CONSORZIO AUTONOMO DEL PORTO DI GENOVA
(THE PORT OF GENOA AUTHORITY)

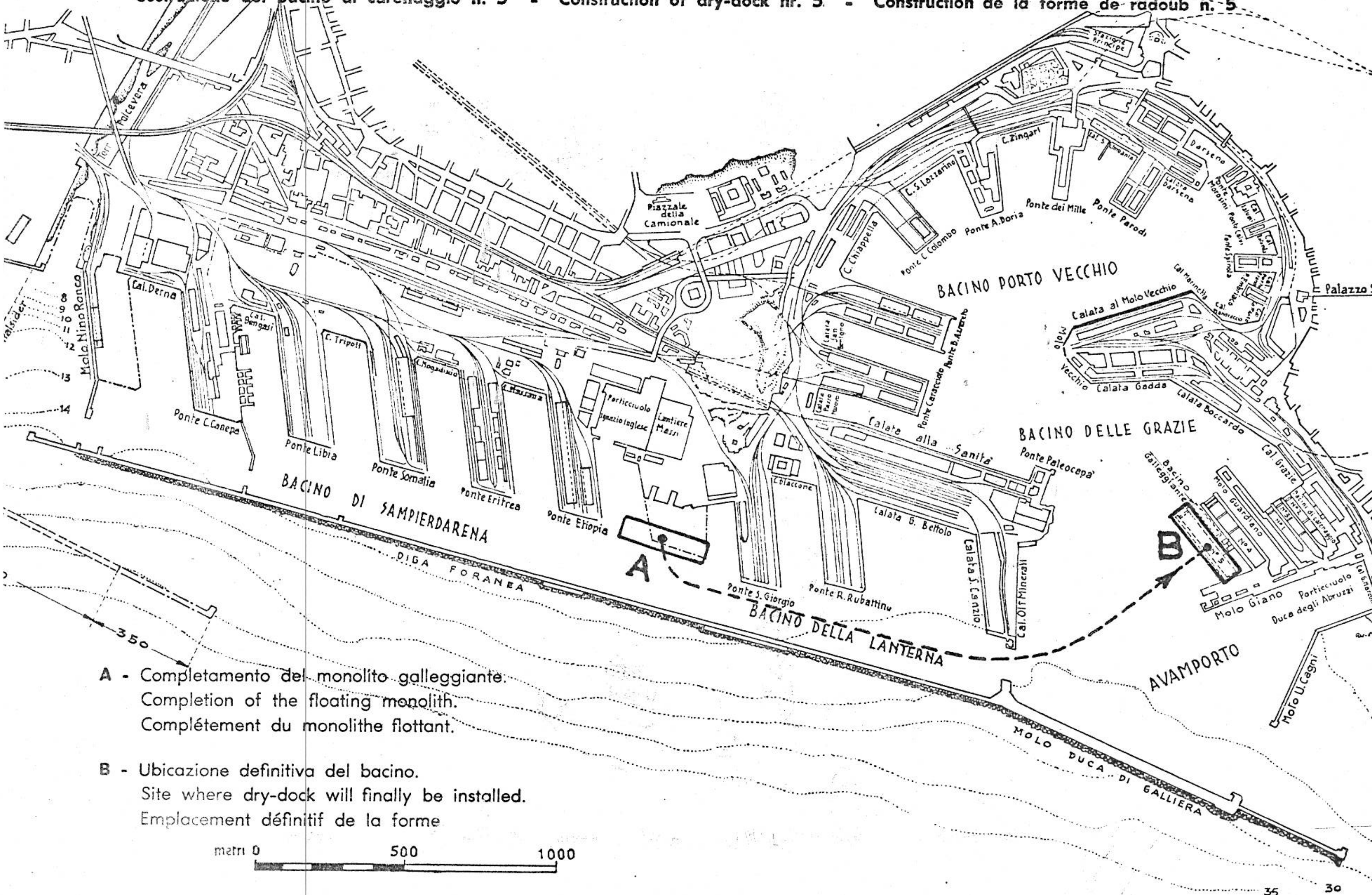
Construction of dry-dock nr. 5

PAPER PRESENTED TO THE XX CONGRESS
OF THE PERMANENT INTERNATIONAL ASSOCIATION
OF NAVIGATION CONGRESSES
BALTIMORE, U.S A. / SEPTEMBER 11th - 19th, 1961

ARTI GRAFICHE NOVIERO - GENOA, ITALY

PORTO DI GENOVA — PORT OF GENOA — PORT DE GÊNES

Costruzione del bacino di carenaggio n. 5 - Construction of dry-dock nr. 5 - Construction de la forme de radoub n. 5



A - Completamento del monolito galleggiante.
Completion of the floating monolith.
Complétement du monolithe flottant.

B - Ubicazione definitiva del bacino.
Site where dry-dock will finally be installed.
Emplacement définitif de la forme

1. GENERAL.

The volume of commercial traffic in the port of Genoa has increased in an exeptional manner in the last few years and, as a result of this, there has been a greatly increased demand for facilities for the maintenance and repair of ships so that the existing five dry-docks, one of which is of very small dimensions, have become insufficient to deal with the situation. The administration of the port therefore decided to build a new dry-dock, and for this purpose opened up a competition for the best design.

Five designs were examined by the judicial commission which was nominated by the Ministry of Public Works. Of these five, three were of a type which has been adopted many times, that is, the side walls were to be constructed in sections of reinforced concrete, prefabricated and sunk into position with the use of compressed air. They were to be lowered until they rested on solid rock and then the base of the dry-dock would be built in of solid concrete. The fourth design was for a monolithic basin prefabricated in reinforced concrete to be built in another place and then towed and sunk into its designed position.

The foundation for this fourth design would have consisted of large diameter piles sunk deep into the rocks. Six rows of piles were to be used, parallel to the axis of the dry-dock. On these piles the cellular structure of the sides and dock bottom would have rested. The two central rows of piles would function in tension when the dry-dock was empty in order to resist the effect of buoyancy.

The fifth design which was presented by the Society « Fincosit » of Genoa, and designed by Ing. Paolo Vian and Ing. Giovanni Borzani was chosen by the judicial commission because of its higher thechnical efficiency and the considerable economy which it offered over the other designs. It is now in an advanced state of construction. This design took into consideration the extremely irregular contour of the rocky bed and was intended to dispense with any connection between the structure of the dry-dock and the rocks, and also to overcome the effects of buoyancy.

As will be explained in greater detail below, the dry-dock constitutes a basin in pre-stressed reinforced concrete of cellular construction forming a single monolithic structure, which was actually floating during the various stages of construction. First the base of the dry-dock was built in fifteen large pre-fabricated caissons held together by means of steel wire ropes arranged in such a manner as to induce a compression in the structure, sufficient to counteract the tensions which would be induced in the normal performance of the dry-dock. The sides of the dock were built in a similar manner and were constructed above that floating platform and afterwards fitted throughout with a similar system of wire ropes in tension.

Upon final completion of the sides the dry-dock will be towed to its designed position and will be sunk by gradual ballasting, first with water and then with sand. It will be based on a bed or foundation formed of sand covered by a thickness of crushed stone carefully levelled off.

In other words, the dry-dock has been built completely as a floating unit and will be sunk onto a prepared bed without being connected to it in any way.

2. CHARACTERISTICS OF THE DRY-DOCK.

The dimensions of the new dry-dock are as follows:

— Overall length	m. 260,49	(feet 854.68)
— Net length between the internal surfaces of the floating gates	m. 250	(» 820.22)
— Depth of water over the platform at mean tide level	m. 10,5	(» 34.45)
— Depth of water over the central docks at mean tide	m. 9	(» 29.53)
— Internal width (constant)	m. 38	(» 124.68)
— Thickness of each side wall	m. 7	(» 22.97)
— Height of side walls over mean tide level	m. 3	(» 9.84)

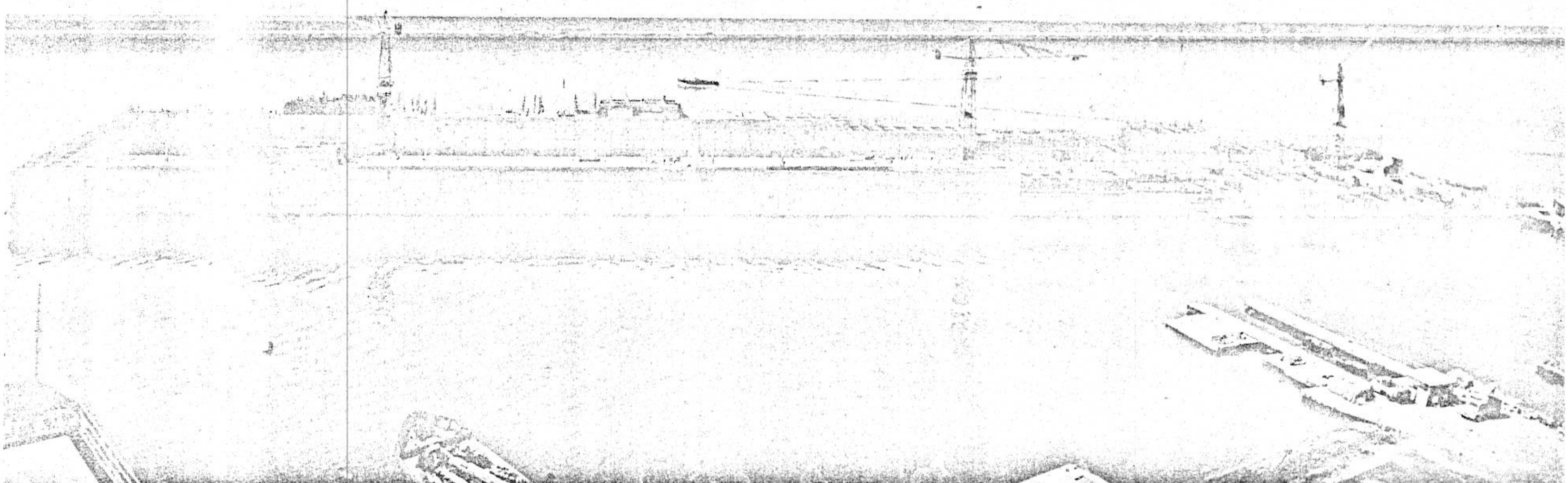
The pumping out of the dry-dock will be effected by three groups of electric impeller pumps designed and built by Messrs. Ansaldo San Giorgio, Genoa, with a total of 2,400 h.p. and four smaller electric pumps, of 112 h.p. to be used for draining the usual small leakages through the floating gates.

This equipment, which is to be arranged within one of the side walls, will enable the dock to be pumped dry within two and a half hours.

Mounted on the side walls there are to be two cranes of seven tons lift at a radius of more than half the width of the dry-dock and the advisability of a third crane with a 30 ton lift is being considered.

In a specially designed tunnel along the side walls there are connections for the distribution of electrical energy (direct and alternating currents) compressed air and fresh and salt water at a height of 60 cm. (23".62) above water level.

Below theses compartments there is a tunnel which runs the full length of the dry-dock with ample openings into the basin when the dry-dock is in process of being pumped out.



Construction of the side walls.

On the side walls there are arranged seven electric capstans as well as mooring bollards, mooring rings and bitts. In addition to the fixed central blocks on the dock platform there are six rows of side blocks (three a side). The upper surfaces of these side blocks may be adjusted by about 40 cms. (15".75) to the forms of different ships by wedges and wooden caps.

There are six internal stairways to the platform and one external as well as six sets of steps to the sea.

The connections for the distrubution of power etc., referred to above are fully accessible even when the dock is flooded. The dock gates, built by « Cantieri del Tirreno » will be of the floating single wall type.

3. CHARACTERISTICS OF THE SEA BOTTOM. PREPARATION OF THE BED.

Taking into accont the elastic properties of the structure chosen for the dock it was very important to make a careful study of the nature of the dock bed, and of the arrangements necessary to render it capable of carrying the dry-dock. The natural bed, which was at a depth of 14 metres (45'.93) was composed at the upper levels of very fine sand mixed with lime with some areas of coarser sand here and there. Below this layer of sand, however, banks of calcareous rocks which were extremely hard and of practically unlimited strength were found and their upper surfaces and contours were extremely irregular. There were very considerable differences in the levels of this rocky bed, both in the longitudinal sense (from a minimum of 17,5 m. (57'.42) below water in the north-west zone, to a maximum of 28 m. (91'.87) in the south-east zone) as well as in the transverse sense. The designed loading on this bed varies from a minimum of about 0,30 Kg/cm^2 (4.267 lb./sq.in.) with the dry-dock empty to a maximum of 1,30 Kg/cm^2 (18.49 lb./sq.in.) with the dry-dock flooded, depending on the conditions of use.

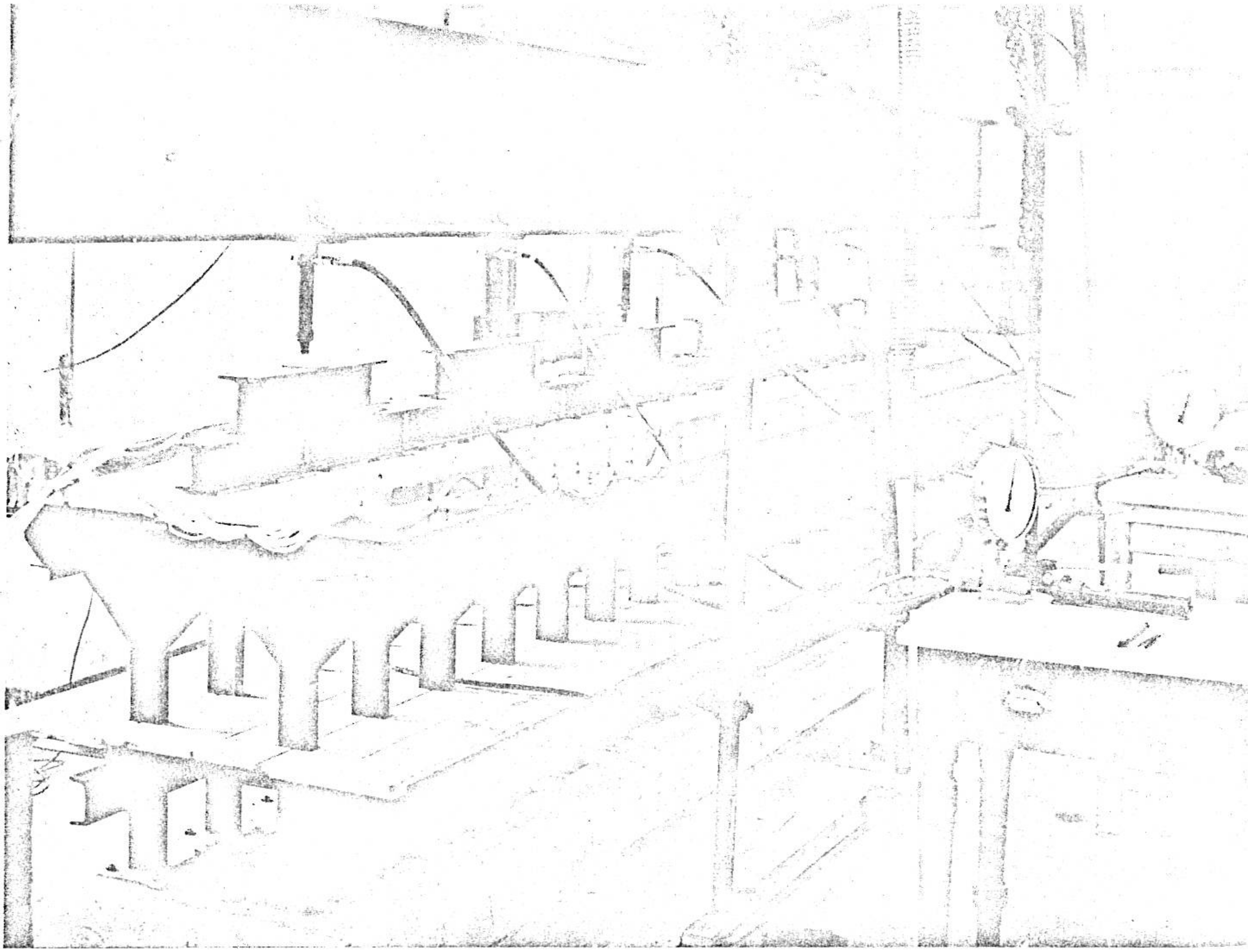
These are quite modest values; even in the condition of maximum load, and in service they will vary only gradually on the surface of the dock bed, but even so they are sufficient to provoke settlements in the layers of compressible materials which are to form the foundations, both during the initial lowering of the dock into position and also during its continual use afterwards. Therefore if excessive variations in the thicknesses of the different compressible layers were to be permitted it would be reasonable to expect differences in the degrees of settlement which would take place in various points over the area of the bed. This condition would certainly produce abnormal stresses in the structure of the dock.

It was vitally important, therefore, to choose the most suitable materials to form this bed in order that the degrees of settlement over the entire area would be such as to give a sufficiently constant level for all conditions of service. For this purpose experimental tests were carried out in Genoa on specimens half a metre (1'.64) in diametre and at the Geotechnic Centre in Padua using normal laboratory equipment of the various materials found in the natural bed as well as of materials of other types so that the most satisfactory and useful materials could be chosen for the formation of the dock bed. We established by these means the moduli of compressibility and the characteristic qualities for the determination of the settlement to be expected with variations in time, load, thickness and quality of all the materials investigated. To complete these studies, a series of investigations were also carried out on models at the University of Genoa and these also served to ascertain the behaviour under static loads of the dry-dock itself. Two models were actually built, one to a scale of 1 : 50 of the entire dry-dock with the object of enabling an experimental investigation to be carried out on the entire dry-dock structure under conditions of loading specially studied to simulate the actual working conditions. The other model, to a scale 1 : 12, reproduced a transverse section of the dock in order to permit a more profound study of the cellular structure of the basin. The models were supported on bases of rubber, the compressibility of which had been arranged in such a manner as to reproduce as closely as possible the expected elastic deformability of the dock bed.

From results obtained from theoretical study of the designs and numerous and careful laboratory tests on various materials as well as the experimental tests on the models, the designers, assisted by eminent consultants from universities decided that variations in the thicknesses of the layers of compressible materials below the dock should be limited to only 50 cm. (19".68). From practical and economic considerations the bed was to be formed of very fine and homogeneous sea sand.

With these criterions it is expected that, with a maximum thickness of 2,5 m. (8'.20) of the compressible layer a settlement of not more than about 7 cm. (2".76) need be expected. This should ensure a maximum angular distortion in either direction of between 1/500 and 1/1,000. These values are considered admissible to ensure the necessary safety margin.

It was decided to remove all mud and soft sand from the natural bottom down to bare rock and to replace it in the deeper areas with underwater concrete using pozzuolana cement up to a level of 21 m. (68'.90) below the surface with gradual smoothing up in the zone of 21 m. (68'.90) to 20,5 m. (67'.26). In all areas where the rocks rose



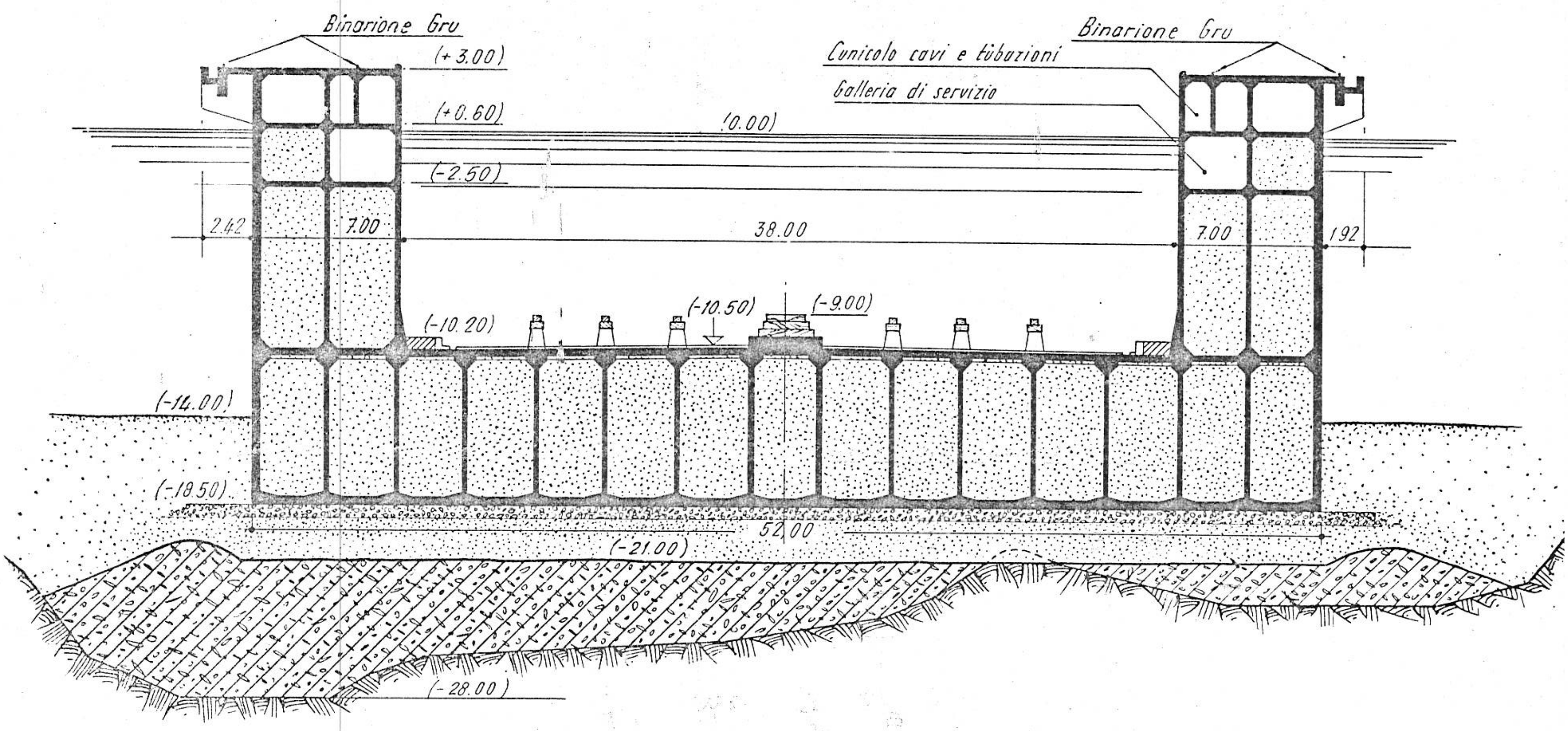
Tests on models. - Model A - Fitted to simulate a condition of longitudinal loading in which the full load is carried on the central block. Scale of model 1:50.

above 20,5 (67'.26) below the surface they were to be removed to that depth.

Above the level of this incompressible material, rocks or concrete, was laid a stratum of sea sand up to a level of 19 m. (62'.34) and above this another layer of crushed stone up to a level of 18,5 m. (60'.70).

The substitution of crushed stone for sea sand in the uppermost level was considered advisable because of the necessity to obtain as perfectly flat a surface below the basin as possible.

By adopting these measures is is believed that we have overcome the grave consequences to be expected from uneven settlement over the area of the dock bed as a result of the great irregularity in the contours of the underlying.



Typical rransverse section

4. CRITERIONS USED IN THE DESIGN OF THE DOCK.

The design of a large dry-dock of cellular and monolithic construction intended merely to sit on a foundation of elastic materials even though that foundation should be of almost uniform thickness presented considerable problems, both in the design of the actual dock itself as well as in the necessity to obtain sufficient knowledge of the physical properties of the foundation which extended such a large area.

From the theoretical point of view it was necessary to calculate a structure capable of supporting not only the external forces such as the weights of the ships to be docked and the weight and buoyancy of water on the side walls, but also the entire effects of buoyancy and the reactions caused by the elastic bed on which the dock had to sit. It was therefore necessary to know the disposition of these reactions and their intensity in various points, values which were intimately connected with the nature of the different strata of materials forming the bottom as well as the distribution of the external loads.

After having established the characteristics of the bed (as explained in Chapter 3) the designers used normal methods of calculation for the structure and stability for the dry-dock itself. They calculated the behaviour of the dock in both the longitudinal and transverse directions separately for each condition of loading to be expected during construction and in actual use.

For verifying the behaviour of the structure in both directions they used the well-known theory of an elastic beam on elastic supports developed by Timoschenko, K. Beyer, Belluzzi, etc. For the relations between the deflections of the structure and the actions transmitted to the supporting bed the theories of Zimmerman-Winkler were used, a relationship of the type $p=cy$.

The theory of Zimmermen, of course, allows for a local deflection between the load and support to be taken into consideration even though this local deflection is the result of the load spread over the entire surface.

It will be realised that to carry out all the necessary investigations by the application of these meticulous methods of calculation — taking into account the number and variety of the conditions of loading and the nature of the support which had to be examined — would have involved an excessive amount of work. Therefore it was decided to proceed with the analitical investigation of deflection and stresses according to the Winkler-Zimmermen theories, but at the same time to effect a systematic series of experiments on two models especially built for this purpose (and already mentioned above).

Both the analytical calculations and the experiments on the models were repeated several times using different values for the elasticity of the materials forming the bed, values which had been obtained from the laboratory tests and experiments carried out on these materials as already described.

The results of the investigations carried out on the first model, that is, the one of the entire dry-dock, showed that the deflections obtained from the analytical calculations in both longitudinal and transverse senses corresponded in a very satisfactory manner to those obtained experimentally.

It may be said that the results obtained from the models with regard to deflections and pressures, especially those in way of the extreme ends of the dock were less than those given in the analytical calculations, and their distribution was more uniform also.

The second model, of only a portion of the dock, also showed values of tensile stresses generally less than those given by calculation (no doubt because of the inevitable simplifications involved in theory and probably also because of the greater stability of the connections between the different portions of the structure obtained in practice). From this model we were also able to obtain the intensity of stresses in particular points of the structure at which concentration of forces occur, but which would not be capable of analytical investigation because of their complexity.

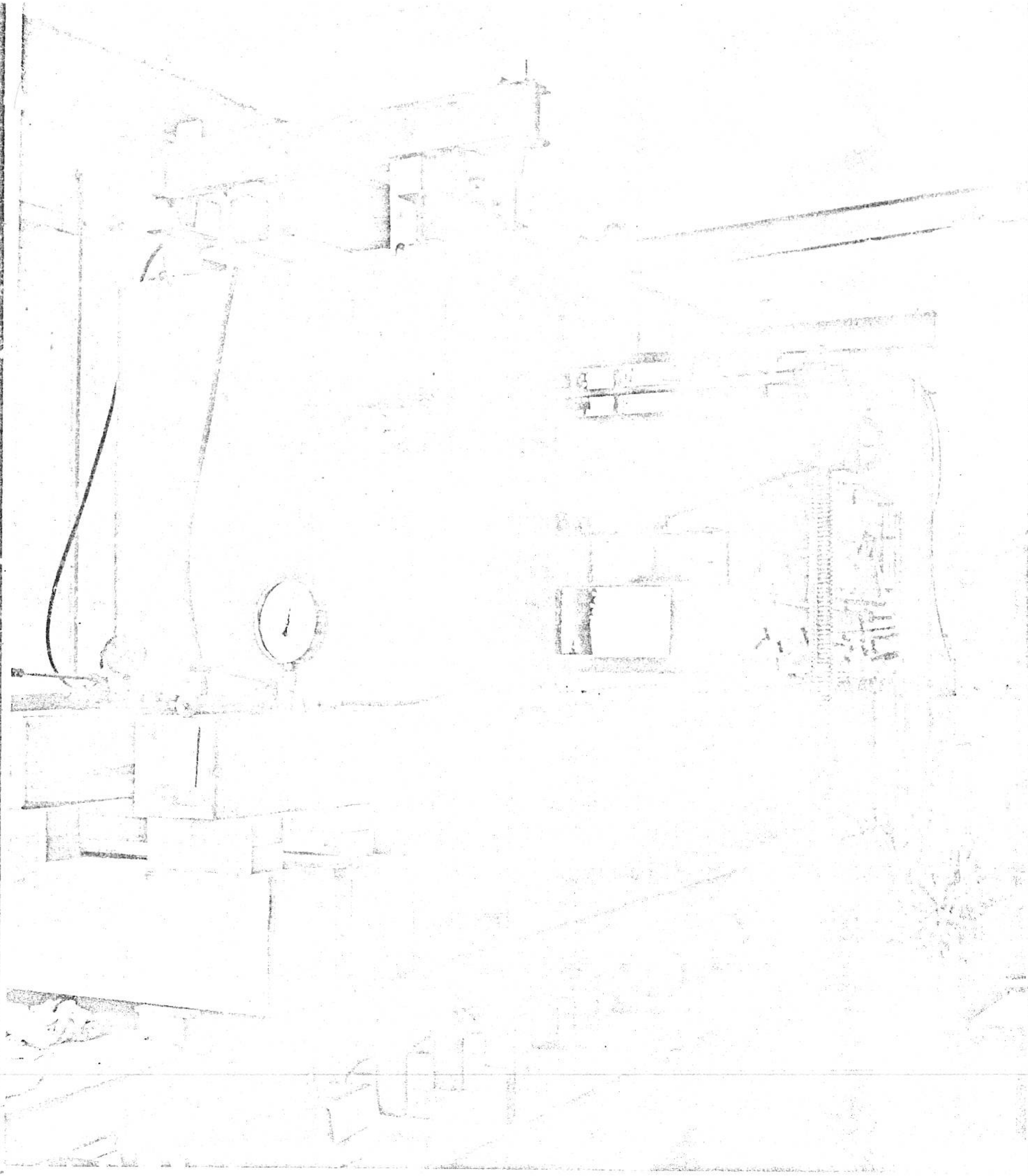
The cellular structure of the dock envisaged in the original design was of normal reinforced concrete material. It was decided, however, with the full agreement of the original designers, the builders and the Judicial Commission, to adopt the use of prestressing the concrete to a large degree using steel wire ropes of high elastic limit passing through the various sections of the dock platform in longitudinal, transverse and vertical directions, similar pre-stressing was also adopted in the side walls.

The principal reason for this variation was to counteract in the most effective manner the stresses caused by contraction which could arise in the concrete — even though the most modern techniques and the highest quality of materials were to be used — and so to eliminate capillary cracks which could in time damage the structure.

The following additional advantages were also taken into account in this decision:

a) To improve the impermeability of the concrete.

b) To overcome in the most secure manner the problems involved in the transverse joints between the prefabricated caissons which constituted the dock platform.



Tests on models. - Model B - Fitted to show the effects of the weight of the side walls and for the study of any uneven settlement in the dock bed. Scale of model 1:12.

c) To reduce tangential stresses caused by shear forces to fully admissible values.

d) The fact that this cellular monolithic structure would react in a better manner elastically, not only to the calculated stresses but also to any unforeseeable load which might come upon it, because the pre-stressing wires would tend to pull the deformed structure back into its initial position of equilibrium. A marked advantage on the uneven deformations which have to be accepted in normal re-inforced concrete structures.

To obtain these results almost 10,000 wires totalling nearly 200 Kilometres (124.27 mi.) were used, each wire is formed of 12 strands, 7 mm. (0.2756 in.) in dia., of steel having a breaking strength of about 170 Kg/mm^2 (107.94 tons/sq.in.) the wires were anchored by means of cement cones of the STUP type.

Caissons forming dock platform. - Particulars of steel reinforcements and of the ends of the pre-stressing steel wire ropes.

5. METHODS OF WORKING.

The building of this drydock required the study of new techniques which interested not only those occupied in the organisation of work but also the designers. In fact these techniques open up new possibilities in the field of maritime constructional work. Work was carried out simultaneously in two directions: on the pre-fabrication of the monolith and on the preparation of the bottom of the sea where it had to be installed.

6. PREPARATION OF THE BOTTOM.

Work commenced by excavating all mud and soft materials first by means of a bucket dredger and then by means of grab pontoons until the rocks were fully exposed. In the north west part it was necessary to cut away the rocks which in that area arrived to only 17 mt. (55'.58) below the surface. After several unsatisfactory attemps with the rock breakers, of 10 tons weight, and with explosives, we obtained optimum results from a compressed air driven demolition hammer weighing about 8 tons with a point 200 mm. (7".87) in diameter.

With careful arrangements for mooring and shifting the pontoons, from which the hammer was suspended, it was possible to use it in spots only 50 cm. (19".68) removed from each other. The hammer was able to penetrate the rocks to a depth of 1½ mt. in an average time of only one minute. The rocks were then fragmented and it was possible to carry them away in a hopper barge using a bi-valve grab of 5 tons. With this equipment about 10,000 cu.mt. (13,080 cu.yd.) of rocks were carried away from the considerable depth of between 18 (59'.06) and 20 mt. (65'.62) below the level of the sea.

Whilst on one side the work of breaking down and carrying away the rocks proceeded, the pouring of under-water concrete to form a solid bed between the levels from 28 mt. (91'.87) below up to 21 mt. (68'.90) below proceeded on the other. A total of 22,000 cu.mt. (28,776 cu.yd.) of concrete were used.

For this purpose we adopted a system of cement mixers on a self-contained barge capable of mixing about 200 cu. mt. (261 cu.yd.) of concrete per day and lowering it to the required depth by a grab of 1 cu.mt. the bottom of which was opened by means of compressed air controlled from the pontoon. The lowering of the grab was effected by a winch driven by direct current, this was found to be easily manoeuvrable and reached the rocks at a depth of 28 mt. (91'.87) in approximately 2 minutes. Continual soundings enabled the work to proceed smoothly with satisfactory precision.

This concrete base has been completed and the pouring of sea sand to form the elastic cushion above the concrete is now proceeding. A suction dredger of 400 cu.mt. (523 cu.yd.) capacity is being used and with suitable care a very uniform and level bed of sand is being obtained at the considerable depth of 19 metres (62'.34).

Above this bed of sand we have now started to place the layer of crushed stone which will arrive to the level of 18½ mt. (60'.70) below the water, at which depth il is intended to place the dock.

7. CONSTRUCTION OF THE MONOLITH IN PRE-STRESSED REINFORCED CONCRETE

The dock consists of a platform 52 mt. (110'.60) wide, 260,49 (854'.68) long and 8 (26'.25) high and of sides and ends 7 mt. (22'.97) wide which are solidly connected to the platform. The platform is built of 15 large cellular caissons each or 52 mt. x 17.4 x 7.8 (170'.60 x 57'.09 x 25'.59) rigidly connected together.

8. CONSTRUCTION OF THE CAISSONS.

Every caisson was built on a mobile metal platform supported on reinforced concrete columns.

The construction of each caisson was commenced above the water on the mobile platform. When the first portion of concrete was sufficiently hardened however the platform was lowered into the water and then the caisson was progressively immersed as its construction proceeded. Using the buoyancy of the water in this manner it was possible to complete the construction of a caisson without exceeding a predetermined load on the platform.

The platform was carried by a group of 48 winches of 35 tons each, all synchronised to work together. They were supported on the reinforced concrete pylons which also carried the steel movable frames from which were suspended the complex system of channels for the distribution of concrete over the large surface of the caisson. The shutters used were steel and of automatic type.

As soon as a caisson was finished this would be launched simply by lowering the platform and it would then be a floating body.

One of the most delicate operations consisted in exactly positioning the tubes or tunnels through which the steel wires had to pass. The longitudinal wires had to pass through from 2 to 4 caissons and

Launch of a bottom caisson. - The upper surface of this caisson will be built immediately after the launch.

it was necessary therefore for the numerous openings in each caisson to be perfectly aligned with those in the adjacent one, these holes were provisionally closed watertight so that the caisson would float.

9. JOINING TOGETHER OF THE CAISSONS.

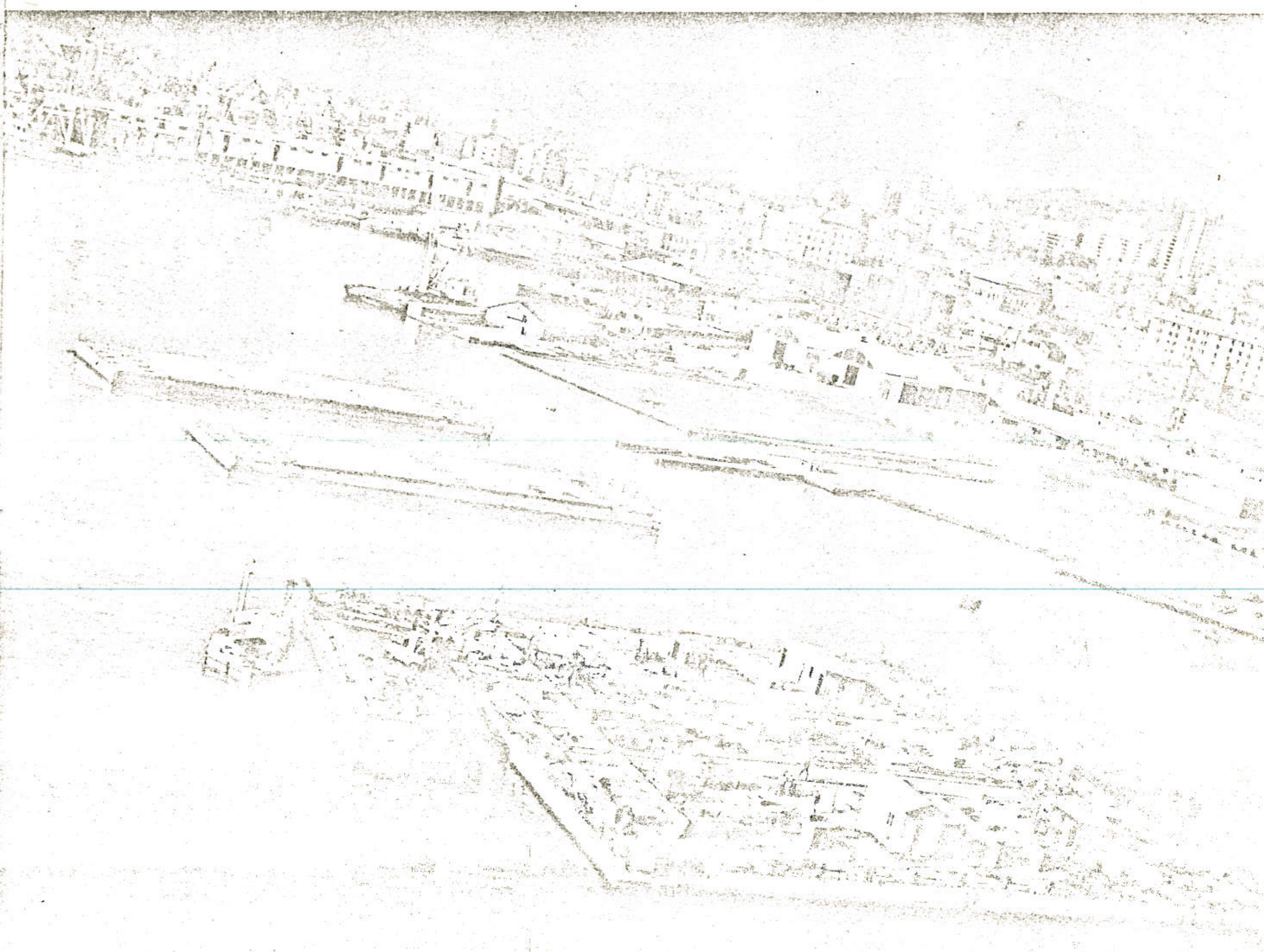
As each caisson was built it was fitted with its upper surface and then towed to another area in the port in order to be connected to the caissons already launched.

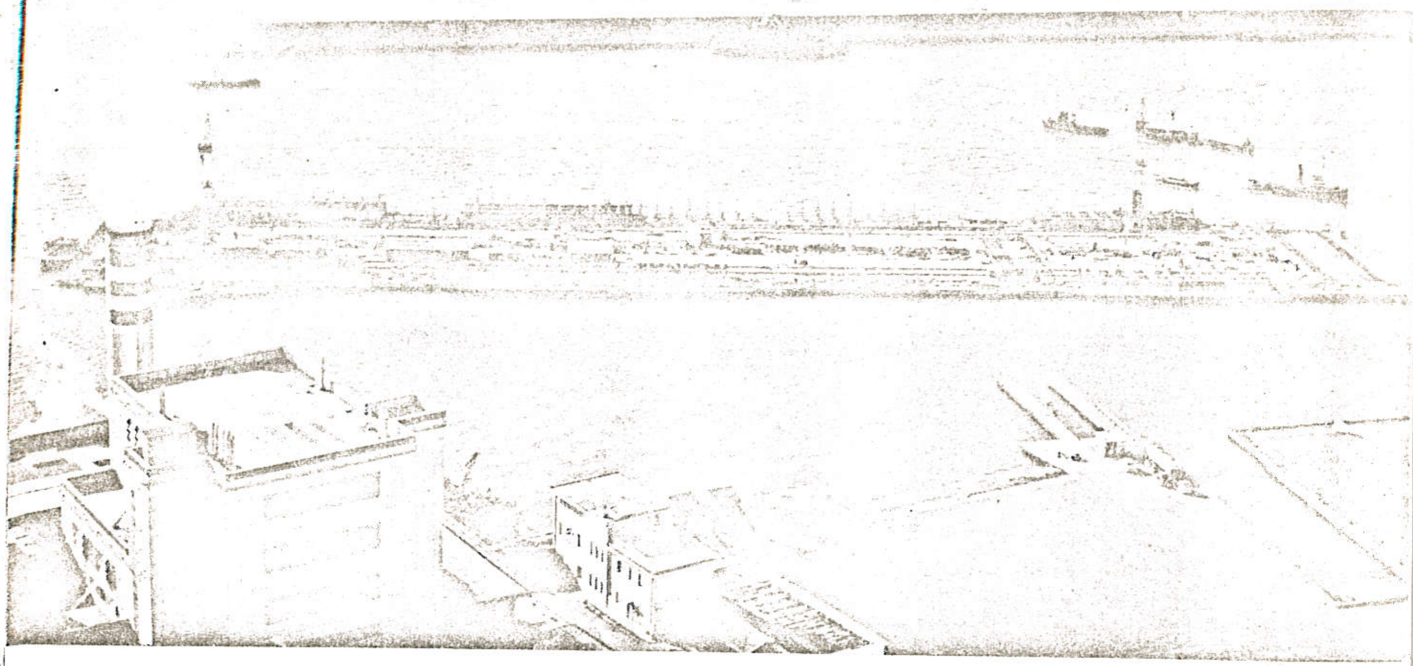
Each caisson was fitted with a fin along the edges to be joined, as the fins of two adjoining caissons came together they were fitted by divers with a rubber jointing to render them watertight and permit the space between the two caissons to be pumped out.

The initial joining of the caissons was obtained by adjusting the water ballast in some cells, and with the use of four hydropneumatic turnbuckles fitted on their upper surfaces.

The steel reinforcing of the joint was then proceeded with, tubes

View from the air of the zone in which the platform caissons were joined together. Note four caissons already joined and two others ready to be connected.





Commencing the construction of the side walls above the already completed dock platform.

for the passage of the steel wires were put in position and then the concrete was poured, then, after an interval for hardening, the longitudinal steel wire ropes were fitted.

At the same time as the above, the system of transverse and vertical steel wires was proceeded with. In this manner the complete joining and pre-stressing of 15 caissons to form the platform of the dock was achieved, it formed a small floating island having a displacement of about 100,000 tons attached to the ground only by a telephone wire.

10. CONSTRUCTION OF THE SIDES AND ENDS.

The pouring of the concrete for the construction of the sides is being effected with 4 cement mixers on floating barges, which were used two at a time, whilst actually to lay the concrete 2 movable tower cranes were temporarily fitted on the dock platform running on rails parallel to the axis of the drydock, the cranes are also used to handle the metal shutters and a third crane, placed where the dock gate is to be, is used for unloading from the barges the steel and everything else required for fitting out the floating island.

11. MOVING AND SINKING OF THE MONOLITH.

When the sides are finally completed the floating monolith will have a displacement about 130,000 tons and a draft of about 10 metres (32'.81). It will then be towed from its present position, near the lighthouse, for about 2 Kms. (1.08 mi.) within the port of Genoa to its final position at the « Grazie » berth where the bed is being prepared.

For the final operation of lowering the dock into position we have provided for ballasting it, to a precise programme, with about 100,000 tons of water which will take the dock from a draft of 10 mt. (32'.81) to the final one of 18½ (60'.60) without imposing any serious stresses on the structure but at the same time maintaining its stability in water.

12. BALLASTING OF THE DOCK AND THE WORK OF FITTING OUT.

When the dock is sunk onto its bed the cellular structure will be ballasted with 84,000 cu.mt. (109,872 cu.yd.) of sand in the internal cells of the bottom and sides. This will be done with the use of a « blower » dredger. The dock will then have acquired sufficient weight to permit the basin to be pumped out for use.

For this purpose the dock gate will be floated into position at the end of the basin which will then be pumped dry so that the other seatings for the gate, the paving of the dock and fitting of the blocks etc. may be proceeded with.

Genoa, August 1961.

Dr. Eng. Leonardo Gasco
Dr. Eng. Mario Grimaldi
Dr. Eng. Ennio Del Balzo