

Appendix-3: Repair Case Study: Section Repair of Superstructure Concrete of a Coal Unloading Jetty Using the PCM Dry-Mix Shotcrete Method

1. Introduction

The subject facility is a coal unloading jetty of a thermal coal-fired power plant located in a warm southern region of Japan. The jetty consists of nine reinforced concrete blocks, each measuring 25 × 25 m in plan, with a total length of 225 m and a deadweight capacity of approximately 60,000 t. Since the commencement of operation, the structure has been exposed to a severe chloride environment for approximately 30 years.

Routine and detailed inspections revealed that deterioration was particularly severe in Blocks No. 3 and No. 7.

Accordingly, repair works were carried out using section restoration and cathodic protection methods. This paper focuses on the section repair works using a PCM dry-mix shotcrete method.



Photo 1 Repaired Blocks No. 3 and No. 7

2. Selection of The Section Repair Method

Among available section repair methods—hand-applied repair, shotcrete repair, and form-and-pour methods—the polymer cement mortar (PCM) shotcrete repair method was selected. Hand-applied repair is unsuitable for large cross-sections, while form-and-pour methods require extensive formwork and higher construction costs.

PCM shotcrete methods include wet-mix and dry-mix systems. In this project, a maximum conveying distance of approximately 100 m and a maximum repair thickness of approximately 100 mm were anticipated. As summarized in Table 1, the dry-mix shotcrete method offers superior applicability under these conditions and was therefore adopted.

Table 1 Performance comparison between PCM dry-mix and wet-mix shotcrete methods

Item	PCM Dry-Mix Shotcrete	PCM Wet-Mix Shotcrete
Cost	Several hundred thousand–1 million JPY/m ³	Several hundred thousand–1 million JPY/m ³
Construction period	Approx. 20 days (100 mm, 100 m ²)	Approx. 40 days (100 mm, 100 m ²)
Spraying capacity	0.8–1.2 m ³ /h	0.3–0.5 m ³ /h
Maximum thickness	Approx. 200 mm (wall and soffit)	30 mm (wall), 20 mm (soffit)
Conveying distance	Up to 300 m	Up to 50 m
Material loss	Approx. 20%	Approx. 15%
Filling performance	Good behind reinforcement	Good behind reinforcement
Required plant area	Approx. 50 m ²	Approx. 50 m ²
Nozzle distance	Approx. 1.0 m	Approx. 0.5 m
Dust concentration	2.04 mg/m ³	3.71 mg/m ³

3. Preliminary Verification Tests Using Model Specimens

Before construction, preliminary verification tests were conducted using model specimens to confirm workability and repair quality. Model formwork simulating reinforcing bar size and spacing was fabricated. Horizontal and overhead spraying tests were carried out using the planned PCM dry-mix shotcrete system.



Photo 2 Formwork for horizontal spraying specimens



Photo 3 Formwork for overhead spraying specimens

Shotcreting was carried out using the same PCM dry-mix system planned for site application, in both horizontal and overhead orientations (Photo 4). In addition, specimens were cast in $4 \times 4 \times 16$ cm and $10 \times 10 \times 40$ cm molds for compressive and flexural strength tests (Photo 5).



Photo 4 Shotcrete application for filling performance test



Photo 5 Shotcrete placement in specimen molds

Fresh properties and hardened performance were evaluated according to the test items listed in Table 2. Core samples were extracted from both reinforced and unreinforced regions to evaluate filling performance. The test results and specification requirements are summarized in Table 3.

Table 2 Preliminary test items and methods

Test item	Test method
Fresh properties	Visual inspection during spraying
Pumpability	Mortar temperature measurement and nozzle observation
Sprayability	Visual confirmation of filling behind reinforcement
Finishability	Evaluation of trowel finishing
Compressive strength	7 and 28 days; cores and molded specimens
Flexural strength	7 and 28 days; $4 \times 4 \times 16$ cm specimens
Bond strength	28 days; pull-off test
Drying shrinkage	28 days; $10 \times 10 \times 40$ cm specimens
Filling performance	Core sampling from reinforced and plain regions

Table 3 Preliminary test results and specification requirements

Test item	Test result	Specification
Compressive strength	48.7–60.5 N/mm ²	≥ 30 N/mm ²
Flexural strength	10.7 N/mm ²	≥ 3.0 N/mm ²
Bond strength	3.4 N/mm ²	≥ 1.5 N/mm ²
Drying shrinkage	0.015%	$\leq 0.20\%$



Photo 6 Core sampling for filling performance evaluation



Photo 7(a) Core appearance in reinforced region



Photo 7(b) Core appearance in unreinforced region

4. Mix Proportion, Material Properties, and Construction System

The mix proportions and standard properties of the polymer cement mortar (PCM) used in the dry-mix shotcrete method are presented. Compared to conventional rapid-hardening cement-based systems, the PCM dry-mix shotcrete method significantly reduces dust generation and rebound.

Material loss rates were found to be comparable to those of wet-mix methods, while dust generation was substantially reduced.

Table 4 Mix proportions of PCM for dry-mix shotcrete

Component	Premixed powder	Polymer emulsion	Mixing water	Volume
Premixed powder	25 kg	1,39 kg	2.18 kg	Approx. 13 L
Polymer emulsion	1,925 kg	107 kg	168 kg	Approx. 1,000 L

Table 5 Standard properties of PCM dry-mix shotcrete mortar

Property	Age	Value
Compressive strength	28 days	46.3 N/mm ²
Elastic modulus	28 days	20 kN/mm ²
Tensile bond strength	28 days	2.7 N/mm ²
Dimensional stability	28 days	-0.013%
Freeze-thaw resistance	300 cycles	90%
Apparent chloride diffusion coefficient	6 months	0.118 cm ² /year
Electrical resistivity	28 days	28.7 kΩ·cm

5. Construction Overview

Based on the results of detailed inspections and referring to manuals such as the “Technical Manual for Maintenance of Port Facilities,”¹⁾ deterioration levels were classified into four grades. Members and blocks with the most severe deterioration (Grade: a) were selected for repair.

Deteriorated concrete was removed to the depth behind the outermost hoop reinforcement, with reinforcement fully exposed and corrosion products removed. Additional reinforcement was installed where cross-sectional loss due to corrosion was significant.

Shotcrete mortar was applied to beams and slabs using a dry-mix system, followed by trowel finishing.



Photo 8 Removal of deteriorated concrete at the beam side surface



Photo 9 Removal of deteriorated concrete at the slab soffit



Photo 10 Cleaning of reinforcing bars



Photo 11 Shotcrete application to the beam side surface



Photo 12 Shotcrete application to the beam soffit



Photo 13 Shotcrete application to slab soffit



Photo 14 Simultaneous spraying on the beam side and soffit



Photo 15 Trowel finishing immediately after spraying



Photo 16 Finished beam surface

6. Conclusions

The PCM dry-mix shotcrete method demonstrated excellent applicability for large-scale section repair of marine concrete structures. In combination with cathodic protection, the method provides enhanced long-term durability. This project represents the world's first application of the dry-mix shotcrete method as overlay mortar for cathodic protection in a marine jetty.



Photo 17 Finished slab surface

References

- 1) Coastal Development Institute of Technology: Technical Manual for Maintenance of Port Facilities, October 2007.