Structural rehab in Portugal...

The Setenave Dry Docks Rehabilitation

by Ivan Ramalho de Almeida, Thomaz José Ripper Barbosa Cordeiro, and José Paulo Veríssimo Maia Costa

Setenave is a general designation for a shipyard built in the early seventies, at the right shore of the Sado River, south of Lisbon, in Portugal. In 1991, an important structural rehabilitation of the reinforced concrete walls of the Setenave dry docks was performed. Repair was required to overcome the problems of generalized reinforcement corrosion, then evidenced by disaggregation of very large areas of the concrete cover (Fig. 1).

The reinforced concrete walls of the dry docks — constructed as semi-buried tanks, about 75 x 900 m (250 x 3000 ft) in plan — are nearly 1 km (0.6 mi) long, about 11 m (36 ft) high in the part designed for ship construction, and 22 m (72 ft) high in the ship repair area. The bottom of those areas lies at about 2.0 and 12.5 m (6.6 and 41.0 ft), respectively, below sea level (Fig. 2).

The area of repair is subject to weekly filling and emptying cycles, whereas the construction area is filled two or three times a year.

Evaluation

Simple visual observation of walls evidenced the intensity of structural concrete disaggregation (which reached more than 10 m^2 at some places) and the resulting exposure of corroded reinforcement. A preliminary quantification of damaged areas supplied the following data:

- total area to be rehabilitated: 25,000 m^2 (269,000 ft^2);
- mean depth of intervention: 10 cm (4 in.);
- volume of concrete to be replaced: about 2500 m^3 (3300 yd^3).

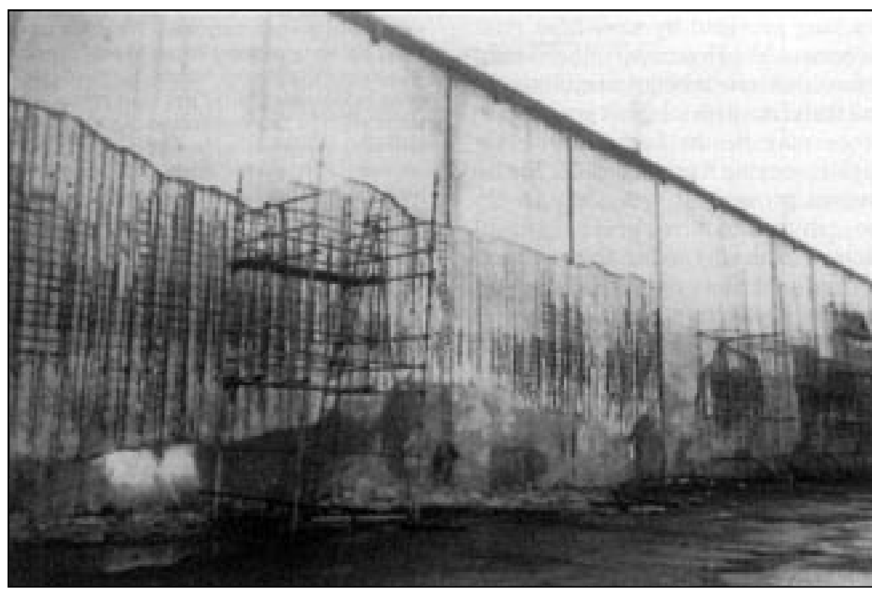

Fig. 1: Concrete disaggregation

In mid-1991, this job was one of the most important structural rehabilitation works in progress in the world.

Investigation and testing

To quantify the causes for degradation, several in-situ and specialized laboratory tests[1-3] were carried out, which gave the following indicators:

1) Composition of original concrete:

- water-cement ratio (*w/c*): 0.63;
- cement proportioning: approx. 300 kg/m^3 (505 lb/yd^3);
- type of aggregate: limestone and siliceous sand;
- mean compressive strength of concrete: 24.6 MPa (3570 psi);
- estimated f_{ck}: 18.0 MPa (2600 psi).

2) Chloride determination:

- The investigation showed the presence of chlorides through diffusion, reaching values at the reinforcement level up to 0.3 percent of concrete mass.

3) Sulfate determination:

- The values detected showed that the amount of sulfates in the concrete mass was not important.

4) Depth of carbonation:

- Depth of carbonated concrete was always less than depth of reinforcement cover.

5) Investigation of leakage currents:

- The result was negative in spite of the presence of winches, traveling cranes running on rails, lighting poles, a transformer substation, and welding shops located nearby.

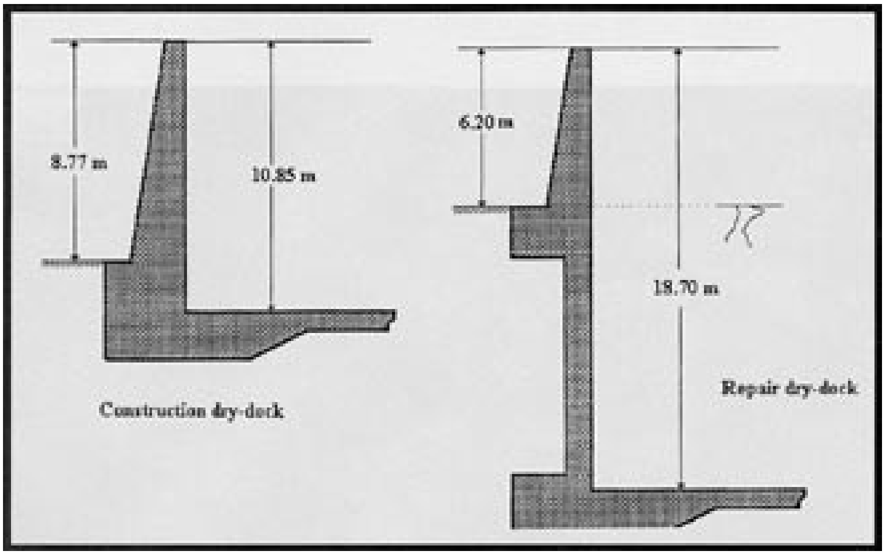

Fig. 2: Cross sections of the concrete walls

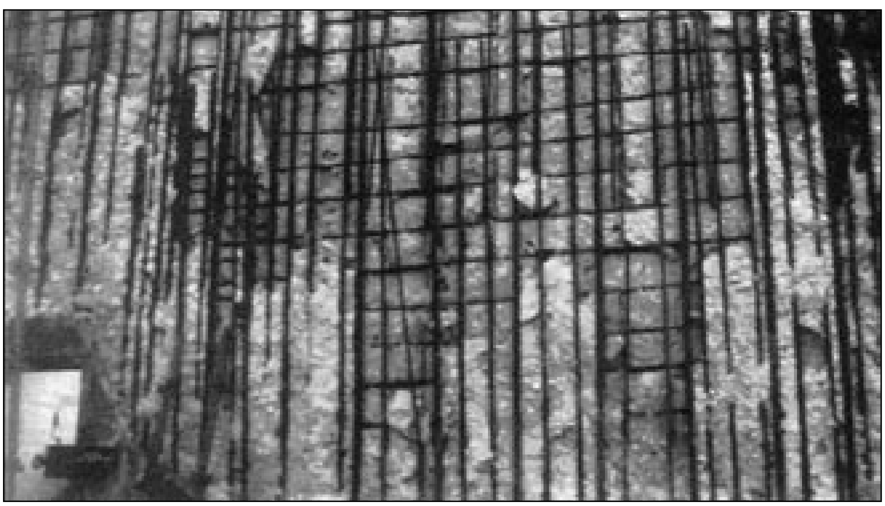

Fig. 3: Corroded reinforcement

Conclusions from investigation

Based on the investigation results, it was concluded that the generalized reinforcement corrosion inside the walls of Setenave dry docks and the resulting scaling of the enveloping concrete was mainly caused by the presence of a high level of chlorides. The chlorides easily penetrated the concrete by diffusion up to the reinforcing bars, due primarily to the extraordinary porosity and permeability of the concrete, resulting from the high *w/c* of the mix.

Rehabilitation approach

Based on data collected from this investigation and on the analysis of the original design elements, a scheme of structural rehabilitation was drawn up, well founded on CEB/FIP recommendations.[4, 5] These included:

- removal of all contaminated concrete up to 30 mm (1.2 in.) behind the reinforcement;
- cleaning of all corroded reinforcement and providing new bars to supplement those whose cross section was reduced (Fig. 3); and
- reconstitution of the walls by using concrete of better quality, including good resistance and durability, as well as low porosity and an appropriate reinforcement cover thickness.

The parts of the structure to be rehabilitated consisted of large plane surfaces which were practically shapeless. The area of intervention was large both in the vertical direction and in the horizontal one. The space available for installation of the worksite inside the dry docks was small. The completion time was tight (six months) and there was one more difficulty: the docks had to remain in operation (filling and emptying inclusively) during the rehabilitation work.

Such conditions practically eliminated the possibility of using hand-applied materials or formwork, and made it necessary to resort to shotcreting for rehabilitation. Nevertheless, shotcrete in this case should have much better characteristics than conventional concrete.

The specifications, prepared by a specialized firm, established limits for a large series of quality parameters, as shown in Table 1. To make sure that shotcrete had the required characteristics, tests were carried out prior to work execution, in the pilot test phase.

Mix tests

This intermediate stage was necessary because of the volume of work, cost of the services, and the accuracy required by the specifications in the qualification of the repair material. A large series of operations were included, which were detailed in a previous paper.[6]

Table 1: Specifications and attained results

Concrete characteristics	Specifications	Works	Remarks
f_{ck} (MPa)	≥ 50.0	57.4	OK!
Permeability (mm) (water penetration)	≤ 10.0	19.0	Less than cover thickness
Porosity (percent)	≤ 15.0	13.2	OK!
Bond (MPa)	≥ 1.0	2.2	OK!
Reinforcement cover (cm)	≥ 4.0	4.0 to 7.0	OK!

On the basis of the best results obtained from pilot tests and the least cost-benefit relation, a composition was selected with:

- only 350 kg cement/m^3 concrete (590 lb/yd^3);
- cement of the lowest strength class, 30 MPa (4400 psi);
- 2003 kg limestone (ϕ_{max} = 10 mm [0.4 in.]) per m^3 of concrete (3400 lb/yd^3);
- 15 kg condensed silica fume (CSF) per m^3 concrete (25 lb/yd^3), i.e. addition relative to only 4.3 percent of the cement mass, when the normal is about 10 percent;
- water: about 145 kg/m^3 (245 lb/yd^3).

Repair procedure

The following services were then carried out:

- removal of deteriorated concrete up to 10 cm (4 in.) mean depth, going behind the reinforcement some 3 cm (1.2 in.). This work was carried out with light pneumatic hammers;
- replacement of reinforcement bars;
- cleaning of reinforcement bars and worked surfaces by successive sandblasting, water blasting, and air blasting performed with the shotcreting equipment;
- reconstitution of the structure with CSF concrete by shotcreting, with dry-mix, two-chamber equipment (Fig. 4);
- shotcrete curing under continuous wetting up to an age of seven days; at younger ages when the docks were flooded, a curing film was applied. Curing started as soon as the shotcrete began to set.

These services required the mobilization of five shotcreting teams on average during the work, so that 25 m^3/day (33 yd^3/day) could be produced. Each team consisted of nozzlemen and machine operators, one dumper driver (transporting the dry mix from the plant to the machines), and unskilled workers to feed the machines.

The mean distance between the dry-mix plant and the shotcreting machines was about 400 m (1300 ft).

Fig. 4: Shotcreting in progress

In the concrete mixing plant outside the docks, dry mixing of materials was carried out by electrical equipment; the binders (cement and CSF) were proportioned in mass whereas the aggregate was proportioned in equivalent volume. The CSF (powder) was previously weighed on a precision weighing machine and put in plastic bags in the amount appropriate for one cement bag.

The minimum time for mixing the dry materials was two minutes, and the mixing plant team consisted of 15 workers and one foreman on average. For preliminary work, up to 35 hammermen and eight ironmen were mobilized. As for the rehabilitation phase, it should be said that the overall service was carried out with no special problems or difficulties that could not be easily solved.

Quality control

Work was subject to effective quality control concerning materials, equipment, workmanship and work execution. The engineer instituted a quality control plan and a methodology of analyzing and checking the contractor's work, through interpretation of test results and overall assessment of the quality of materials and services.

In accordance with the specifications, there was intensive follow-up of all execution, including technological control of raw materials and verification of proportioning, application, and cure, including the technological control of the concrete applied.

An 18.2 m^2 (196 ft^2) laboratory was available at the worksite and was able to perform the current tests specified. More lengthy and sophisticated tests were carried out off-site.

Several tests on core specimens from shotcreted panels were carried out during execution of the services, at the rate of 2 per 30.0 m wall section. Furthermore, as a way to control nozzlemen, the *w/c* and the rebound content were measured, the latter being about 45 percent and mainly consisting of coarse aggregate particles.

To control the beginning of cure by water sprinkling, the initial setting time of shotcrete was measured. In the course of the work, this time ranged from one hour (winter) to twenty minutes (summer). The determination of the thickness of the reinforcement cover was periodically performed on the hardened concrete by using a covermeter.

Bond between shotcrete and the underlying concrete was checked with pull-off test equipment. The most important results of these tests are shown in Table 1.

The weather conditions were recorded throughout the work (namely, air relative humidity, rainfall, wind direction and velocity), and were not found to considerably affect the quality of the services.

Upon completion, the engineer recommended that the repair work be ac-

Fig. 5: The docks, again in operation, after the rehabilitation

cepted by the owner; in fact, though some parameters as defined in the specifications had not been obtained, such as the case for permeability — in which case the water penetration was higher than 10 mm (0.4 in.), but less than the cover thickness — the overall quality of the service was considered very good.

Monitoring procedure

In-situ tests are expected to be carried out every year to determine the following:

- the penetration profile of chlorides,
- depth of carbonation,
- surface permeability, and
- corrosion capacity.

The purpose of these tests is to check the specifications used and the work done to ensure structural durability.

Conclusions

The main conclusions that can be derived are as follows:

- The use of a rational shotcrete proportioning procedure was successful. A very technically accurate and economically profitable result was achieved.
- It is possible to obtain high-performance shotcrete with current materials and conventional shotcreting techniques and equipment, without any sophistication or change in procedures.
- The composition of the concrete used in this work involved low cement and low CSF consumptions, in spite of the fact that the concrete exhibits high mechanical strength and prospects of high durability.
- Encouraging results were always obtained, largely exceeding the requirements.
- The good results obtained were certainly due to the careful attention given to the structural rehabilitation procedure from the start. A valuable output has already been obtained: the development of a pilot technology providing excellent technical results, and the reopening of the normal operation of the docks (Fig. 5).

Moreover, the philosophy of service adopted in this work is expected to be useful for a long time, both with regard to the durability and integrity of this structure and in future applications.

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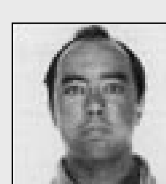

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