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Application of Simplified Deterioration Diagnosis Method to Existing Fishing Port Facilities

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Abstract. For the efficient maintenance of a large number of fishing port facilities distributed over various locations, establishment of simple deterioration diagnosis method with acceptable precision is needed. In this study, the applicability of the rebound method and the mechanical impedance method to the existing fishing port facilities was examined with laboratory tests focusing on the effect of testing conditions, measurement positions, aggregate contents on compressive strength, and influence of polishing of the test surfaces followed by in-situ surveys. As a result, the mechanical impedance method showed an acceptable precision as compared with the rebound method and was able to easily estimate compressive strength without polishing the test surfaces. It was very likely that the mechanical impedance method could be highly applicable to deterioration diagnosis method for the existing fishing port facilities.

1. Introduction

A total 2866 fishing ports with huge fishing port facilities distribute over Japan [1] and their deterioration with time is a major concern [2].

Reflecting this condition, the Fishery Agency of Japan has started the Fishing Infrastructure Stock Management Project on April 2008 for realizing a longer life and lesser maintenance cost of existing fishing port facilities. Those who are responsible for the management of fishing port facilities are now executing repair constructions and performance maintenance planning on the basis of the project [1].

Fishing port facility is characterized by its volume, variety of structure types and local government control [3]. This leads to a shortage of maintenance/repair budget and difficulty in employing expertized staffs in the local governments [4]. Another problems with deterioration diagnosis method of fishing port facilities including development of simple method, avoidance of data scatter by human factors, improvement of precision in degradation prediction and LCC estimation have been left for the future study. The improvement of the precision in degradation diagnosis is important particularly in human factors at visual observation and in conditions of site such as immersion in the sea or masking by wave-dissipating constructions leading to a need of simple deterioration diagnosis method with an acceptable precision [5].

In this paper, simple deterioration diagnosis methods applicable to existing fishing port facilities were examined. In addition to the laboratory tests performed on factors affecting the compressive strength and testing conditions including testing position and surface pre-treatment, on-site testing was also carried out using rebound method that can estimate compressive strength by the rebound hardness as a result of impacting concrete surface and mechanical impedance method that can also estimate compressive strength by the response waveform originated from an impact on the concrete surfaces by a hammer.

2. Fishing port facilities, rebound method and mechanical impedance method

2.1. State of the fishing port facilities

Fishing port facilities in our country have been steadily developed since 1960's and accumulated total length became greater than 5000 km in 2005. Most of these facilities are expected to reach their service lives shortly (Figure 1.) and the deterioration problems may become apparent (Figure 2.).
Prefectural and city governments, whose estimated yearly repair cost for fishing port facilities in the twenty years ahead exceeds that of 2009 F.Y., are 24 out of 40 among which 12 are more than twice as much [2].

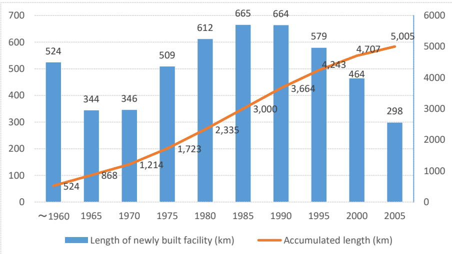

Figure 1. Changes in number of stocks in fishing port facilities.

Figure 2. Deterioration of fishing port facilities.

2.2. Characteristics of fishing port facilities

Fishing port facilities are characterized by the following conditions for which any deterioration diagnosis method should pay particular attentions [4].

(1) Most of the structural elements are made of concrete particularly that without reinforcements.
(2) Lengthy structures such as breakwater form a major part.
(3) Structures are likely to be deteriorated due to ocean waves and seawater [6].

3. Simple degradation inspection method applicable to fishing port facilities

3.1. NDT methods applicable to fishing port facilities.

Because major fishing port facilities are made of concrete without steel reinforcement, deterioration of concrete structure has been estimated in terms of cracking, flaking, internal flaws such as voids and compressive strength [7]. Among these measures, near-surface compressive strength of concrete may be a reliable deterioration index because non-reinforced concretes suffer from less effect of chloride attack and carbonation [8, 9].
Compressive strength of concrete in structure becomes most reliable when sampled from the targeted structures and tested according to JIS A 1108, while its destructive nature and time-cost from sampling to testing are known as major disadvantages [7]. Another compressive strength estimation methods include rebound method against concrete surface hardness [10, 11] and minute-destructive strength testing [7] and, for flaking and internal flaws, non-destructive methods using ultrasonic [12] and impact-echo methods or small core sampling method have been used [10, 13, 14]
Because repair of the targeted structure is not necessary and large number of data can be acquired, the non-destructive testing methods are favourably applied to the cases with the following conditions,

(1) Preliminary test for the subsequent detailed inspection,
(2) Cores necessary for compressive strength testing cannot be sampled,

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(3) Number of tests for the strength estimation are huge, where statistical treatment or calibration curves shall be accompanied.

On the other hands, several problems with the non-destructive testing methods including low precision and limitation in applied ranges have been pointed out [7].

In this study, rebound method and mechanical impedance method which is a kind of the impact echo method, were focused as possible deterioration diagnosis methods applicable to existing fishing port facilities [4, 15, 16, 17]. Reasons of the selection are as follows.

(1) Easy operation
(2) Fast, continuous and multiple measurements.

3.2. Characteristics of rebound method and mechanical impedance method.

The rebound method estimates compressive strength of concrete with rebound number resulting from an impact on the concrete surfaces by a rebound hammer, as shown in Figure 3. It is much easier in operation and less destructive to targeted structures compared with core sampling method, and favourably applied as a supplement of visual inspection and preliminary tests [4]. However, several disadvantages, including large variation of data by instruments, impossibility of repeated test at the same point and large variation by the type of material, have been reported [18, 19].

Mechanical impedance method estimates compressive strength of concrete with contact impedance resulting from response waveform of an impact on the concrete surfaces by an impulse hammer [18, 19] as shown in Figure 3. More precisely, the measured response waveform, as shown in Figure 4, is divided into two parts: time domain when a hammer presses concrete and that concrete elastic response thrusts back the hammer. These measurements provide compressive strength estimation, deterioration degree of concrete surfaces and flaking/separation of near-surface concrete [18, 19].

Figure 3. Measurement of rebound method (left) and mechanical impedance method (right).

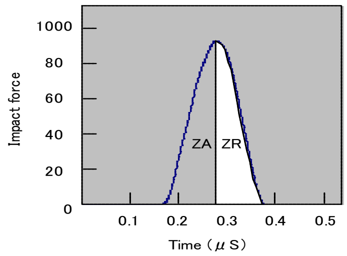

Figure 4. An example of impact response waveform of concrete surface.

4. Laboratory and in-situ testing methods

4.1. Laboratory tests: Comparison of compressive strengths obtained with rebound method, mechanical impedance method and standard core testing method.

In order to compare the results obtained with the rebound method, mechanical impedance method and core compressive strength, and to examine influences of the testing position on the compressive strength, prism specimens of 300 × 300 × 600 mm with a water cement ratio (W/C) of 35, 50 and 65% were prepared and subjected to measurements by the rebound method and the mechanical impedance method to estimate compressive strength. Appearance of the prism specimen is shown in Figure 5. Materials used for the prism specimens and mix proportions are listed in Tables 1 and 2.

Figure 5. Concrete prism specimens.

Table 1. Materials used for the prism specimen

	Type	Notation	Characteristics
Cement	Ordinary portland cement	C	Density: 3.16 g/cm3, Blaine specific surface area: 3300 cm2/g
Fine aggregate	Pit sand from Kikugawa influent	S	Density: 2.59 g/cm3, Water absorption: 2.18%, Fineness modulus: 2.42
Coarse aggregate	Hard sandstone from Oume	G	Density: 2.70 g/cm3, Water absorption: 0.62%, Maximum aggregate size: 20 mm
Admixture	AE water reducing agent	Ad1	Lignin sulfonic acid compound and polyol complex
	AE auxiliary agent	Ad2	Modified rosin acid compound anionic surfactant
	Superplasticizer	SP	Polycarboxylic acid ether compound

Table 2. Concrete mix proportion of the prism specimen

W/C (%)	s/a (%)	Air content (%)	Unit content (kg/m3				Admixture (kg/m3)			Measured value	
			W	C	S	G	Ad1	Ad2	SP	Air content (%)	Slump (cm)
35	42.8	4.5	162	463	717	998	−	0.009	3.70	4.5	15.5
50	45.8		167	334	809	998	1.67	0.003	−	4.0	15.8
65	47.2		172	265	854	998	1.06	0.004	−	4.3	11.0

4.2. Laboratory tests: Effects of surface deterioration on the compressive strengths estimated with rebound method and mechanical impedance method.

In order to confirm the influence of difference in test surface conditions on the measured value, one side of the prism specimen, which was not used for tests as described in the previous section 4.1, was dipped in a hydrochloric acid (diluted concentration: 3.3%) for 5 to 10 mm in depth. After deteriorating the surface for 24 hours, it was washed with a water jet and used as a test surface. The appearance of the prism specimen with a deteriorated surface layer is shown in Figure 6.

After completion of these measurements, a core with a diameter of 75 mm was taken at each measurement point and subjected to the compressive strength test (JIS A 1108).

The test surfaces were prepared in three conditions (without deterioration, deterioration without polishing, polishing after deterioration) and then measured with the rebound method and mechanical impedance method. These measurement positions were at the centre portion of 30 cm from the upper surface, and the number of measurements was 50 times. For all the tests, measured values are all used without invalidating ±20% or more unlike the conventional procedure of the rebound method.

Polishing of the specimen surfaces was performed using a motorized disc polisher with a disc diameter of 100 mm and a grain size of # 60. (surface layer about 1 mm).

Figure 6. Concrete prism specimens with a deteriorated surface.

4.3. In-situ concrete strength estimation with rebound method and mechanical impedance method at the existing fishing port facilities.

In order to estimate concrete strength with the rebound method and mechanical impedance method for the application to existing fishing port facilities, the measurement with both methods and concrete compressive strength test using sampled cores (JIS A 1108) were carried out.

Structure type, year of completion, measurement position, measurement items, number of measurement points at existing fishing port facilities are listed in Table 3.

In these fishing port facilities, measurement for the test surface with or without polishing was executed with the rebound method and the mechanical impedance method, and at the same position, cores were taken and the compressive strength test (JIS A 1108) was carried out. The number of measurements was 25, and polishing was performed using an electric disk grinder (100 mm disk grinder, grain size # 60) to a degree (approx. 1 mm) that it can be judged that the concrete surface had no irregularities by visual observation as in the previous report.

Although each facility had a wide range of the year of completion as listed in the fishing port ledger, the history of repair was unknown or judged as having no achievement. Neither facility has left design documents, while it was judged from the structure type to be a non-reinforced concrete structure although the mix proportions of the material was unknown.

Table 3. Measurement positions at existing fishing port facilities

Prefecture	Fishing port	Facility	Structure type	Year of completion	Location	Measurement items and number of tests
Aomori	Port U	Breakwater	Concrete single block	1983	2 locations (No.1, 40)	Core compressive strength test: 1 Rebound test: each 25 points (3cm mesh) Mechanical impedance test: each 25 points (3cm mesh) before and after polishing
		wharf		1982	1 location (No.2)	
Niigata	Port N	Sea wall	Retaining wall	1980-2006	1 location (NN.1)	Core compressive strength test: 3 Rebound test: each 25 points (3cm mesh) Mechanical impedance test: each 25 points (3cm mesh) before and after polishing
	Port T	Breakwater	Retaining wall	1980-2005	2 locations (TB1, TB3)	
Kanagawa	Port M	Breakwater	Concrete debris with on-site concrete top	1953	2 locations (NO9, 16)	
		Mooring pier	Concrete block masonry	1961	1 location (NO.11)	

Table 4. Estimated compressive strength of rebound and mechanical impedance methods as compared with average core compressive strength (Unit: N/mm^2)

W/C=35%			W/C=50%			W/C=65%		
Rebound method	Mechanical impedance method	Average core compressive strength	Rebound method	Mechanical impedance method	Average core compressive strength	Rebound method	Mechanical impedance method	Average core compressive strength
27.4	31.4	50.8	25.1	27.5	45.7	22.0	27.1	29.5

Figure 7. Overview of breakwaters at fishing port U (Upper left), fishing port T (Upper right), fishing port M (Lower left) and mooring pier of fishing port M (Lower right).

5. Results and discussion

5.1. Laboratory test: Comparison of compressive strength estimated with rebound method, mechanical impedance method and core strength test

Results of compressive strengths estimated with rebound and mechanical impedance method, and measured with sampled core are listed in Table 4. Rebound test was performed 25 times at each point and the averaged rebound number (R-value) was used for the estimation of compressive strength.

Estimated strength = $-18.04+1.27R_o$ [20] (1)

Measurement and estimation of compressive strength with mechanical impedance method were performed according to the Proposed Operation Manual for Assessing Concrete Strength using Mechanical Impedance Method at Fishing Port Facilities and strength was estimated using 25 impacts per point.

Estimated strength = 2.98 ZR (mechanical impedance value) -13.35 [21] (2)

By comparing the compressive strengths obtained with the three methods, the magnitude of compressive strength tends to be in the order of, the rebound method < mechanical impedance method < average core compressive strength, at any W / C (see Table 4), and the mechanical impedance method showed closer results to the average core compressive strength than that of the rebound method.

5.2. Laboratory tests: Effects of surface deterioration on the compressive strength estimated with rebound method and mechanical impedance method

Estimated strengths and coefficient of variation by the rebound method and mechanical impedance method are shown in Figure 8. for specimens of three different surface conditions: without deterioration, deterioration without polishing, and polishing after deterioration. The estimated strength of the mechanical impedance method tended to be larger than the rebound method in any W/C or surface condition, showing similar tendency to the laboratory test result as shown in section 5.1.

The estimated strength of the rebound method tended to decrease for specimens with a surface condition “deterioration without polishing” compared to that of the mechanical impedance method leading a remarkably large coefficient of variation in this case. This may imply that the polishing of test surface is necessary for the rebound method when applying to existing fishing port facilities.

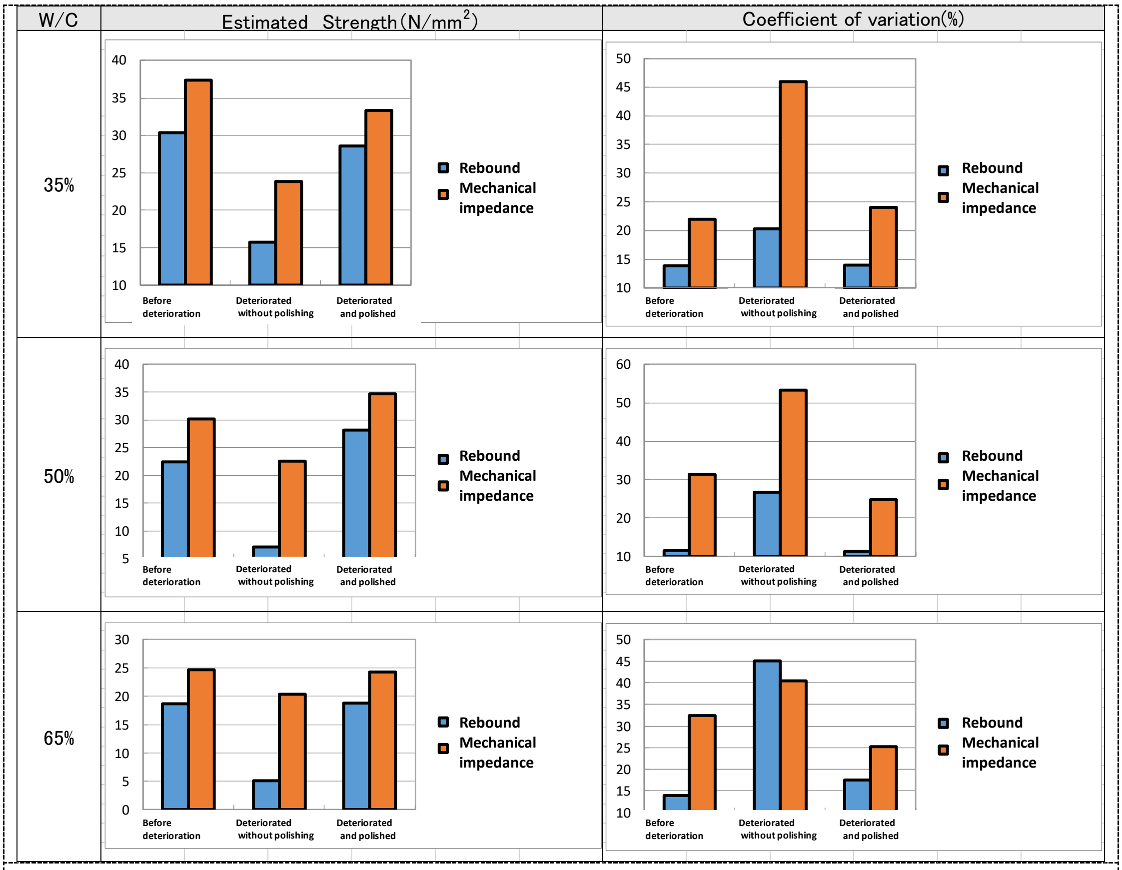

Figure 8. Effects of surface conditions on the estimated concrete strength and coefficient of variation measured with rebound method and mechanical impedance method.

5.3. In-situ concrete strength estimation with rebound method and mechanical impedance method

Results of the in-situ measurements with the rebound method, mechanical impedance method and core compressive strength test at each fishing port are shown in Table 5. The strength estimation by the rebound method was performed in the same way as described in sections 5.1 and 5.2, while deviation larger than ± 20% was invalidated [20], while in the mechanical impedance method, those with the asymmetrical ZA and ZR and disturbed waveform in the impact response waveform were invalidated [21].

The estimated strength of the rebound method in any of the fishing port approached the average core compressive strength when specimens were polished. Comparing the estimated strength after polishing (a) and the average core compressive strength (c) at each fishing port, the values ranged from 80.3 to 102.9% which were nearly the same as the average core compressive strength, while those of the breakwater NO. 1 and 40 at the fishing port U, breakwater No. 9 and No. 11 mooring pier of fishing port M showed considerably lower ranging from 37.3 to 70.1% (see Table 5). These support the fact that the rebound number shows considerably scatter depending on the type of the targeted material, the surface condition, and the aggregate beneath the test surfaces [10]. It should be noted that the application of the rebound method to the existing fishing port facility needs extensive number of measurements, polishing of test surfaces as well as core compressive strength tests as conventionally believed [10, 20].

Also, the mechanical impedance method tended to show the estimated strength close to the average core compressive strength (c) after polishing like the rebound method, and much closer to the average core compressive strength than that of the rebound method as b/c of 61.0 to 94.9% before polishing and 67.8 to 117.4% after polishing.

Mikami et al. compared the average core compressive strength and the measured value by the mechanical impedance method at the existing levees (20 points) of the coastal structures [5], and proposed a correction formula (3) for applying this method to the levee facility in order to estimate the core average compressive strength from the mechanical impedance measurement.

$$Y = 1.07\,X + 8.46\ (R^2 = 0.73) \qquad (3)$$

where Y: average core compressive strength N/mm2 and X: estimated strength by mechanical impedance method N/mm2.

Correlation between the estimated compressive strength obtained with the mechanical impedance method before polishing and the average core compressive strength at 9 fishing ports in this study was given by the equation (4).

$$Y = 1.2\,X + 0.71\ (R^2 = 0.80) \qquad (4)$$

The correlation coefficient is higher than that of the correction formula (3) of Mikami et al. [5], and it is considered that the proposed method could estimate the compressive strength with a high precision using conversion equation (4), even applied before polishing. In the future, continuous data accumulation is needed by types of facility and structure.

Because the proposed method tends to show closer values to the average core compressive strength than that of the rebound method, it is confirmed that simple estimation of compressive strength close to that the core compressive strength test without polishing the test surfaces could be possible when data accumulation is repeated associated with the waveform analysis of the impact response waveform

Table 5. Comparison of the measured data with tree methods at each fishing port facility

Prefecture		Aomori					
Fishing port		Fishing port U					
Facility		Breakwater				Wharf	
		NO. 1		NO. 40		NO. 2	
Polishing of the test surface		Before	After	Before	After	Before	After
Core compressive strength	Averaged compressive strength: c (N/mm^2)	42.3		23.4		25.2	
Rebound	Estimated Strength: a (N/mm^2)	18.8	22.6	7.8	16.4	11.1	22.6
	a/c (%)	44.4%	53.4%	33.3%	70.1%	44.0%	89.7%
Mechanical impedance	Estimated Strength: b (N/mm^2)	33.6	36.3	14.3	15.9	20.51	25.06
	b/c (%)	79.3%	85.8%	61.0%	67.8%	81.4%	99.4%
Prefecture		Niigata					
Fishing port		Fishing port N		Fishing port T			
Facility		Sea wall		Breakwater			
		NN1		TB1		TB3	
Polishing of the test surface		Before	After	Before	After	Before	After
Core compressive strength	Averaged compressive strength: c (N/mm^2)	27.3		23.3		22.0	
Rebound	Estimated Strength: a (N/mm^2)	11.3	28.1	11.6	18.7	14.4	21.9
	a/c (%)	41.4%	102.9%	49.8%	80.3%	65.5%	99.5%
Mechanical impedance	Estimated Strength: b (N/mm^2)	21.6	26.2	22.1	25.3	19.7	23.6
	b/c (%)	78.9%	96.0%	94.9%	108.8%	89.6%	107.4%
Prefecture		Kanagawa					
Fishing port		Fishing port M					
Facility		Breakwater		Mooring pier			
		NO. 9		NO. 16		NO. 11	
Polishing of the test surface		Before	After	Before	After	Before	After
Core compressive strength	Averaged compressive strength: c (N/mm^2)	30.3		20.8		38.8	
Rebound	Estimated Strength: a (N/mm^2)	7.8	11.3	14.6	16.7	15.4	22.4
	a/c (%)	25.7%	37.3%	70.2%	80.3%	39.7%	57.7%
Mechanical impedance	Estimated Strength: b (N/mm^2)	26.7	28.3	19.1	24.4	27.5	35.0
	b/c (%)	88.2%	93.2%	91.7%	117.4%	70.8%	90.2%

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in the future.

6. Conclusions

As a simple deterioration diagnosis method, applicability of rebound and mechanical impedance methods to fishing port facilities was examined and following conclusions were obtained.

(1) Compressive strength estimated with the rebound method was lower than that obtained with the averaged value of core compressive strength and showed large scatter with or without polishing test surface. It was confirmed that polishing of the test surfaces as pointed out in JIS, larger number of measurements and combined core compressive strength test are needed when applied to fishing port facilities.

(2) Even though test surfaces were not polished, concrete strength estimated with mechanical impedance method tended to be closer to mean core compressive strength unlike that estimated with rebound method. The mechanical impedance method could be more favourably applied to simple on-site strength estimation when relationship between impact response waveform and compressive strength is further accumulated.

As shown above, application of mechanical impedance method to fishing port facilities, forming large volume and huge stock, is a reasonable option as a simple estimation method of compressive strength. Based on these methods, further research shall be made by accumulating data from various locations, structure types and date of completion, and by taking into account effects of concrete age and surface deterioration conditions. The inspection of existing fishery port facilities was a result of authors' compilation of the inspection data based on the Infrastructure Inspection Project sponsored by the Fisheries Agency of Japan.

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