Superplasticizers and Other Chemical Admixtures in Concrete

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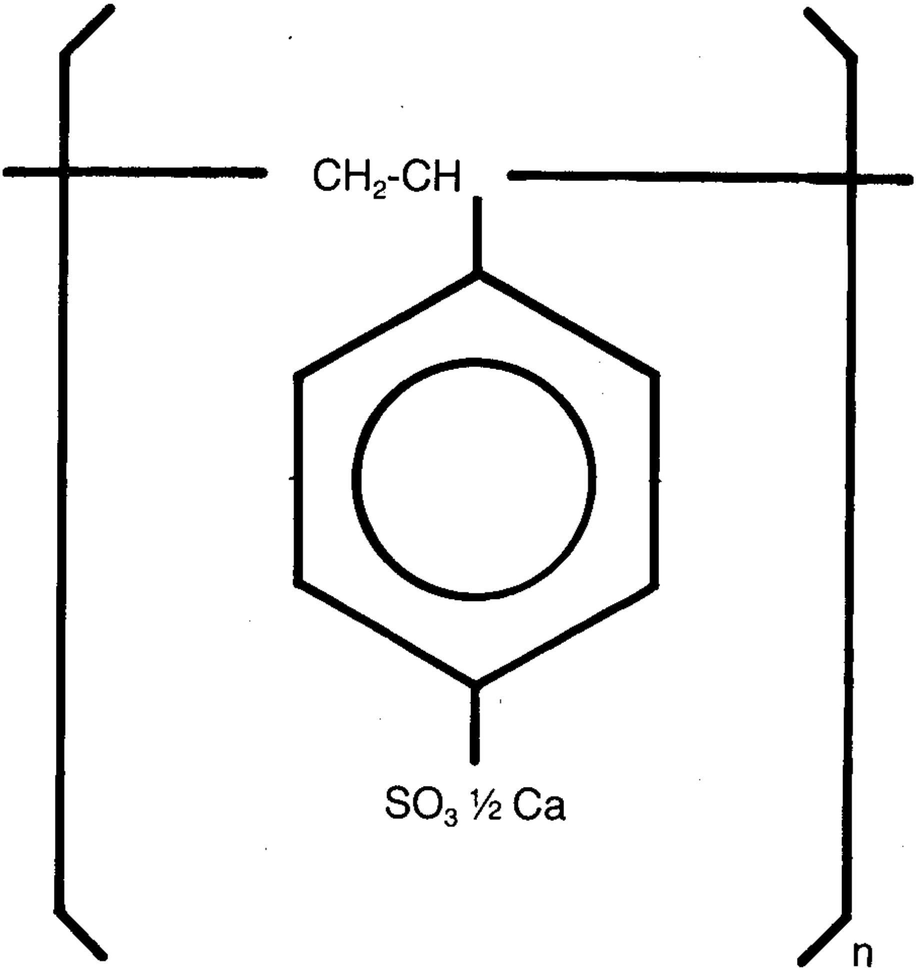

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Construction of a Dry Dock Using Tremie Superplasticized Concrete

by M. Collepardi, R. Khurana, and M. Valente

Sinopsis: This paper describes the construction of San Marco dry dock in Trieste, Italy. Approximately 82,000 m^3 of superplasticized concrete having a slump of 250 mm were placed; of which 40,000 m^3 underwater at a depth of 16 m using a tremie system. The concrete was mixed at a central plant, transported to the site where it was pumped for 250 m from a fixed station to the hopper of the tremie located on a floating barge. The presence of heavy reinforcement (steel trestles) made the positioning of the tremie pipe and inspection by divers very difficult.

To limit the number of shiftings of the tremie pipe, concrete had to have a very high workability and had to be very cohesive in order to prevent washing of by sea water. Moreover, the specification required an impermeable, sulphate resistant concrete having a strength of 25 MPa. In the first stage a slab of 4 m thickness was created by placing overlapping "pizzas" each of 45 m^3 volume and 15 m diameters. If the concrete was not superplasticized, then the size of the "pizzas" would have been much smaller (approximately 20 m^3 volume and 3 to 4 meter diameter). After dewatering, the slab was completed with a second pour of self levelling concrete of 1 m thickness. The use of a superplasticizer helped the contractor to complete the job 3 months ahead of schedule.

Keywords: concrete construction; concrete slabs; drydocks; permeability; plasticizers; sulfate resistance; tremie concrete; workability

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INTRODUCTION

The Trieste San Marco dry dock for handling 140,000 dwt ships was constructed in the period 1980-81. It has a surface area of approximately 16,000 m^2 and a maximum length of 295 m. The first part of the foundation consisting of an area of 8,000 m^2 involved the pouring of 40,000 m^3 of concrete underwater at 16 m of depth using a tremie system. Figure 1 shows a general view of the complete foundation. On the top is the area of the under water concreting which was carried out in two stages as shown schematically in Figure 2. In the first stage, a slab of 4 m thickness was created by placing overlapping "pizzas" each of 45 m^3 volume and approximately 15 m in diameter. They were staggered to avoid cold joints between successive layers. After dewatering, the slab (placed underwater) was completed with a second pour of self levelling concrete of 1 m thickness. For the remaing part of the dry dock slab above water, concrete was placed in monolithic pours of 1000-1900 m^3 volume.

THE CONCRETE MIXES

Laboratory and Field Tests

Two types of concrete mixes were studied; one for the underwater pouring and the other for the placement in the open. The underwater pour required a very high flowability and, above all, a high cohesion to resist the washing of by sea water. These characteristics were obtained by using a high cement content and aggregates of smaller maximum size.

Before starting the project a long and accurate series of laboratory and field tests were carried out to find the appropriate composition which met the technical and economical requirements of the design engineer and the contractor. The design specifications required that the concrete have the following characteristics:

1. Compressive strength = 25 MPa

2. Resistance to sulfate attack (sea water)

3. Protection of reinforcement against corrosion.

4. Impermeability of the foundation slab.

To obtain the required design strength (25 MPa) using an Ordinary Portland cement, a water cement ratio of 0.62 would have been sufficient. But the FIP-CEB reccomendations concerning sea water attack on concrete (1) require that the concrete should have a low porosity which can be achieved by having a water cement ratio of not more than 0.55. To ensure the impermeability of the concrete between successive pours underwater it was decided to limit the water cement ratio to 0.47. This was determined experimentally and will be discussed further on.

5. High flowability and low slump loss.

As shown in Figure 3, concrete is pumped from the truckmixer to the tremie hopper from which it flows to the bottom of the sea through a pipe.

At the bottom there were horizontal and vertical impediments such as foundation piles and their sleeves for anchoring into the slab (Fig. 4) and heavy steel trestles for reinforcement.

For these reasons, the concrete had to have a very high flowability (slump > 250 mm) and low slump loss for the transport and placement operations.

6. Cohesiveness and absence of segregations.

To ensure trouble-free, smooth pumping and prevent the washing away of the fine particles by sea water, it was necessary to have a concrete which was very cohesive, non segregating and at the same time very fluid. It is worth saying that these characteristics would lead to a high amount of mixing water which is in contrast with the requirements of point 2, 3 and 4 where the water cement ratios are limited to values between 0.47 and 0.55. To meet these contrasting requirements it was decided to use a very fluid and a cohesive concrete with an addition of a naphthalene sulfonate base superplasticizer.

Taking into account also the particle size distribution of the available aggregates (Figure 5), the average mix composition shown in table 1, was adopted.

The concrete mix was very fluid (requirement no. 5) and at the same time very cohesive and non segregating (requirement no. 6). It maintained workability satisfactorily; the slump dropped from 250 mm to 230 mm in 2 hours. Field tests allowed this concrete to be pumped for a distance of 250 m and at a rate of about 45 m^3/hour.

Tests to determine the compressive stength, chemical resistance to sulfate attack, reinforcement protection and permeability were carried out on hardened concrete in order to check the requirements mentioned in points 1-4. To simulate the real pouring conditions, all tests were carried out on concrete placed without vibration.

The average compressive strength was 42 MPa with a characteristic strength of over 37 MPa. To test the resistance to sulfate attack some concrete specimens, cured in the forms for 24 hours, were immersed in fresh water and sea water to assess their relative length change. The curves in Figure 6. show the expansion during a period of 12 months. The two curves are almost identical thus indicating that the concrete tested had an excellent resistance to sulfates. The reason for this behaviour is mostly due to the low porosity of the conglomerate which hinders the penetration of sulfate salts into the concrete.

To test the reinforcement protection, 100 mm cube specimens were reinforced with 5 mm dia deformed steel bars. Concrete (Table 1, column A) with and without admixture was used. The specimen were cast without vibration and, after 24 hours of curing in the forms, were immersed in sea water for 2, 6 and 12 months. Periodically some specimens were subjected pull-out tests and others were sectioned to assess possible reinforcement corrosion.

The data of Table 2 show that the high fluidity and the low water cement ratio of the non vibrated superplasticized concrete allows it to envelope completely the reinforcement thus giving a much better bond and protection to steel than the stiff concrete.

Figures 7 and 8 show the state of the steel bars after keeping the specimens under sea water for 6 and 12 months. Specimens made with stiff concrete (Figure 7) show a very serious reinforcement oxidation, caused by penetration of chlorides into the stiff concrete and the formation of white stains, caused by the production of gypsum and ettringite. On the contrary, the reinforcement steel is well protected by the superplasticized concrete (Figure 8).

Field tests were carried out to evaluate the ability of superplasticized concrete to caulk the cold joints. For this purpose, 8x14x1 m specimen were cast in the open to assess visibly the self levelling ability of the concrete (Figure 9) and under sea water in layers of about 1 m thickness at 1 day intervals (Figure 10) to simulate job site conditions.

Then the specimen was pulled out of the sea water to undergo core boring and permeability test. The 145 mm hole drilled into the block, was filled with water and the pressure was increased gradually until water leaked at the level of the cold joint (Figure 11). This occured at a pressure of 3.5 atm corresponding to 35 m of water head, which is definitely higher than the water head in the deepest part of the dry dock (16 m). This test evidenced the good adhesion of rheoplastic concrete between successive pours.

The characteristics of concrete for pours in the open greatly differed from those chosen for the pour underwater mainly because of the different operating procedures. First of all fresh concrete was neither required to resist sea-water washing away nor to be self-levelling (slump = 250-270 mm). In fact, the use of a vibratory screed made finishability easy. Rapid placement speed and the presence of a high percentage of reinforcement led to choose a workability equal to a 180-200 mm slump.

The maximum diameter of the aggregate was 30 mm (instead of 15 mm nominal size chosen for the underwater pour). Using the superplasticizer the total water content (moisture content of aggregate included) required to obtain a workability of 180-200 mm was 165 l/m^3. The water-cement ratio was 0.55, as per FIP-CEB recommendations. The average composition of the concrete used for the pour in the open is shown in Table 1, column B.

The substantial differences with respect to the mixture used in the underwater pour, in addition to the lower workability, is the lower cement content (300 kg/m^3) which gave the advantage of having a lower drying shrinkage and lower heat of hydration, thus minimizing the risk of cracking.

EXECUTION OF THE UNDERWATER POUR

The following paragraphs will describe the equipments and the execution techniques of the pour.

Equipment

a. Batching Plant:

A horizontal plant (Loro Parisini type) with four hoppers for aggregates, three silos for cement and two tanks for the superplasticizer was used.

b. Admixture Dispensing Equipment:

The admixture dispenser was a compressed air type with a transparent graduated cylinder for visual control of the addition of the admixture to the concrete mix.

c. Truck Mixers:

Six 6-m^3 truck mixers were used.

d. Pump:

A Putzmeister pump Elephant BRA 1046 type, powered with an electric motor was used. Pumping capacity: 60 m^3/hour.

e. Pump Station:

It consisted of:
- a space large enough to allow two truck mixers to approach the hopper simultaneously in order to assure continuous concrete feeding;
- a shelter over the station to allow operations to be executed even under heavy rain, thus avoiding the addition of extra water to concrete.

f. Distributor Arm:

A Scheele MT 29 type with a 29-m range. The distributor arm was positioned laterally on the pontoon so that the crane supporting the pipe , could move backwards and forwards on a track.

g. Pipeline:

It was specially prepared on site with the following characteristics:

- a steel pipe with internal diameter of 177 mm and wall thickness of 9 mm;
- pipe length (including flanged elements) = 20 m
- funnel-shaped hopper with a circular gangway and breastwork so as to allow the presence of an operator for visual inspection of the flowing concrete. The discharge end was provided with a special valve to prevent the vertical pipe from emptying out during the changing of the pouring position.

h. Pipe for Concrete Transport:

The distance of the pump from the distributor arm varied from 50 to 250 m. The pipe was protected with sacks of sands kept damp to minimize heating during summer. A rubber pipe was placed between the pump and the steel pipe to avoid stresses to the couplings of the pipeline.

i. Operation Base:

A pontoon (12x25 m) was prepared to support the distribution arm and the crane for the pipe.

j. Telephone Communication:

To control the delivery of concrete to the hopper of the tremie pipe there was a telephone communication between the pumping station and the operation base on the pontoon.

k. Telephone Communication Underwater:

Divers -inspecting the positioning of the pipe and the flow of concrete underwater- were connected with the operation base by telephone.

Underwater Pour Technique

Placing concrete underwater by means of a pipe is not a new technique and is commonly know as the Tremie method (4). Nevertheless, it has remarkable operative difficulties. For the placement described here, the special qualities of rheoplastic concrete viz. high flowability and low segregation were exploited to the maximum. The changes in the pipe positions were kept to a minimum and consequently the rate of concrete placing was increased to 600 to 700 m^3 per day. The underwater pour was carried out as described below.

a. At the beginning of each work shift the pipe was positioned and immersed vertically with the outlet valve closed into the sea down to the surface of the previous pour. Divers controlled the operation. During this phase water could not enter into the pipe as the outlet valve was watertight and closed.

b. The pumping was then started. Concrete flowed from the hopper into the pipe, so that a column of concrete was formed to counterbalance by its weight the pressure on the ground due to the height of the water column. Taking into account the different specific gravities, a column of concrete of about 7 m was required to offset the pressure of a column of water of 15 m. A column of concrete higher than the one needed to counterialance the pressure on the ground would have caused, when starting the pour, an exaggerated pressure on the concrete flowing out, thus favouring the separation of aggregates from cement paste and causing, around the outlet valve, the formation of heaps of segregated gravel, which would have hindered the regular flow of concrete.
Having set the column of concrete to counterbalance the water pressure, the flow was started by opening the outlet valve. This was the most delicate phase of the operation because if the amount of concrete flowing into the hopper was lower than the one flowing out at the bottom, water could rise into the pipe and consequently, wash the concrete inside the pipe. In this case the operation would have to be stopped and the pipe cleaned out completely before starting the placement operation once again. This procedure was used at the beginning of each work shift in order to avoid the segregation of concrete during its first descent down the pipe. To change the position of the pipe it was necessary:

- to stop the pumping of concrete and, simultaneously, close the outlet valve;

- to lift the pipe (half-full of concrete) and place it in the new position of placement;

- to open the outlet valve and, simultaneously, start the pumping again.

By this technique it was possible to carry out more than 20 position changes of the pipe in 16 hours' work.

Depending upon the obstacles present (trestles and piles), flowing concrete coming out of the pipe self levelled itself around it in a more or less circular shape. The thickness of the "pizza" formed increased progressively. The rate of flow was maintained constant and with the help of divers who ordered if necessary the lifting of the tremie pipe to keep it embedded for 50-60 cm in the fresh concrete.
Using this technique it was possible to place round-shaped "pizzas" of flowing and cohesive concrete having a diameter of over 15 m, thickness of 80 cm approx. and volume of about 45 m^3.
The use of a concrete without admixture would have hardly allowed a diameter of 3.5 m, with a consequent increase in the number of position changes of the pipe and divers' inspections. Due to the high flowability of superplasticized concrete each placement operation was completed in about one hour, thus minimizing visual inspections of concrete flow and concrete embedment of piles and trestles.
Taking into account the conditions of the sea bed and the water temperature (15° C), the superplasticized concrete maintained its workability for about 4 hours. This allowed the placement to be carried out rather easily and gave enough time to cope with any problem which might have occured during such a complex operation.
Hardening started after 15 hours and a new layer was placed before the hardening had occured. Divers eliminated all incoherent material deposited on harding concrete prior to placement of the next layer.

d. The underwater placement of concrete generally requires skilled labour and an adequate and well-organized job-site. Although the use of flowing concrete made placement operations considerably easy, the underwater pour of such a large foundation slab with such congested reinforcement required a diligent and accurate coordination among the different working groups. As an example, think of the divers' work, inspecting the starting of the pour and its regular placement and of the whole team (for the mixing, transport and placement of the concrete) who had to feed the hopper of the pipe with adequate syncronism and without any break.

Results

Figure 12 shows the concrete slab with the protruding parts of trestles and precast concrete annular members needed to anchor the piles to the foundation slab. Figure 13 shows the part of foundation slab placed underwater, after being dewatered. It can be observed how well the concrete self-levelled, even though it had not been vibrated. In order to obtain a better planarity, a layer of concrete was placed subsequently in the open and its surface was adequately smoothened.

EXECUTION OF THE SLAB IN THE OPEN

The following paragraphs describe the equipments and construction practices used in the completion of the foundation slab previously placed underwater and the execution of the remaining slab placed in the open by monolithic pours of 1,000 to 1,900 m^3 concrete.

Equipment

The equipment used were the ones described in points a-f of the previous section. Obviously the ones for the underwater pours were excluded.

Technique for the Pour in the Open

Superplasticized concrete (Table 1) was placed after positioning reinforcement on the previous layer of concrete placed underwater. The workability of the mix allowed a rapid placement, in spite of the high density of reinforcement.

For the pours in the open concrete was made to flow from one end toward the other, thus placing successive layers of approx. 50 cm thickness.

Finishing and Curing

The finishing operation of the surface of the foundation slab was made by a vibratory screed sliding on rails previously fixed at a given elevation. In order to optimize compaction concrete was vibrated before finishing with the vibratory screed.

A concrete surface hardener -based on cement, siliceous aggregates (quartzite) and admixtures- was then applied as a dust-coat in order to improve the resistance to abrasion. In general, a pour of concrete was completed at night so that in the first hours of the following morning concrete had the optimum consistency for the application of the dust-coat. After completion of the trowelling operation, the slab -mainly cast during the summer- was protected with damp canvas for at least 15 days. Then a membrane of curing compound was sprayed in order to keep concrete damp for the longest time possible.

CONCLUSIONS

To the great satisfaction of the Contractor, the use of a particular superplasticizer helped to achieve excellent results and complete the job three months ahead of schedule!

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(2) M. Collepardi and M. Corradi, "Superplasticizers in Concrete", p. 315, Publication SP-62, American Concrete Institute, Detroit, (1979).Editor V.M. Malhotra.

(3) ACI Committee 201, "Guide to Durable Concrete", ACI Manual of Concrete Practice 1983, Part 1.

(4) ACI Committee 304, "Recommended Practice for Measuring, Mixing, Transporting and Placing Concrete", ACI Manual of Concrete Practice 1983, Part 2, p. 304-27 to 304-28.

TABLE 1--AVERAGE COMPOSITION OF CONCRETE FOR UNDERWATER PLACEMENT (A) AND FOR THE POUR IN THE OPEN (B)

	A	B
Ordinary Portland Cement	400 kg/m^3	300 kg/m^3
Water (aggregate humidity included)	190 l/m^3	165 l/m^3
Sand from the river Po (saturated, surface dry)	180 kg/m^3	210 kg/m^3
Crushed sand (saturated, surface dry)	990 kg/m^3	690 kg/m^3
3-14 mm gravel (saturated, surface dry)	630 kg/m^3	---------
5-30 mm gravel (saturated, surface dry)	---------	1020 kg/m^3
Superplasticizer	6 l/m^3	4.5 l/m^3
Slump	260 mm	190 mm
Water/cement	0.47	0.55

TABLE 2--PULLOUT TESTS (MPa) OF DEFORMED BARS FOR CONCRETES AIR CURED OR IMMERSED INTO SEA WATER

TIME	Stiff Concrete (slump = 30 mm; without admixture)		Superplasticized Concrete (slump = 260 mm; with admixture)	
	air	sea-water	air	sea-water
2 months	0.3	0.7	18.0	18.3
6 months	0.4	0.3	17.0	21.0
12 months	1.4	0.3	16.8	22.6

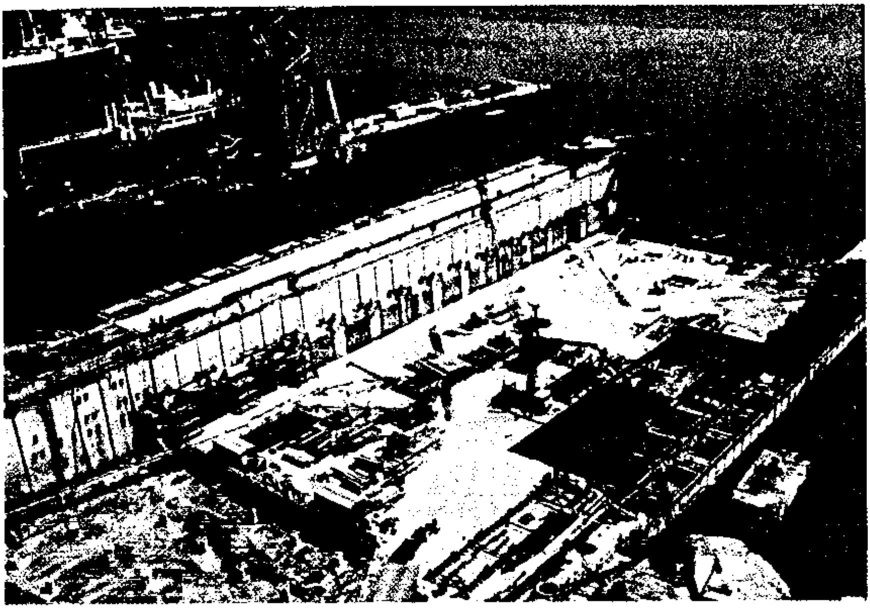

Fig. 1--Overall view of the foundation slab -- for the top of the slab, concrete was placed underwater by a tremie

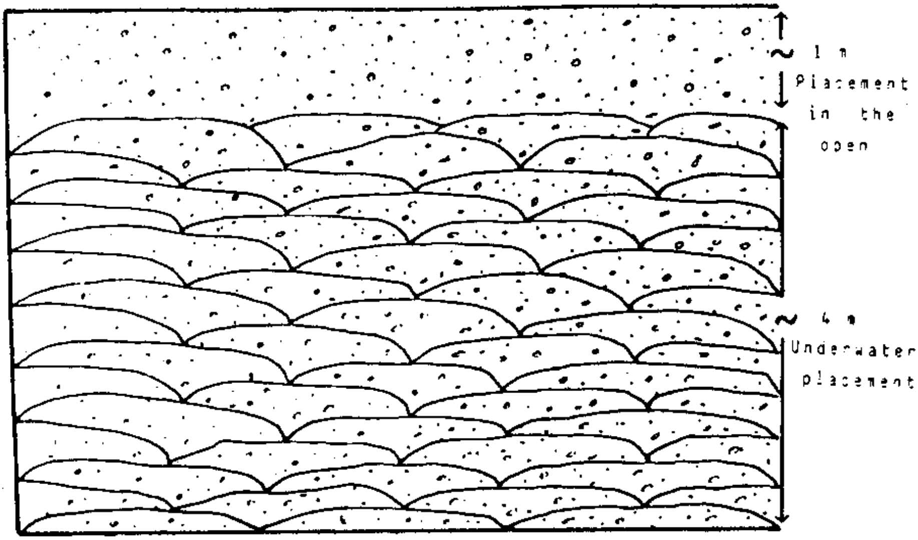

Fig. 2--Outline of the underwater placement, completed by the pour in the open

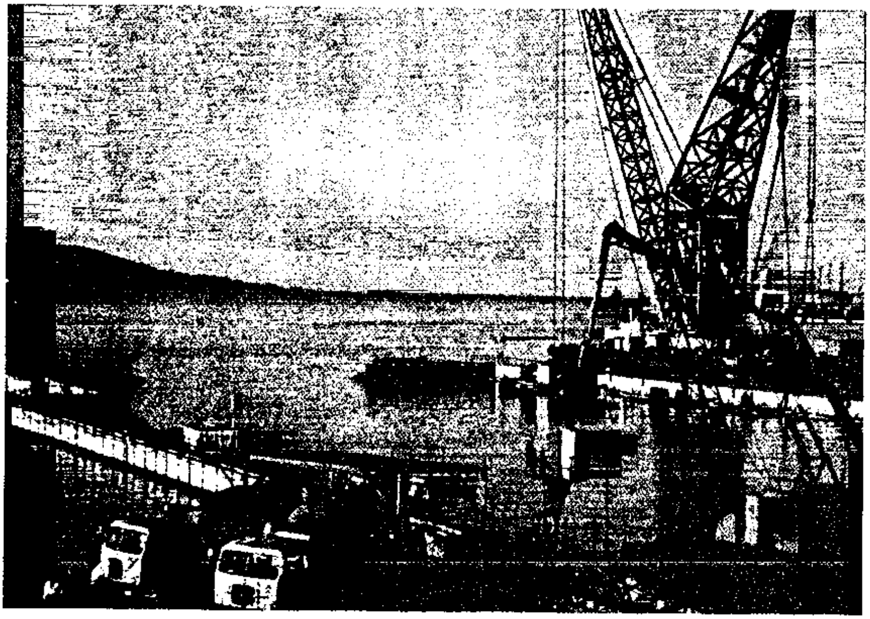

Fig. 3--View of the jobsite during underwater placement -- concrete is pumped from the truck mixer to the tremie hopper from which it flows to the bottom of the sea through the pipe

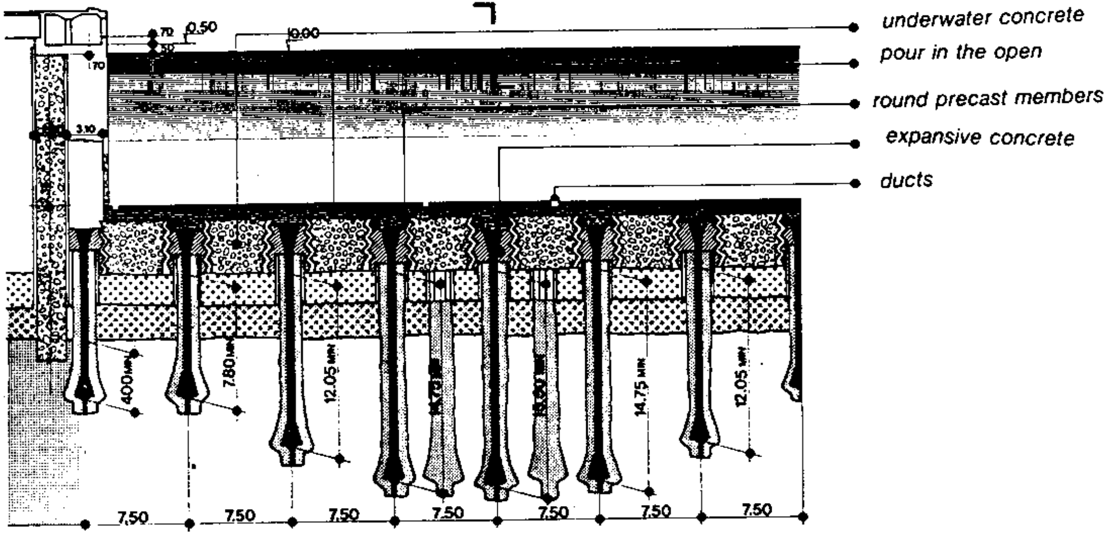

Fig. 4--Scheme of a section of the foundation slab with foundation piles

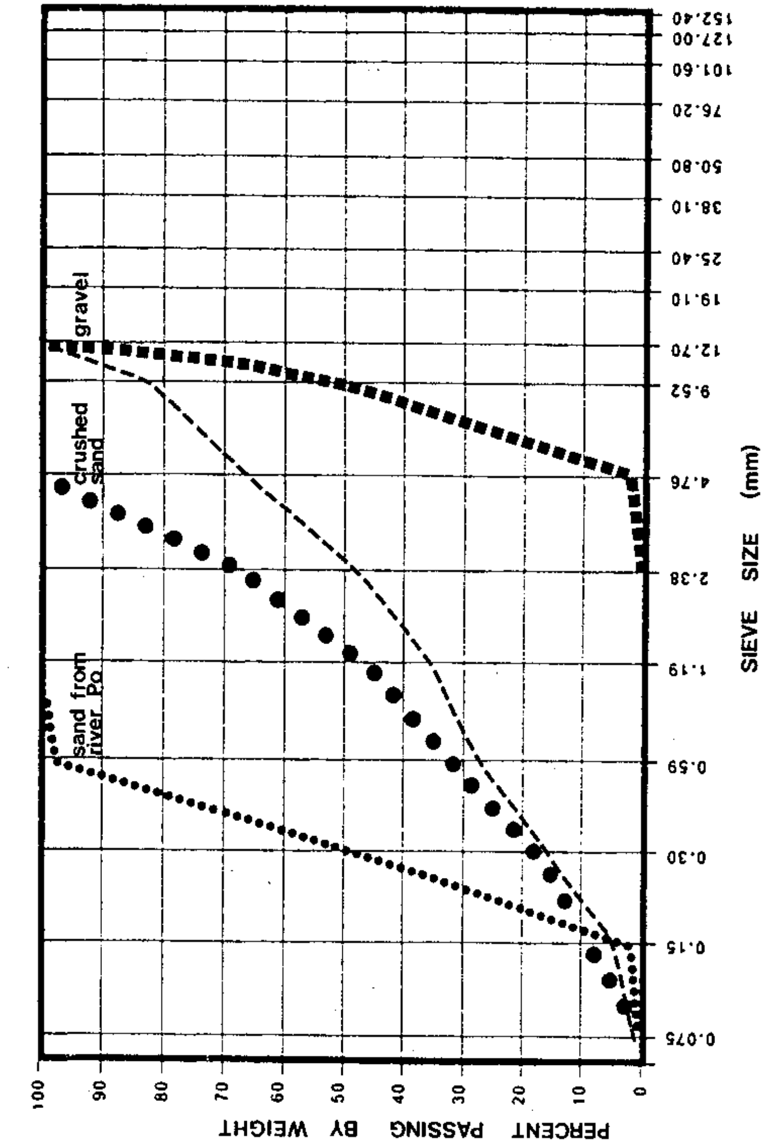

Fig. 5--Particle size distribution and combined aggregate grading curves

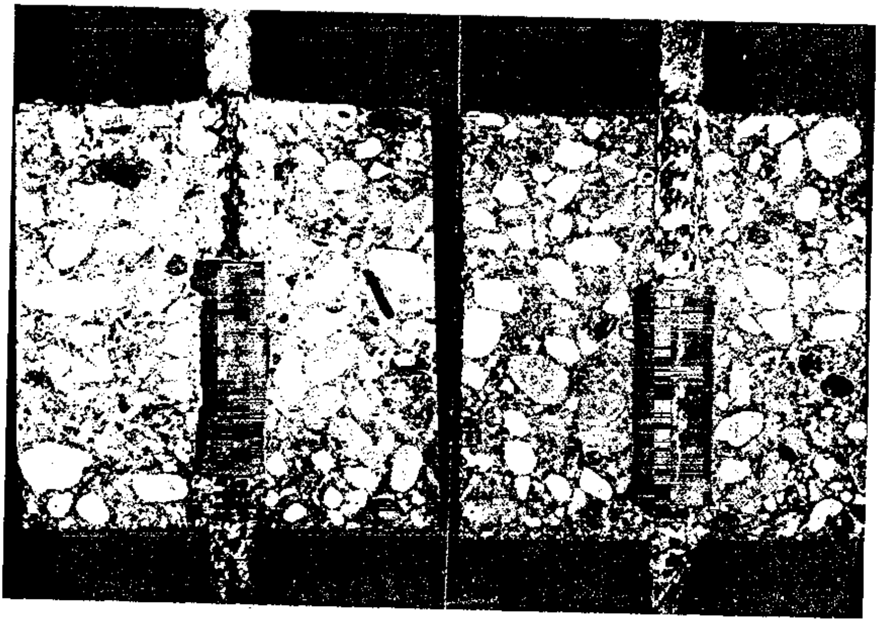

Fig. 8--Section of reinforced superplasticized concrete specimen after 6-month (A) and 12-month (B) immersion in sea water

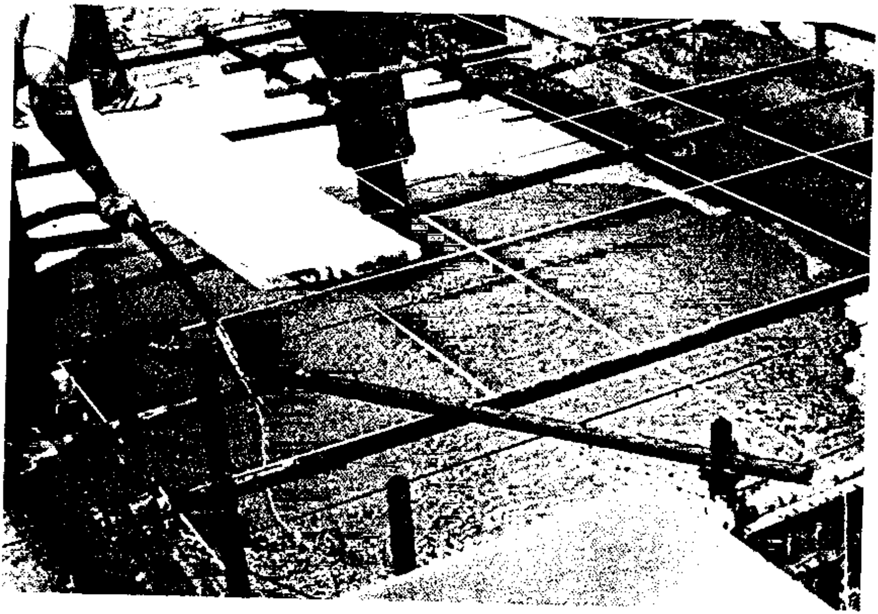

Fig. 9--Field tests of superplasticized concrete placement: self-leveling concrete

Fig. 10--Field tests for the underwater placement of superplasticized concrete

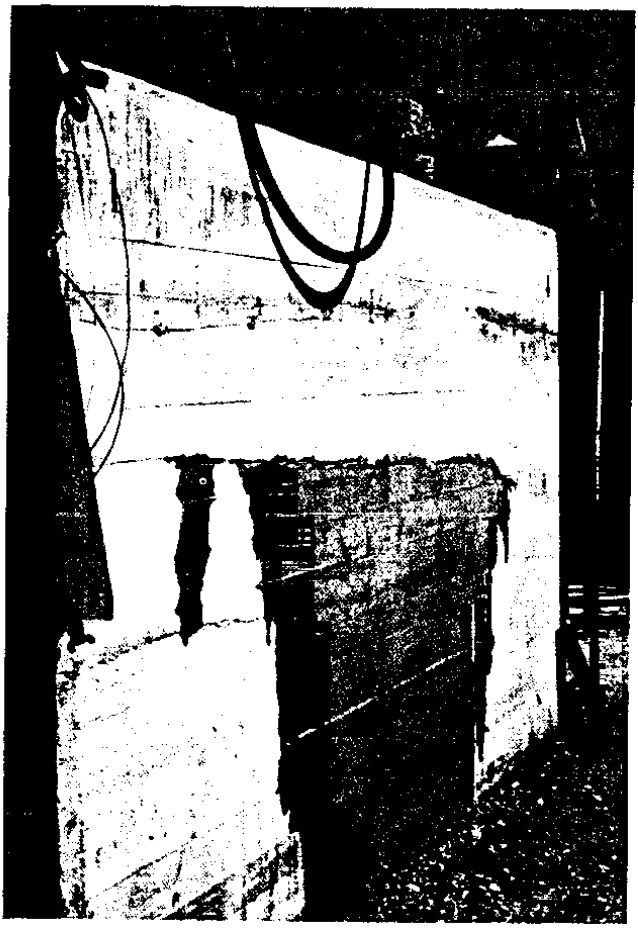

Fig. 11--Water (at the pressure of 3.5 atm) leaking out through a cold joint

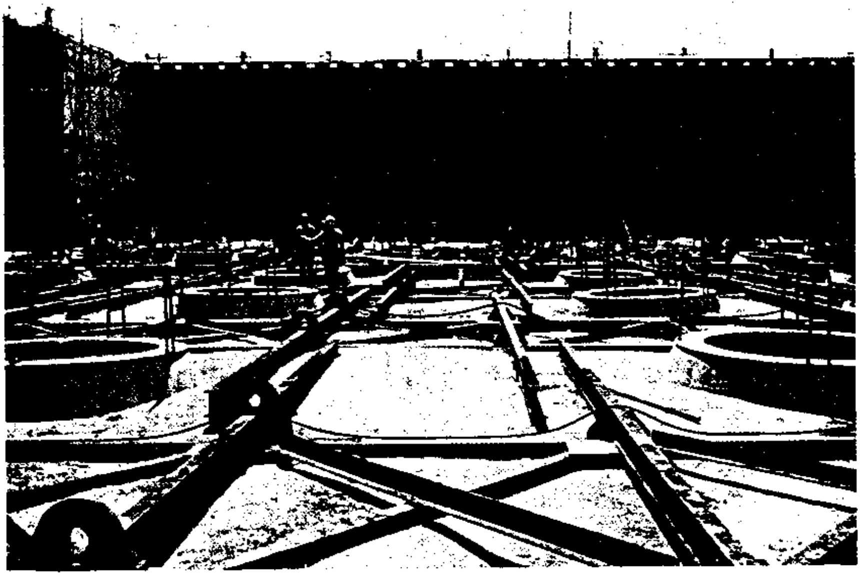

Fig. 12--Detail of the foundation slab placed underwater: top of trestles immersed in concrete

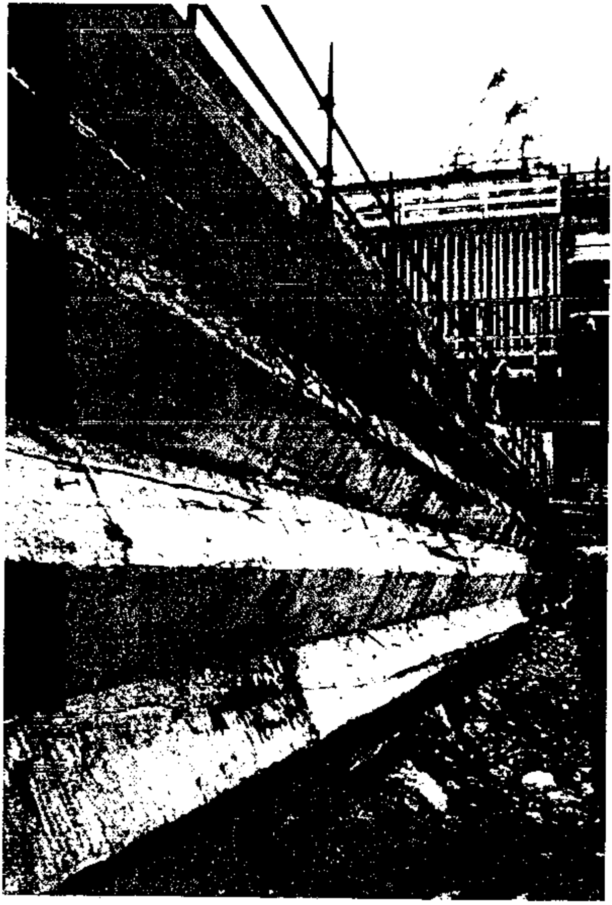

Fig. 13--Detail of the foundation slab placed underwater