths shown on the chart of 1880; but in other places the cement bottom was merely kept well below the greatest depth the channel had attained at each place, whilst the actual bed of the estuary in the model was formed by the flow of water over a layer of sand.

Arrangements for the tidal and fresh-water flow.—The mouth of the Seine estuary faces west, but the tidal wave comes in from the northwest, and the earliest and strongest flood tide flows through the northern channel between Havre and the Amfard bank; whilst the influx through the southern Villerville channel occurs later, and is stronger toward high water. Accordingly, the tidal flow had to be introduced from a northerly direction, at an angle to the mouth of the estuary; and the line of junction of the hinged tray, producing the tidal rise and fall, was made at an angle of about 50° to a line running from east to west in the model, so that the tidal flow approached the estuary from a point only about 5° to the west of northwest. The tray was made of zinc, inclosed by strips on three sides to the height of the sides of the estuary; and it was hinged to the model, at its open end, by a strip of india-rubber sheeting along the bottom and sides, so as to make a water-tight joint, with sufficient play at the sides to admit of the tray being tipped up and down from its outer end. The rise and fall of the tray was effected by the screw of a letter press, from which the lower portion had been detached, by raising and lowering the upper plate of the press, half of which was inserted under the tray. After the requisite amount of sand had been introduced to raise the bottom to the average level, the model was filled with just enough water for the surface of the water to represent low water of spring tides when the tray was down and the screw at its lowest limit; and the tray was made of such a size that, when the screw was raised to its full extent, the water in the model was raised, by the tipping of the tray, to the level representing high water of spring tides. The water representing the fresh-water discharge of the Seine was admitted into the upper end of the model from a tap in a small tin cistern; and the efflux of a similar quantity of water was provided for at the lower extremity of the estuary, on its northern side near the tray, by a cock with a larger orifice placed at such a level as to allow the water to flow out into a second cistern, of similar size, during the higher half of the tide.

First results of working the model.—The construction of the model was commenced in October, 1886, and its working was commenced in November. Silver sand was used in the first instance for forming the bed of the estuary. From the outset the *bore* at Caudebec indicated by a sudden rise of the water, and the reverse current just before high water near Havre, called the "*verhaule*," were very well marked. The *verhaule* is evidently a sort of back eddy, on the northern shore, occasioned by the influx of the tide, and by the final filling of the estuary from the southern channel; whilst the *bore* appears to result from the concentration of the tidal rise by the sudden contraction of the estuary above Quillebeuf. The period given to each tide in working was about twenty-five seconds, which appears fairly to reproduce the conditions of the estuary.* After the model had been worked for a little time, the channels near Quillebeuf assumed lines resembling those which previously existed, and a small channel appeared on the northern shore, by Harfleur and Hoc Point, which is clearly defined in the chart of 1834. The main channel

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*According to the formula in the paper by Prof. O. Reynolds on his Mersey model, read at the Frankfort Congress in August, 1888, the tidal period would be nearly twenty-three seconds.

also shifted about in the estuary and tended to break up into two or three shallow channels near the meridian of Berville, where the influences of the flood and ebb tides were nearly balanced. The model, accordingly, fairly reproduced the conditions of the actual estuary previous to the commencement of the training walls, though the channel in the estuary did not attain the depth, as represented by the proportionately large vertical scale, which the old channels possessed, owing, doubtless, to the comparatively small scouring influence which the minute currents in the model possess. The sand did not prove satisfactory for producing the requisite changes when the training walls were inserted in the model. It became, therefore, essential to search for a substance which the water could to some extent carry in suspension for a short period. At last, in July, 1887, I found a fine sand, on Chobham Common, belonging to the Bagshot beds, which combined the advantages possessed by silver sand with a considerably greater fineness.

Results of working the model with Bagshot sand.—The bed of the estuary having been formed with the sand obtained from Chobham Common, after the model had been worked for some time, the channels assumed a form very closely resembling the chart of the Seine estuary of 1834. Accordingly, the first stage of the investigation was duly accomplished by the reproduction of a former state of the estuary in the model, with the single exception of a decidedly smaller depth in the channels, except in places where the scour was considerable; which is readily accounted for by the circumstances of the case. It is probable that with a larger model, and especially if the bed was not so nearly level as in the Seine, the depth would approach nearer to the proper distorted proportion as compared with the width.

Introduction of the existing training walls into the model.—The second stage of the investigation consisted in the introduction of training walls into the model, corresponding in position to the actual training walls established in the estuary down to Berville. These walls, formed with strips of tin, cut to the corresponding heights at the different places, and bent to the proper lines, were gradually inserted in sections; and the model was worked between each addition, to conform, as far as practicable, to the actual conditions. The fine particles of the sand accreted behind the training walls, and the channel between the walls was scoured out, corresponding precisely to the changes which have actually occurred in the estuary of the Seine. The foreshores at the back of the training walls were raised up in some parts to high-water level, whilst in other places the accumulation was somewhat retarded by the slight recoil of the water from the vertical sides of the model, and by the wash over the vertical training walls, these forms being necessitated by the great distortion of the vertical scale of the model. On the whole, however, the accretion and scour in the model correspond very fairly to the results produced by the existing training walls in the estuary. The accretion, moreover, in the model, extended beyond the training walls on each side, down to Hoc Point on the right bank, obliterating the inshore channel close to Harfleur, which had been reproduced in the model, and down to Honfleur on the left bank, corresponding in these respects also to the actual changes in the estuary. The main channel also, beyond the ends of training walls, was comparatively shallow, and was unstable, reproducing the existing conditions in the estuary.

The experiments relating to this stage extended over a year and a half; they formed the turning point of the investigation, and have the interest of being, as far as I am aware, the first attempt at putting training walls in a model, and obtaining the resulting accretion on a small scale. Without the accomplishment of this stage, it would have been useless to continue the investigation; and its satisfactory attainment proved so difficult in actual practice, that for a long time it seemed probable that the attempt must be abandoned.

Application of the system to ascertain the probable effects of any training works.—As the first and second steps in the investigation, by the aid of the model, had furnished results which corresponded very fairly with the actual states of the estuary of the Seine before and after the execution of the training works, the final stage of the investigation, for ascertaining the probable results of any extensions of the training walls, could be reasonably entered upon. In selecting the lines of training walls to be experimented on, it appeared expedient to adopt those which have been designed, after careful study, by experienced engineers, both on account of the results from these being far more interesting than those of a variety of theoretical schemes, and also in the hope that some assistance might thereby be rendered to French engineers in the prosecution of this important work. Moreover, the schemes exhibit sufficient variety to admit of their being taken as types of schemes for throwing light upon the principles on which training works should be designed in estuaries. Accordingly, the third stage in the investigation consisted in extending the training walls in the model, in accordance with the lines of some of the schemes proposed; and, after working the model for some time with each of the extensions successively, the several results were recorded, as shown in figures 1-4. The lines of training walls experimented on in the model were taken, with one exception, from five out of the seven most recent schemes proposed, as these five schemes are, I believe, the only ones which are still put forward for adoption. The lines shown on figure 5, represent merely a theoretical arrangement of training walls, inserted for a final experiment in the model, to ascertain the effect of the most gradual enlargement of the trained channel which the physical conditions of the estuary would have admitted of at the outset, whilst maintaining the full width at the mouth.

Scheme A.—The first arrangement of extended training walls introduced into the model was taken from a scheme put forward in an amended form in 1886. The design, as inserted in the model, consisted of an extension of the parallel training walls from Berville down to Honfleur, and the formation of a breakwater across the outlet, from Villerville Point, on the southern shore of the estuary, out to the Amfard bank, thus restricting the mouth to the channel between Amfard bank and Havre. The lines of these works were formed in the model with strips of tin, as shown on fig. 1; the northern training wall was kept low, and the southern wall was raised to the level representing high water of neap tides; whilst the strip representing the breakwater was raised above the highest tide level, thus forcing all the flood and ebb water to pass through the Havre Channel. The results obtained in the model with these arrangements, after working it for about six thousand tides, are indicated on the first chart (Fig. 1). The channel between the prolonged training walls had a fair depth throughout, partly owing to the concentration of the fresh-water discharge between the walls, and partly from the retention of some additional water in the channel at low water, by the hindrance to its outflow offered by a sand-bank which formed in front of the ends of the training walls. A deep hole was soon scoured out in the narrowed outlet by the rapid flow of the water filling and emptying the estuary at every tide. The absence, however, of connection between the direction of the flood tide current through the outlet and the ebbing current from the trained channel, aided by the accretion of sand in the sheltered recess behind the breakwater, led eventually to the formation of two almost rectangular bends in the channel, one just beyond the training walls and the other near Hoc Point, in the model. This tortuous channel, moreover, was shallow, except at the bends and the outlet, and a bar was formed a short distance beyond the outlet. The contraction of the mouth of the estuary by the breakwater interfered so much with the influx of the tide into the estuary as to render it impossible to raise the tide inside to its previous height, and the reduction in height of the tide was clearly marked at Tancarville Point in the model. Sediment accumulated in the estuary beyond the trained channel, being brought in by the rapid flood current, and not readily removed by the ebb, except in the trained channel and near the outlet; and this accretion, by diminishing the tidal capacity, gradually reduced the current through the outlet, and consequently the depth of the outlet channel. A considerable accumultion of sand took place outside the breakwater, along the southern seacoast, so that the bank opposite Trouville in the model was connected with the shore, and the foreshore advanced toward the end of the breakwater.

Scheme B.—The second arrangement of training walls inserted in the model below Berville, was taken from a scheme proposed in 1888, representing a modification by another engineer of the design from which Scheme A was copied. It comprised the retention of the breakwater from Villerville Point to the Amfard bank, the most essential

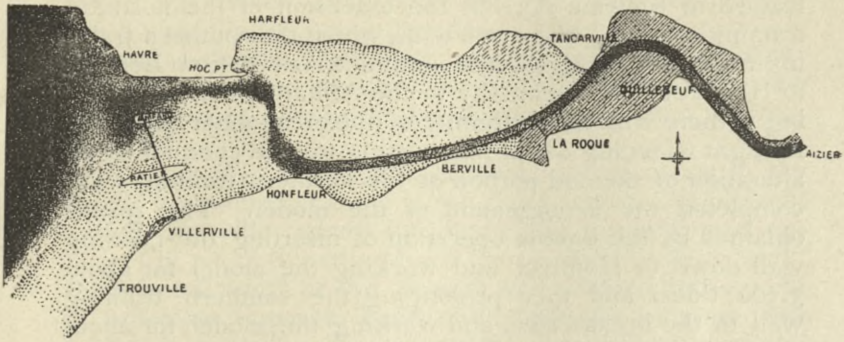

Fig. 1 — Scheme A.

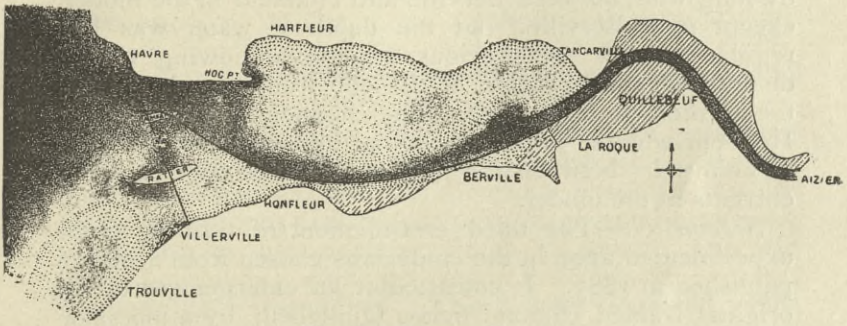

Fig. 2 — Scheme B.

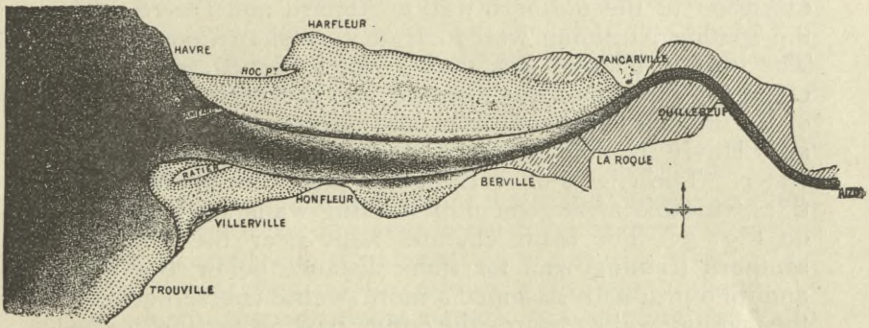

Fig. 3 — Scheme C.

The existing training walls stop at Berville.

feature in Scheme A; but the extension of the northern training wall was dispensed with, whilst the southern training wall was prolonged, in a continuous curve, from Berville to Honfleur, and eventually to the Amfard bank, connecting it there with the extremity of the breakwater (Fig. 2.) A slight widening out of the existing trained channel by an alteration of the end portion of the northern training wall, completed the arrangement of the model. The results obtained by the double operation of inserting the training wall down to Honfleur and working the model for about 3,500 tides, and then prolonging the southern training wall to the breakwater, and working the model for about 3,700 tides, are shown in Fig. 2. The channel followed pretty nearly the concave line of the prolonged southern training wall, between Berville and Honfleur in the model, except near Berville; but the depth of water was less regular than in the previous experiment, owing to the diminished concentration of the ebb from the absence of the northern training wall. The channel, however, above Honfleur was not improved, owing apparantly to the want of uniformity between the directions of the flood and ebb currents in the model.

Scheme C.—The third arrangement of training walls experimented upon in the model was chosen from a design published in 1885. It consisted of an enlargement of the original trained channel below Quillebeuf, by a modification of the southern training wall from Quillebeuf, and of the northern training wall from Tancarville, and the extension of the northern wall to Amfard and Havre, and the southern training wall to Ratier, as shown on Fig. 3. The trained channel was thus given a curved, gradually enlarging form, and was directed into the central channel of the model, between Ratier and Amfard, the Villerville and Havre channels being practically closed near low water. The effects of working the model for about 6,500 tides with this arrangement of training walls are indicated on Fig. 3. The main channel kept near the concave southern training wall for some distance below Berville, and then gradually assumed a more central course between the training walls towards the outlet, passing out just to the south of the Amfard bank. The channel thus formed had a good, tolerably uniform depth, together with a fair width, owing apparently to the flood and ebb tides produced in the model following an unimpeded and fairly similar course. Deposit occurred behind the training walls on each side; and the foreshore advanced in front of Trouville in the model, in consequence of the shutting up of the Villerville Channel.

Scheme E.—In the next scheme as laid down in the model the trained channel in the bend between Quillebeuf and Tancarville, where the depth was greatest, was enlarged in width by setting back the southern training wall; the original width of the channel was retained at the point of inflection opposite Tancarville, and the channel was widened out below La Roque by a modification of the lines of both training walls down to Berville. The training walls were also extended beyond Berville in sinuous lines, as shown on Fig. 4, the southern wall being carried down to Honfleur, and the northern wall not quite so far. The portion forming the last bend of the northern training wall was kept low, whilst the others were made high, according to the design. Both in this and the preceding arrangement of training walls experimented on, the expanding trained channel was somewhat restricted in width along the portions near the changes of curvature, to make it conform to the principles which experience has laid down for training winding rivers in their non-tidal course, as previously mentioned. The results obtained, after working the model for about 3,700 tides, are represented on the chart (Fig. 4). The channel between the training walls was somewhat shallow in places, and though a deep channel was formed along the inner concave face of the southern wall below La Roque and Berville, a shoal emerging above low water appeared along the concave face of the last bend of the northern training wall. This bank appeared to be due to the protection the extremity of the bend afforded from the action of the flood tide in the model, whilst the ebb followed the central flood-tide channel, instead of passing over to the concave bank, as would have occurred with the current of a non-tidal river. The main channel beyond the training walls, which, though of fair depth, was somewhat narrow and winding, was also unstable, for in the early part of the experiment its outlet was in the central channel between Ratier and Amfard in the model, whilst at the close of the experiment it had shifted, as shown, to the Havre Channel. Accretion occurred behind the training walls in the model, and some silting up took place in the Villerville Channel and along the foreshore in front of Trouville, owing apparently to the preference of the main channel for the other outlets, and the diminished capacity of the estuary, resulting from accretion.

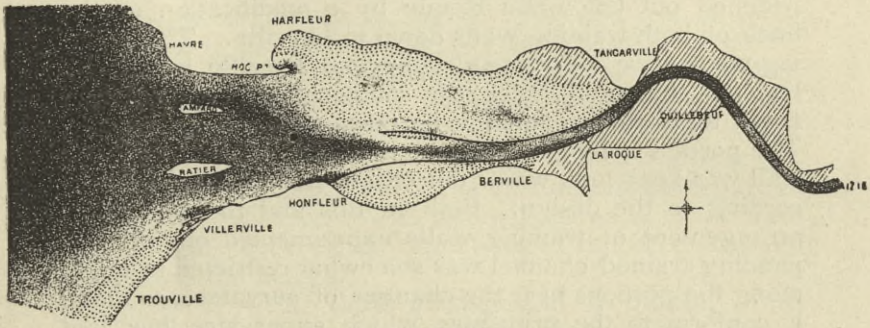

Fig. 4 — Scheme E.

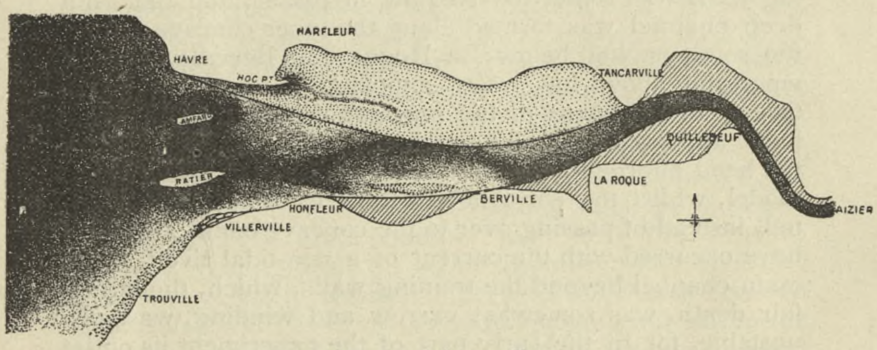

Fig. 5 — Scheme F.

Scheme F.—The last experiment was made on an arrangement of training walls inserted in the model, making the trained channel expand as gently as practicable between Aizier and the sea, whilst retaining the natural width at the outlet (Fig. 5). This is the form of channel which theory indicates as the most suitable; for whilst it facilitates the influx of the flood tide, it prevents, as far as possible, the abrupt changes in the velocity of a river in passing from its estuary to the sea, which are so prejudicial to uniformity of depth in a channel. It was therefore of interest to ascertain what results would be produced by this theoretical arrangement of training walls in the model, which, in order to leave the outlet free, and thus avoid favoring a progression of the foreshore outside, had to provide a wide channel near Honfleur, compared with the restricted width available at Quillebeuf. The direction of the channel between Aizier and Quillebeuf, together with the cliffs bordering the river at Quillebeuf and Tancarville Points, determined the maximum width obtainable at Quillebeuf and the direction of the channel from Aizier to Tancarville; and the extension of the training walls in the model from this point was regulated by the necessity of passing close to Honfleur at the south, and not impeding the approach to Havre on the north. The effects produced in the model by working with this arrangement of training walls, for about 7,300 tides are indicated on the chart (Fig. 5). The southern training wall was kept above high-water level all the way to its termination at Honfleur in the model, but the northern training wall was gradually reduced in height from nearly opposite Honfleur toward Havre. The trained channel had a good width at low water throughout, in spite of the distance apart of the training walls in the model, the whole channel being below low-water level, except near the southern wall between Berville and Havre, and against the northern wall nearly opposite Hoc Point, where banks emerged slightly above low water. The channel, moreover, was distinctly, though slowly, improving with the continuance of the working, and the banks diminishing. There was also a fair depth in the channel, the shallowest place being opposite Berville, whilst a deep place was formed just above, near the southern wall between La Roque and Berville. The depth in all the outlet channels was well maintained; and though deposit naturally took place behind the northern training wall, no accretion was visible along the foreshores outside.

The value of experiments resembling those just described depends entirely upon the extent to which they may be regarded as producing effects approximately corresponding, on a small scale, to those which training works on similar lines, if carried out in an estuary, would actually produce. If the effects of any training works could be foreshadowed by experiments in a model, the value of such experiments, in guiding engineers toward the selection of the most suitable design, could not be overestimated.

Some of the influences at work in an estuary cannot possibly be reproduced in a model — such as winds and waves. Winds coming from different quarters are variable in their effects; but the direction of the prevailing wind indicates the line in which the action of the wind has most influence, which may be exerted in re-enforcing the flood or ebb currents, and may aid or retard accretion by blowing the silt-bearing stream more into or out of the estuary. Waves are the main agents in the erosion of cliffs along open sea-coasts, and in stirring up sand in shallow places; and the material thus put in suspension may be transported by tidal currents, aided by wind, into an estuary, and be deposited under favorable conditions; but the action of waves in modifying the channels is stopped by the intervention of training walls. Accordingly, the further the training walls are extended, and the more an estuary is protected by works such as those indicated in Figs. 1–2, the more is the modifying influence of waves eliminated, and therefore the more are experiments in a model likely to correspond with the conditions of estuaries under similar conditions.

HYDRAULIC WORKS AND PNEUMATIC FOUNDATIONS MADE AT GENOA.

The Duke of Galliera having bequeathed to the Kingdom of Italy several million francs for the improvement and extension of the harbor of Genoa, the special commission of engineers appointed to execute this work, in view of its exceptional technical difficulty, opened an international competition. Eight competitors responded to the invitation of the commission, and after a long examination they reported in favor of the project presented by MM. C. Zschokke and P. Terrier. The works to be constructed included the quays and two graving docks.

Character of the foundation.—The soil upon which the works had to be founded is a calcareous stratified rock of the Miocene formation, with shelving banks, covered with fine layers of sand and rock ruins. The formation is very variable, both as to the quality and hardness of the rock.

The water has washed away the soft parts and left the hard, so that the surface of the rock presents a series of projections with the hollows filled with sand and fragments; hence the same arrangements had to be made as if the rock had been completely porous, by substituting a béton bottom for the natural soil. The submarine operations were as follows: First, the blasting of the rock; second, the removal of the sand and rock blasted; and, third, the laying of the masonry on the bottom thus cleared.

The thickness of the banks and their great depth under water precluded, for the boring, any arrangement employing machinery set up above the level of the water. The same circumstances would have rendered the extraction of the pieces of rock by dredges very difficult. Again, the sinking of béton under water at such great depths would have given only mediocre results.

Recourse to a pneumatic process was necessary. That which the contractors proposed, and which was adopted by the commission, consisted in removing the rock and laying the masonry under water in great diving-bells, furnished with the apparatus necessary for rapidly effecting the horizontal or vertical displacement of those machines best adapted to the boring and extraction of the blasted material and the introduction of new.

This process permitted the direct building of the foundation upon the prepared bottom, avoiding risks of change of form and of rupture in the perfectly homogeneous and continuous masonry, in which no portion of iron remained imbedded. It allowed the different portions of the work to go on independently. To carry out this plan the contractors constructed,—First. A movable caisson for blasting out the rocks. Second. Two other movable caissons for constructing the quay and basin walls. Third. A great floating caisson for removing the rocks, and for laying the floor.

Caisson for blasting out the rocks.—The blasting caisson (Fig. 1) is 20 meters long and 6.50 meters wide. The working chamber does not differ from those ordinarily used for the construction of bridge piers, except that the walls are lighter, as they do not have to bear the load of the masonry above the bottom.

Iron pigs placed between the beams of the roof balance the underpressure and keep the caissons on the bottom. Two horizontal plate-iron cylinders are fixed above the frame parallel to the transverse axis of the caisson. They are open at their lower parts. A tube connects one with the other, and puts them in communication with the compressed-air pipes which supply the working chamber. Water is allowed to ascend in the cylinders to fill them when the caisson is kept at the bottom for blasting. The

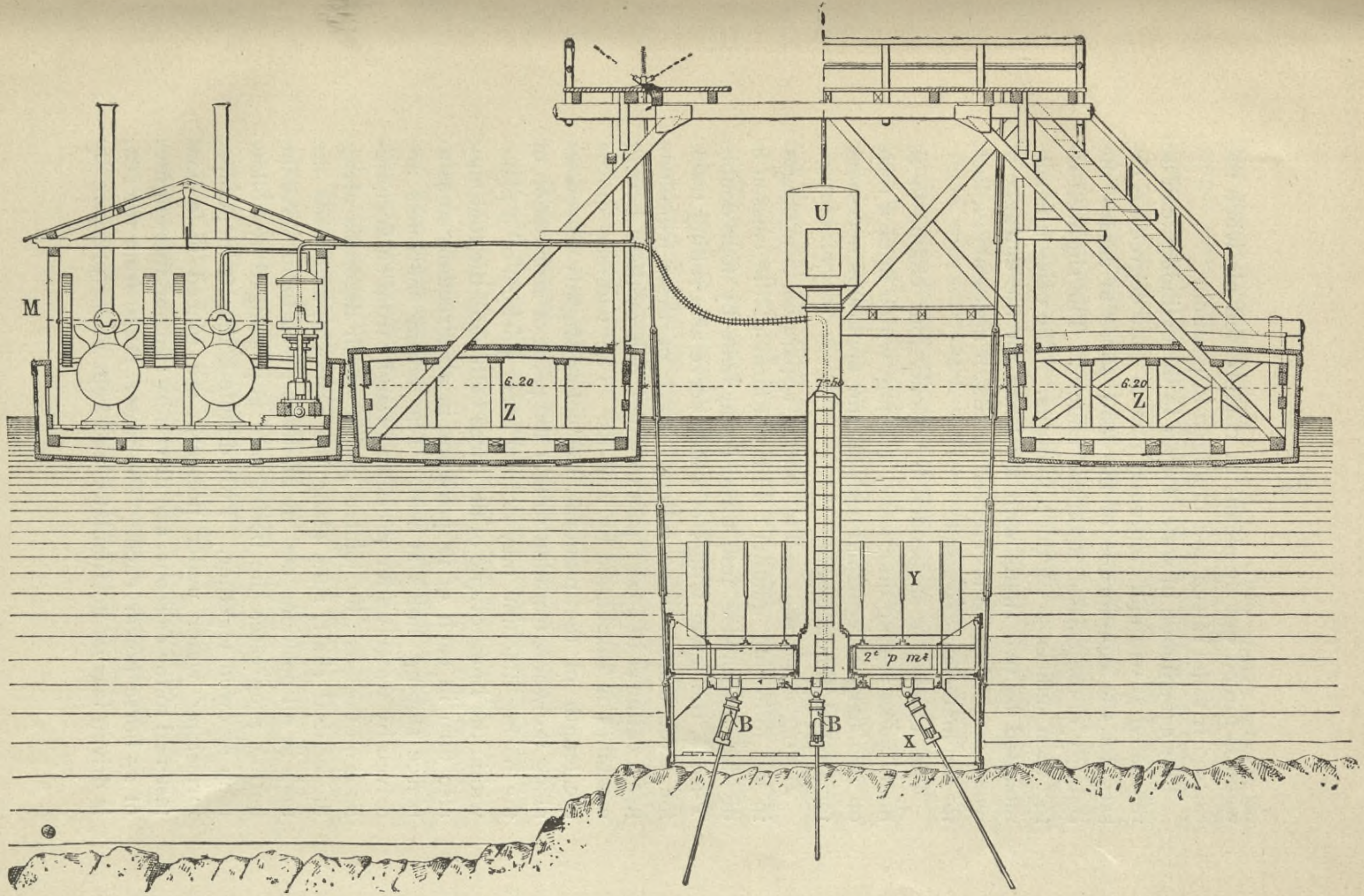

FIG. 1.—Transverse section of the movable caissons used for drilling the rock for the purpose of submarine blasting. X, the working chamber; Y, the lightering chamber; Z, pontoons supporting the caisson; U, lock for the workmen; B, drills (Brandt's system); M, two steam engines, driving pumps feeding an accumulator from which water under pressure is conveyed to drive the boring machines.

water is forced out by means of compressed air when the caisson is to be raised and changed in position.

This substitution of water for air in the cylinders, can be regulated at will and continued just to that degree necessary for the equilibrium of the load so as to assure the stability of the caisson upon the bottom. The slightest effort then suffices to lift the apparatus. The caisson is surmounted by two shafts with air locks for the entrance of workmen. A third is reserved to add, if necessary, a lock for the materials extracted.

The caisson is suspended by twenty-four chains to as many jacks resting on a heavy staging, which in turn rests on two barges furnished with all the apparatus necessary for a rapid displacement.

Boring apparatus.—The boring apparatus is arranged in the following manner: The platform of the caisson is divided lengthwise into three equal belts by four double T-irons, the lower wings of which serve as a rolling track for three trunnions on rollers. Each of these trunnions has a collar at its lower part to which one of these boring machines is suspended by a joint. The trunnion moves the length of the platform, the collar slightly unscrews along the whole trunnion so that the point of articulation of the boring machine may occupy every position of a plane within the limits of one of the three belts, and the tool may also turn in each of its positions in all directions so as to pierce sloping holes at will. The boring machines are driven by water under pressure brought from an accumulator on the boat, by jointed piping which descends along the central shaft, runs along the platform, and feeds the tools in all positions and inclinations given them. As the boring progresses the boring tool is prolonged by hollow rods screwed together. Two double-acting twin pumps, furnishing water under pressure, are placed in a boat fastened to the caissons, and driven by two portable engines of 25 horse power each. The water, taken from the sea, is driven into an accumulator and kept under pressure by the steam from the engine boilers. The steam acts on the upper surface of a plate, fourteen times the section of the piston, which transmits directly to the water the pressure of 60 or 70 atmospheres, necessary for boring. This arrangement avoids the great load which would have to be placed upon the barge with an accumulator so weighted as to be capable of giving such a great pressure. When the boring of the holes has been completed just to the required depth over the whole surface covered by the caisson, they are filled with cartridges or dynamite gelatin, the wires are attached to a floater which is passed under the cutter, the caisson is raised and moved by the supporting barges, and the mines exploded by an electric battery. By experience in regulating the distance between the holes and the amount of the charges, they succeeded in giving to the fragments of rock broken off, the dimensions most convenient for use.

The two caissons, which served also for the removal of the broken material, were constructed, ballasted, and suspended like the one just described. They were provided with a man lock, and a second lock* for the removal of the spoil and the introduction of the materials, and a third for the introduction of béton.

The second lock, small, light, and very easy to move, allowed the rapid removal of very considerable quantities, and quite large blocks without requiring for its management the presence of a single man in the compressed air.

The chain drum is driven by means of two friction wheels by a Schmid water motor taking its supply directly from the city reservoir situated 100 meters above the sea.

The two caissons served not only to introduce the béton, but also to lay the masonry and the revetement in brick and cut stone of small dimensions. When the hewn stones were of too great dimensions to be carried in through the locks they were lowered outside by means of a floating crane, the caisson which had to be removed for this opera-

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*For the details of this lock the reader is referred to the U. S. Paris Exposition Report of 1889, page 729, Vol. III., by the author.

tion was replaced, and the workmen found in the working chamber the stones to be set up.

Great floating caisson.—The great floating caisson shown in Fig. 2 is intended for the removal of the fragments of rocks made by the explosion of the mines just described and the putting in place of the béton flooring.

The caisson consists of three essential parts: First. The working chamber with its two tight plate-iron envelopes. Second. The equilibrium chamber above the first, completely enveloped with plate iron and traversed by shafts giving access to the working chamber.

Third. The iron reservoirs or regulating pits, which rest upon the equilibrium chamber without communicating with it, and which are open at their upper parts above the level of the sea. These pits, four in number, are connected, and the rectangular central portion formed by their interior walls communicates by a pipe with the sea. The walls and braces of the four pits form the framework to support the service bridges and stagings which lead to the different air locks, and carry the tracks, cranes, etc., required for the handling of the excavations and the materials.

Arrangements have been made for filling the equilibrium chamber with water or compressed air, as may be necessary, and for changing, at will, the level of the water in the regulating pits, which may even be completely emptied by means of pumps. The apparatus is thus maintained in equilibrium under all circumstances. It is brought into the condition of stability required for working by placing iron ballast between the braces and over the ceiling.

The weight of the ballast and the dimensions of the pits depend on the depth at which the work goes on with a stable caisson. At Genoa the arrangements were made for a depth of from 8 to 14.50 meters.

The rock excavations are taken out by six locks. The béton is spread along the whole length of the flooring in superposed layers of 0.50 meter thickness.

In order not to allow the caisson to be floating during these operations, it is supported upon two rows of jacks resting upon iron plates placed on the layer of béton previously spread.

The air-compressors, which supply the pneumatic apparatus above described, are placed on the land in a shop, by the side of the four 150 horse power engines which drive them. The flexible jointed supply pipes leading to each caisson are placed on rafts.

The free air spaces are lighted by Gramme arc lights, and the caissons by incandescent lamps. The shops and the caissons are connected by electric bells.

FOUNDATION OF THE JETTIES AT LA PALLICE, THE PORT OF ROCHELLE.

The foundations of the two jetties in the outer harbor of La Pallice had to be laid below the level of the lowest tide. The specifications required them to be made of great blocks of masonry, 20 meters long by 8 broad, separated by an interval of 2 meters and carried up to the level of 1.50 meters; the choice of methods for carrying out the work was left entirely to the contractors.

Above this series of blocks arose the body of the jetty, which was carried over the spaces between the blocks by little segmental arches of 3 meters span.

Process adopted for constructing the blocks.—As the blocks had to be built on the coast, without shelter against the sea, and especially against the southwest gales, the contractors could not employ the usual system of caissons, and build upon the interior flooring of the caisson, which the sea would have carried away and destroyed, but by the use of movable caissons they were able to lay dry at sea, without leaving a particle of iron in the masonry, twenty-four monolithic submarine blocks containing 1,150 cubic meters each.

Description of the caissons and air locks.—Two similar iron caissons were built by MM. Baudet & Donon, 22 meters long and 10 meters wide, with two superposed compartments. The lower compartment was the working chamber, 1.80 meters high, and the upper, the equilibrium chamber, 2 meters high, and completely tight; a platform was placed on the latter which carried a scaffolding 7 meters high, supporting a second platform 16 by 4 meters. Four locks and shafts led from the platform to the working chamber. Two of these passages carried the ordinary air locks, and two others served for the discharge of the excavations and the introduction of the cut stone.

At Rochelle, the caisson worked easily at several hundred meters from the shore, and the waves, during the tempests, passed over the scaffolding. Schmid motors were used, supplied by the compressors set up on shore. The caissons weighed 110 tons each. They carried between the braces and on the lower platform a permanent load of 220 tons of masonry. They were set up on the shore, rolled down on rollers at low tide to the bottom of an inclined plane; launched at the next high tide, and towed near to the grounding place. The draught of water, with the equilibrium chamber filled with air and the working chamber filled with water, was then 3.30 meters. The grounding was an operation always delicate and sometimes dangerous. It was necessary to go down exactly upon the location of the block to be constructed, against the waves, and especially against strong currents. It was anchored to six fixed points, one of which was furnished by the jetty behind and five others by buoys strongly anchored. The anchoring lines passed over the grooves of pulleys fixed above the upper platform and terminated at winches placed on the platform. By hauling and letting go with these winches, the position of the caisson and its alignment were regulated.

The height of the water above the bottom at low tide was, for the first blocks, below the draught of the floating caisson. It was sufficient then to let it go down with the tide. When it struck upon the bottom the valves were opened, giving the water access to the equilibrium cham-

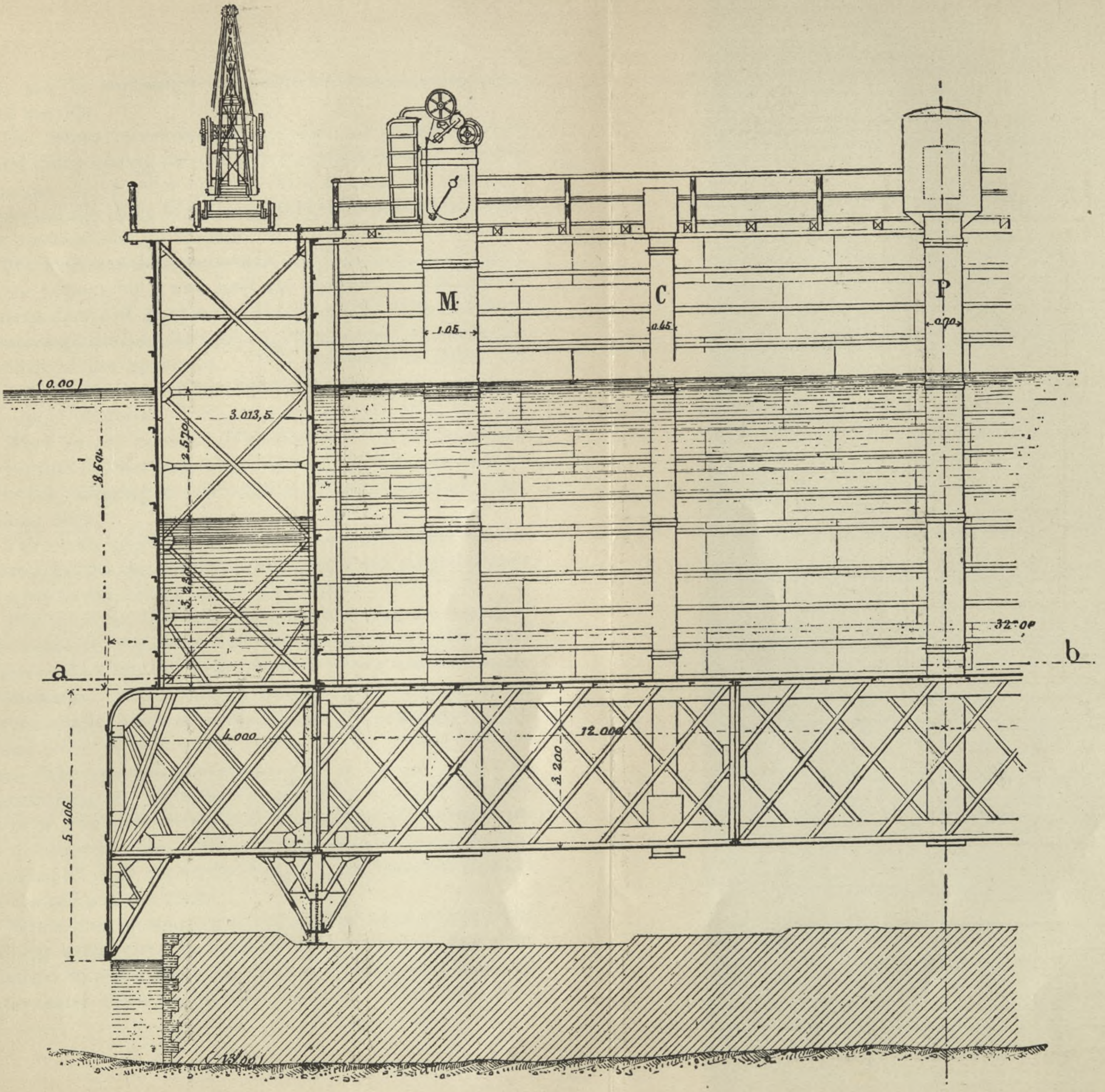

FIG. 2.—Great floating caisson used in laying the flooring of dock No. 2; transverse section. M, Shaft for the materials, 1.05 meters; P, Shaft for the workmen, 0.70 meter; C, Shaft for the béton, 0.45 meter interior diameter.

ber, and the surcharge prevented the caisson from rising with the tide.

The depth increasing as the work advanced, the low water did not bring the cutter to touch the bottom. In this case the valves were opened when the caisson was lowered, and the entry of the water into the equilibrium chamber produced the grounding.

The load was then more than sufficient to fix the caisson on the bottom, but a new load was necessary to balance the underpressure of 400 tons produced by the introduction of compressed air into the working chamber and to assure the stability of the apparatus. This surcharge of about 220 tons was given by cast-iron ballast which was stowed upon the upper platform.

Work in the caisson.—The first care of the workmen going into the working chamber was to put the caisson on a level by digging at first under the highest portions of the cutting edge.

They then proceeded to remove the upper layers of the bottom just to the limestone bed which was judged proper to serve as the foundation of the block.

The operation of raising the caisson during the laying of the masonry was done with the aid of twenty-four great screw-jacks with steel rods 1.80 meters long and 0.10 meter in diameter. These rods passed through brass nuts set up on the smaller bases of reversed plate-iron cones, the larger bases being riveted to the ceiling of the working chamber. The rods were in line parallel to the wall and 1.50 meters from it. The lower extremity terminated in the form of a hemisphere carried in a hollow of the same form in a cast-iron plate resting on the masonry, which thus avoided all rigid connection between the suspending pieces of the rod and the plate.

When the masonry was begun, the twenty-four jacks having been raised to the end of their course, had their plates 0.80 meter above the ground. A layer of masonry 0.80 meter thick could then be laid. They then took the support on this layer to raise the caisson. As there was to be overcome in this first operation, not only the weight of the apparatus, but the friction of its walls in the ground, they worked six hydraulic jacks of 30 tons, at the same time as the screw-jacks. The caisson being thus raised 0.40 meter, they kept as points of support one jack out of two, that is, twelve in all, and took away the other twelve jacks to build 0.40 meter of height under their plates. They then carried the caisson upon these twelve jacks, raised it, and then placed the twelve others to lay the masonry under. They had thus, around one block and just to the walls, a continuous belt of masonry 1 meter thick and 0 40 meter high. By a double working of the jacks identical with the preceding, they raised the caisson again 0.40 meter and carried the height of the surrounding belt to 0.80 meter. They then filled with masonry the portions within the belt, which completed the second course of 80 centimeters. They proceeded in the same manner until the block rose to the reference, 1.50 meters.

High waves interrupted the work sometimes for several weeks, during which the caisson, exposed to the tempests, had to rest upon its twenty-four jacks. First, they limited themselves to removing the underpressure and allowing the water to come into the working chamber and placed a number of struts between the walls of the caisson and the partly finished block. Experience having shown that these precautions were insufficient, they built upon the block four great pillars of masonry reaching up to the ceiling, upon which the caisson rested during the interruptions of the work.

They worked night and day in the caissons (except during the incessant stoppages caused by heavy seas). An average of eight hours out of the twenty-four was used for laying the masonry, the sixteen others to raise the caisson and to carry the stone into the working chamber. Fifteen masons worked in the caisson, with thirty laborers, laying 50 cubic meters of masonry per day. These hands did not include those employed on the service bridge for carrying materials and for the preparation of the mortar on shore. The caissons were raised by sixty men, forty-eight to work the twenty-four jacks, and twelve for the six hydraulic jacks. It took on an average one and three-quarter hours to raise the caisson 0.40 meter.

Displacement of the caisson.—When a block was finished they waited to the next high tide to disengage the caisson.

The reference of the top of the block being 1.50 meters and that of the high tide 5.40 meters, with a draught of water of 3.30 meters, there was a margin of about 0.60 meter for the grounding.

The operation of displacement consisted in withdrawing the cast-iron ballast, which was deposited upon the boat, in replacing the six anchorages at low tide and in driving out the water from the equilibrium chamber, and allowing the caisson to rise with the tide. At the moment of high tide they pulled with the winches upon the anchorage chains toward the open space, and they let go on the opposite side until the caisson was brought over its new anchorage. They then repeated the operations already described for immersion.

The difficulty of this operation arose because the caisson had to float nine hours, often in the night, from the moment when it lost its support upon the finished block to the moment when the following low tide allowed it to be grounded anew. If a tempest arose when the caisson did not cover the block they could, although not without risk, precipitate its immersion; but the danger would be very much greater if a sudden change of weather, as was often the case in these regions, had overtaken the cassion floating at the moment when one could not disengage it from the block nor ground it again upon it, hence they did not move the caisson except when the weather appeared to be favorable and the tide sufficiently high. It was not possible always to fulfill this double condition, except by waiting five or six weeks, during which the materials and the workmen were idle.

These operations of incontestible boldness were repeated twenty-four times.

Access to the caisson was from the jetty, which was built as the first blocks were laid, and by a service bridge constructed upon the last blocks not yet finished.

This service bridge rested on an iron framework having its uprights of channel iron fixed in the masonry. It was constructed as light as possible, so as to not offer much resistance to the waves, but at the same time solid enough to give passage to the cars loaded with materials for the work. Over this bridge passed the electric wires for lighting, the two air pipes which supplied the working chamber, and the air for driving the little motors of the excavation locks.

The level of this service bridge was constant, while the platform surrounding the locks varied according to the height of the caisson on the block. When the platform was sensibly higher than the service bridge the two were joined by a safety planking, carrying rails upon which the little cars were raised by means of a winch driven by one of the little compressed-air motors of the locks.

The construction of these great blocks began in 1884, and terminated in 1888. During this time the two caissons constructed twenty-four blocks.

The depth at which the blocks were laid varied from the reference, 0.76 to 5.35 meters.

The total cubic mass was 18,000 cubic meters ; it was paid for at the rate of 70.49 francs per cubic meter, the excavated rock and cement being provided by the Government.

For the purpose of maintaining a large coffer dam it became necessary to join the blocks with solid masonry ; this very difficult operation was accomplished by converting the interval into a caisson formed by the two walls of the blocks and two lateral iron panels* held together by

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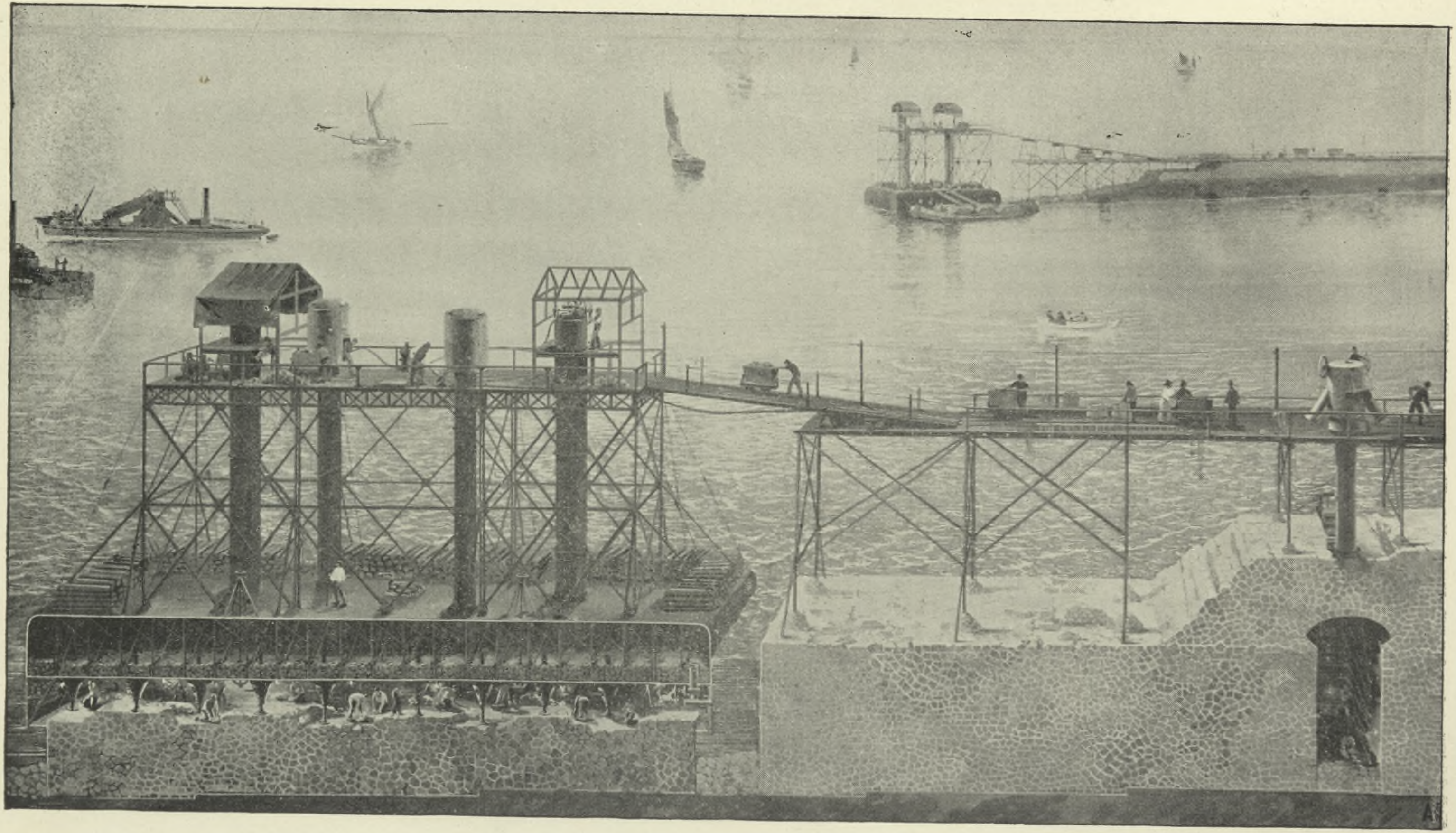
*The details of this operation are given on pp. 742–744 Paris Exposition Report Vol. III., 1889.

tie rods and turn buckles, the whole covered by an arch through which an aperature was left for the passage of the lock shaft.

This operation is shown in Plate 1. At the right is seen the arch loaded with masonry to resist the under pressure, through which passes the shaft surmounted with its air lock. One panel being removed, the tie rods are seen hanging from the other.

PLATE I.

OUTER HARBOR OF LA PALLICE (ROCHELLE).



VIEW OF THE CAISSONS IN OPERATION — METHOD OF JOINING THE BLOCKS.

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