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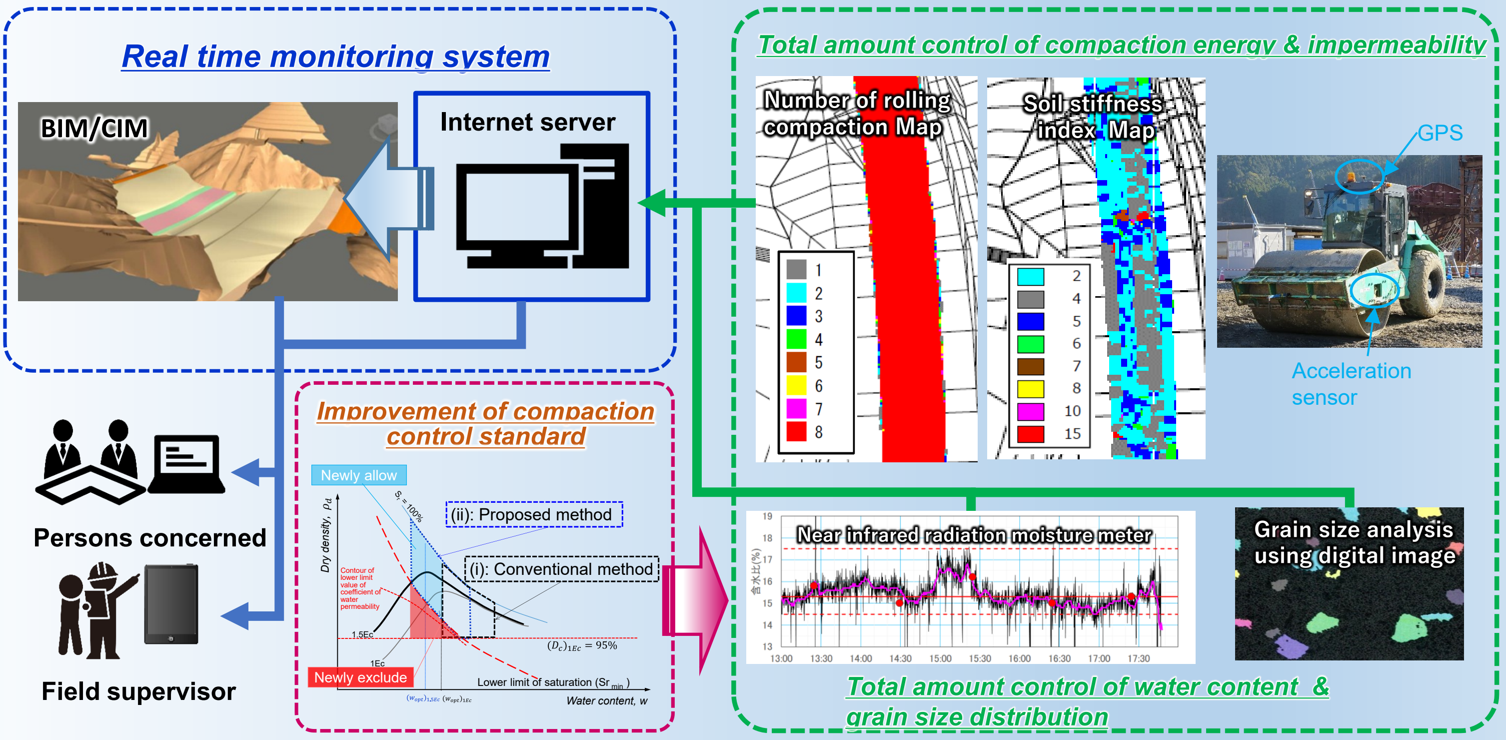
Infrastructure Development Institute—JAPAN

The comprehensive quality control method for impervious embankment
New quality control based on the collaboration of the latest soil compaction theory and ICT



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Infrastructure Development Institute – Japan (IDI)
Plaza Edogawa-bashi 3F. 1-23-6, Sekiguchi, Bunkyo-ku, Tokyo, 112-0014, JAPAN

24th Infrastructure Technology Development Award 2022

Japan Institute of Country-ology and Engineering (JICE) was established as a public interest corporation to promote construction engineering in Japan by conducting cutting-edge research and development activities.

As more incentives should be provided for construction technology researchers and research institutes to enhance the level of construction engineering more effectively, JICE commenced Infrastructure Technology Development Award with Coastal Development Institute of Technology (CDIT) under the auspices of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT).

37 technologies competed for the 24th Infrastructure Technology Development Award. In principle, the applicants' technologies should have been developed within the past five years and applied to the real sites already.

As a result of examination, institutes and researchers with the following technologies were awarded the 24th prizes.

The grand prize is"The comprehensive quality control method for impervious embankment".

And the two excellence prizes are "Precast PC floor slab using UFC as waterproof layer", and "Evaluation method of residual structural performance for piers using artificial intelligence".

The grand prize and the two excellence prizes are introduced below.

Any inquiries/ comments please contact to JICE :
Homepage: http://www.jice.or.jp/
(Japanese version only)
E-Mail: webmaster@jice.or.jp

The comprehensive quality control method for impervious embankment

New quality control based on the collaboration of the latest soil compaction theory and ICT

1. Background and Opportunities for Technological Development

In recent years, i-Construction, which is construction using ICT, has been promoted in Japan. In general earthwork, productivity has been improved in terms of quality control, with global navigation satellite system (GNSS)-based quality control, in which in-situ density tests are replaced by GNSS recordings.

However, GNSS-based quality control cannot directly measure quality control items on embankment. For this reason, the quality control of impervious embankments such as fill dams has not yet broken away from the multi-point control type of quality control based on a large number of in-situ tests. As a result, time- and labor-intensive in-situ tests cannot be omitted, and productivity has not been improved, in the construction of impervious embankments.

2. Contents of the Technology

This technology controls the factors that determine the quality of embankment by using ICT: (1) the grain size of embankment material, (2) the water content ratio, and (3) the compaction energy. In addition, this technology manages all of these factors (1) ~ (3) and (4), soil stiffness index (SSI), using ICT (Figure-1).

In the past, hydraulic conductivity has been managed indirectly by "dry density" and "water content ratio”.This technology has developed a new management method in which "density" and "water content ratio" are replaced by "in-situ compaction energy" and "ground stiffness," respectively, enabling areal compaction management of impervious embankments using ICT (Figure-2).

In addition, the control values of (1)~(4) were set considering the on-site compaction energy (1.5 Ec in this case) and the lower limit of the saturation degree (Figure-1(5)).

The ICT construction management information from (1) to (4) is integrated in the cloud to enable real-time, remote control of compaction management (Figure-1(6)).

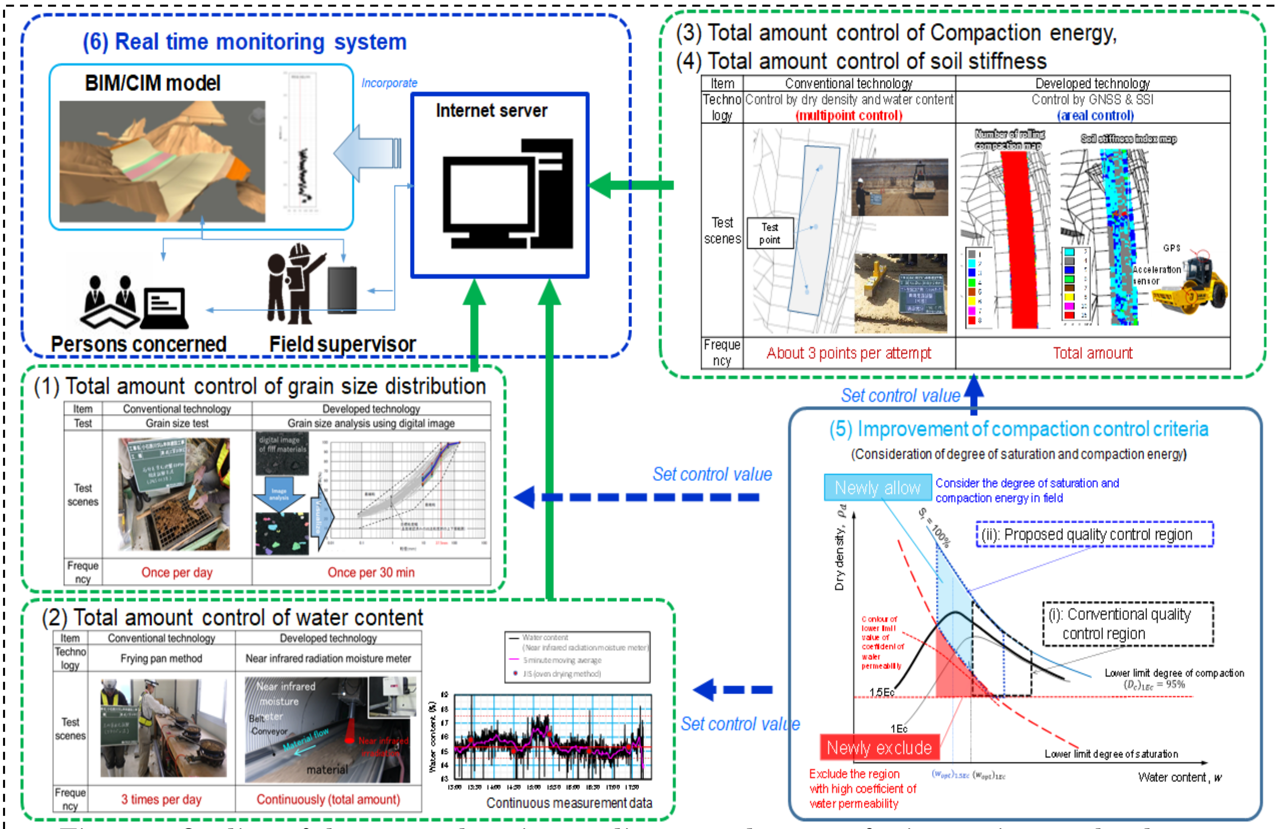

Figure-1 Outline of the comprehensive quality control system for impervious embankment

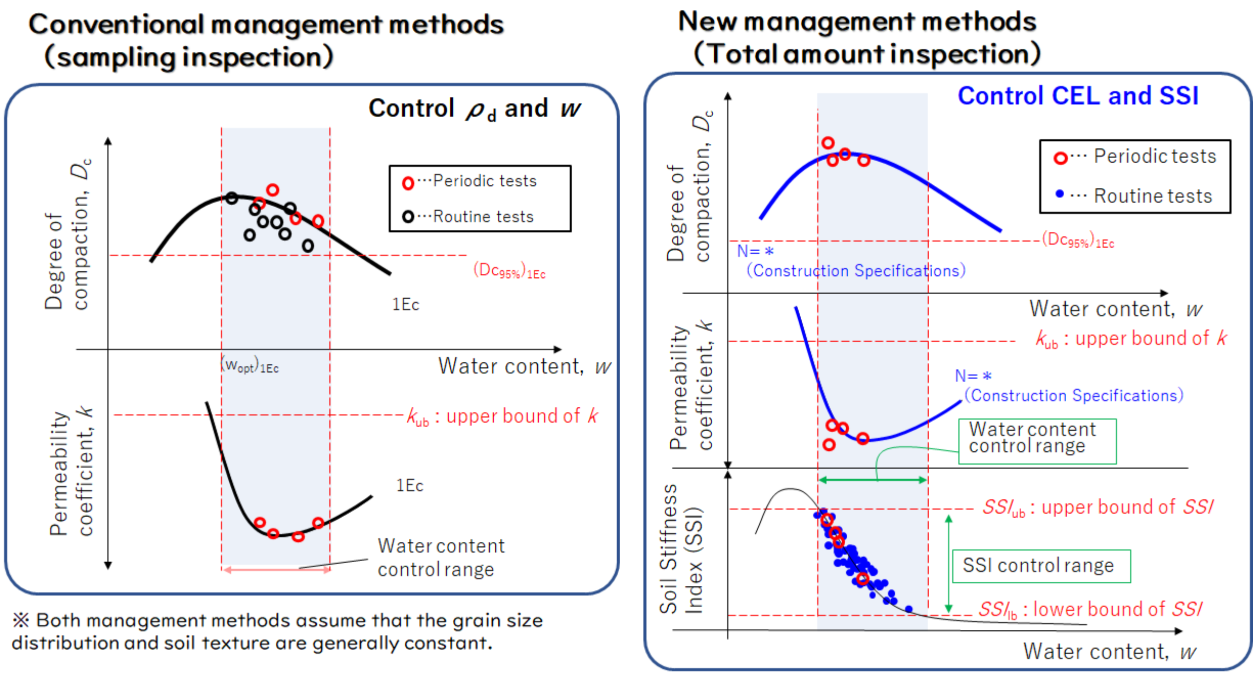

Figure-2 Comparison of new management method and conventional management method

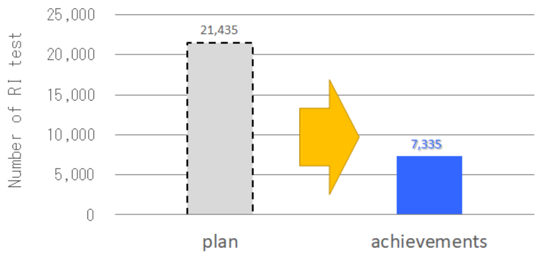

Figure-3 Reduction in field density test

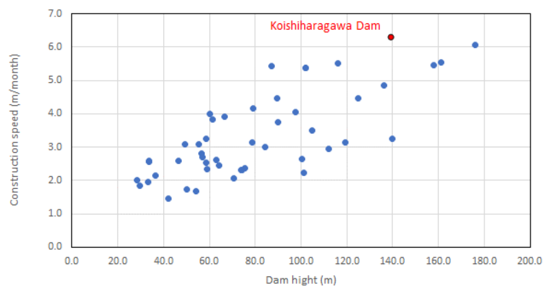

Figure-4 Construction speed

Photo-1 Remote monitoring

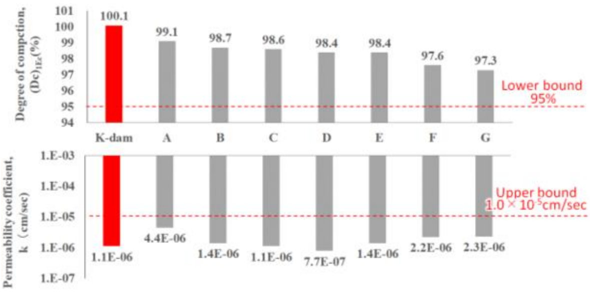

Figure-5 Comparison of quality test results with past dams (degree of compaction & permeability coefficient)

3. Scope of Application of the Technology

In order to apply this technology, it is necessary to control the particle size distribution of fill materials and the in-situ compaction energy within a range that can be regarded as constant.

Therefore, this technology is highly compatible with large-scale impervious embankment projects such as fill dam construction, where compaction and material management are carefully controlled.

4. Effects of the Technology

In the Koishiharagawa Dam construction project, the time required for in-situ quality control tests was reduced by more than 1,300 hours (Figure-3).

Real-time remote confirmation of quality control records became possible (Photo-1), and the number of personnel required by the operator was reduced to about half of those required for dams of the same size in the past.

The construction speed of the core zone of the fill dam (monthly fill height (m/month)) was the fastest among fill dams over 100 m in Japan.

The average compaction degree was higher than that of dams constructed using the conventional management method (Figure-5). All measured hydraulic conductivity values satisfied the control values.

5. Social Significance and Development Potential of the Technology

This technology has realized for the first time areal compaction control in impervious embankment construction, which had been considered difficult in the past. As a result, it contributed to the promotion of i-Construction.

This technology is expected to be applied to construction projects for impervious embankments such as fill dams, river embankments, and final waste disposal sites, both in Japan and overseas.

6. Track Record of Application of the Technology

Koishiharagawa Dam construction project, impervious zone construciton, Oct 2017- jul 2019.

7. Contact Information

Technology Developer:
Japan Water Agency／Kajima Corporation Construction Technology Dept. Civil Engineering Management Division

https://www.water.go.jp
TEL:+81-48-600-6553
E-mail:webmaster@water.go.jp

http://www.kajima.co.jp
TEL:+81-3-5544-1111

Precast PC floor slab using UFC as waterproof layer

Floor slab of composite structure with UFC layer

1. Background and Opportunities for Technological Development

Currently, expressway companies are strongly promoting the replacement of steel bridge floor slabs as a representative work of expressway renewal projects. In these projects, precast concrete floor slabs are used as the standard for newly installed floor slabs in order to improve the durability of the floor slabs and reduce the impact of long-term traffic restrictions. Considering that it is important to develop even more durable floor slabs to prevent the effects of long-term traffic restrictions, we focused on the application of Ultra-high-strength Fiber reinforced Concrete (UFC), which has high strength and excellent water and salt barrier properties.

In addition, it has been difficult to shorten the work schedule for on-site waterproofing work for the floor slab, which is the last step of highway construction work. Therefore, we have been hoping for a waterproofing system that enables us to shorten the traffic regulation period and be unaffected by the weather.

2. Contents of the Technology

This technology is a precast PC floor slab with a composite structure in which dense, high-strength, and durable UFC is layered and integrated on the upper covering of the floor slab (Figure-1, Photo-1). The newly developed composite PC slab provides a waterproof function by replacing the upper concrete of the precast PC floor slab with a UFC layer that is 20 to 40 mm thick, and also uses in-situ UFC at the joints of precast floor slabs, thereby waterproofing the entire bridge surface by UFC. The joints between precast floor slabs and in-situ UFC have a serrated shape (Figure-2, Photo-2) to ensure waterproof performance and transmit the tensile stress of the UFC.

3. Scope of Application of the Technology

・Concrete floor slabs of steel road bridges

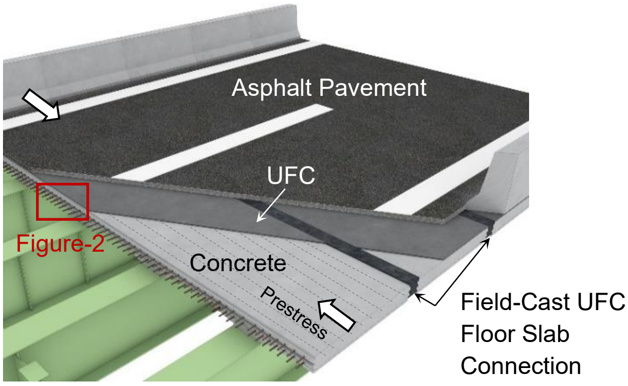

Figure-1 Outline of Precast PC floor slab with UFC layer

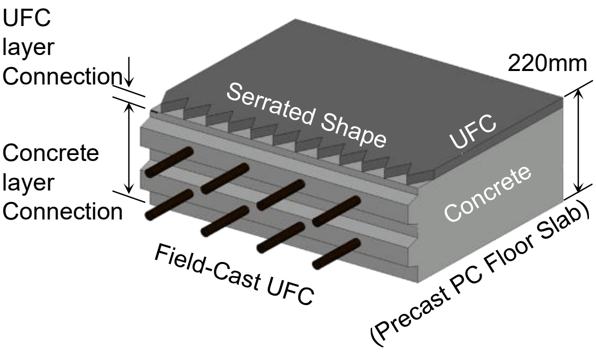

Figure-2 Edge of Precast PC floor slab with UFC layer

Photo-1 Precast PC floor slab with UFC layer

4. Effects of the Technology

(1) Shortening of the traffic restriction period for floor slab replacement work: Since floor slab waterproofing work is not required on site, it is possible to shorten the traffic restriction time (Table-2).

(2) Avoiding the risk of delays in floor slab replacement work: Since floor slab waterproofing work cannot be carried out during rainfall, there is a risk that unseasonable weather will delay the work schedule and affect the traffic restriction period. By applying the floor slabs of composite structure, this situation can be avoided (Table-1, 2).

(3) Reduction of life cycle costs (LCC): Due to the high strength of UFC, the waterproofing function of the floor slabs with UFC layers will not be impaired even when the pavement is renewed once every 30 years. In addition, labor savings and LCC reduction can be achieved.

(4) Improved floor slab durability: By laying UFC on top of a precast PC floor slab, the fatigue durability of the floor slab can also be improved.

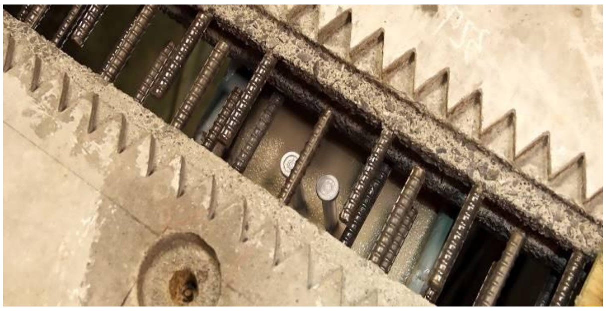

Photo-2 Precast PC floor slab connection before filling UFC

Photo-3 Completed construction of Precast PC floor slab with UFC layer

Table-1 Direct effects of Precast PC floor slabs with UFC layer (life cycle costs) (Unit: million yen)

	with UFC layer (A)	Conventional technology (B)	Increase/Decrease (A-B)
100 years LCC (a+b)	154	169	- 15
(a) Construction cost (incremental)	154	26	+128
(b) Maintenance cost	0	143	-143
Delay cost due to bad weather	0	17	- 17

Table-2 Indirect effects of Precast PC floor slabs with UFC layer (traffic restriction period) (Unit: days)

	with UFC layer (A)	Conventional technology (B)	Increase/Decrease (A-B)
Traffic regulation period through 100 years (a+b)	51	121	-70
(a) Regulation period for floor slabs renewal	34	37	-3
(b) Regulation period for pavement renewal	17	84	-67
Additional period due to bad weather	0	25	-25

5. Social Significance and Development Potential of the Technology

By applying this technology, it is possible to shorten the period of traffic restrictions during floor slab replacement work, thereby reducing the occurrence of traffic congestion due to traffic restrictions, thus contributing to the reduction of the impact on public life and social loss. In addition, since the conventional floor slab waterproofing work, which had to be renewed every 30 years, is no longer required, it contributes to labor saving and productivity improvement in construction. It also contributes to improving the durability of floor slabs.

The deterioration of road bridge floor slabs is progressing around the world, and we believe that we can contribute to this problem through the international deployment of this technology.

6. Track Record of Application of the Technology

The floor slab replacement work on Tohoku Expressway Miyagi Shiroishigawa bridge from October 2020 to November 2020, and 4 other projects.

7. Contact Information

East Nippon Expressway Company Limited
Hidekazu Hayashi
Structural Engineering Section
Technology & Environment Department
h.hayashi.ac@e-nexco.co.jp

Obayashi Corporation
Masumi Muto
Research & Development Management Department
Technology Strategy Planning Office
Technology Division
muto.masumi@obayashi.co.jp

Evaluation method of residual structural performance for piers using artificial intelligence

Contribution to rational and planned maintenance by predicting the durable period of piers

1. Background and Opportunities for Technological Development

Of 58,839 public port facilities, 10,178 facilities were identified that require emergency measures (as of March 31, 2019). In addition, approximately 30,000 other port facilities are owned by the private sector, which includes steel, cement, and nonferrous metal companies. Although inspections of port facilities have become mandatory with the revision of the Ports and Harbors Act, in many cases, especially in the private sector, "breakdown maintenance" is performed, wherein measures are taken after a failure of a facility occurs (Figure-1). The degrees of deterioration and performance degradation obtained from maintenance surveys represent the condition of the facility at the time of conducting the surveys.

Till date, there have been no rational indicators to determine whether the facilities can continue to be used or when repairs and reinforcements should be carried out (Figure-2). Therefore, in this technological development, we devised a tool for port piers to estimate the durable period of port structures based on their residual performance and provide information that facilitates decision-making by facility managers.

Figure-1 Port pier deteriorated due to reinforcing steel bar corrosion

2. Contents of the Technology

Our proposed technology makes it possible to estimate the durability period of port structures based on their residual performance that indicates how deteriorated piers will be damaged during an earthquake. The residual performance of a pier depends on the degree of corrosion of the reinforcing steel bars in the beams; however, chipping concrete each time to measure the residual performance is not realistic.

Therefore, we first fabricated beam specimens corresponding to deterioration degrees "a" to "d" by forcibly corroding the reinforcing steel bars. Next, we determined the flexural capacity of beam members through structural testing and reproduction analysis via the Finite Element Method. Then, we created skeleton models corresponding to each deterioration degree, and evaluated the residual flexural capacity of the beam members through structural analysis based on each deterioration degree.

In addition, by removing a portion of the aged pier beams for pier renewal work and conducting loading tests, issues with regard to the effects of different corrosion methods of reinforcing steel bars and scale effects were resolved. Furthermore, by having the AI learn the combination of structural analysis conditions and analysis results for approximately 2,000 cases, we constructed an AI model that outputs the degree of damage from the degree of deterioration, and confirmed that it can predict the degree of damage with high accuracy (Figure-3).

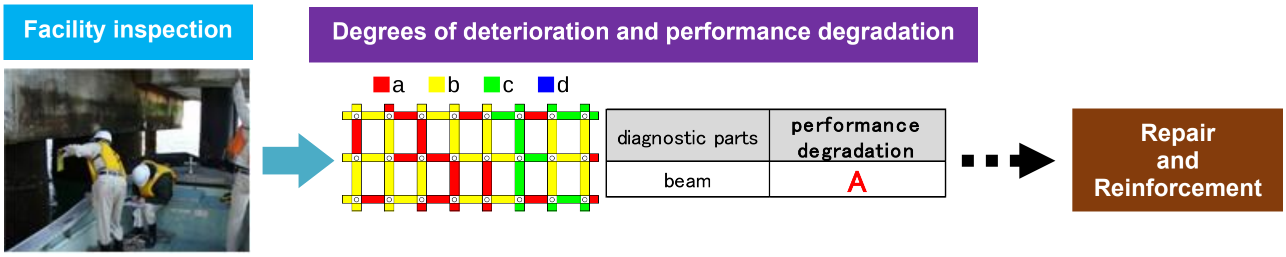

Figure-2 Flow of survey and diagnosis on current maintenance and management

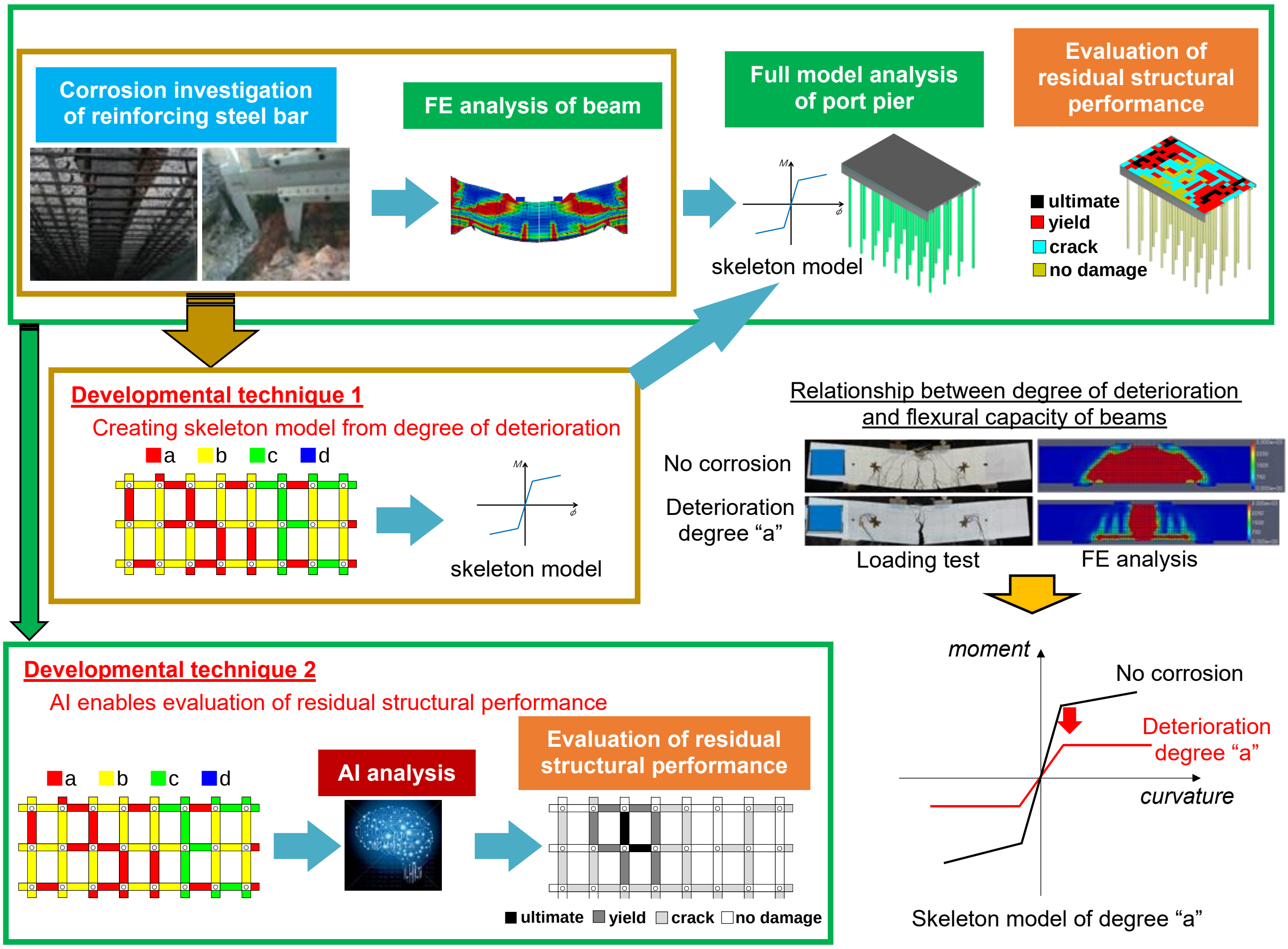

Figure-3 Flow of technological development

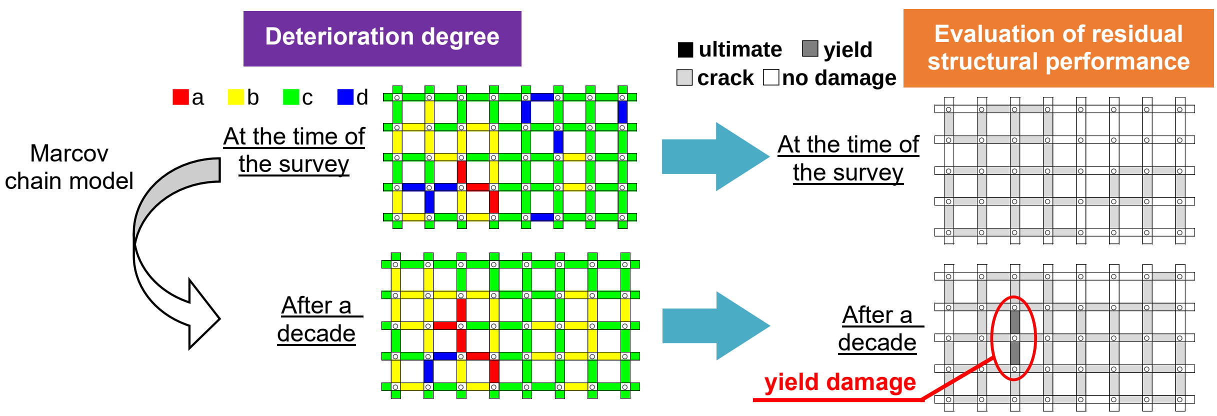

Figure-4 Example of residual structural performance using AI

3. Scope of Application of the Technology

Generally, the piers for which the residual performance can be evaluated are vertical pile structures. In many cases, piles are fabricated using anti-corrosion technology, and they are meticulously maintained; therefore, the AI model was trained on the assumption that piles would not deteriorate.

In designing a pier structure, only the inertial force as the weight of its slab is considered against external forces such as seismic forces, and the slab is generally not regarded as a structural member that resists such external forces.

4. Effects of the Technology

Our AI-based evaluation technique makes it possible for us to immediately identify the specific beam members that will be damaged by seismic forces and their degree of damage.

In addition, by using a probability model of deterioration progression, such as a Markov chain model, together with this technology, determining the change in residual performance over time is possible, thus we can set a specific period during which piers can remain in service (Figure-4).

Furthermore, as predicting recovery depending on various repair and reinforcement patterns (the quantitative effects of repair and reinforcement) is possible, we can formulate a rational maintenance and management plan.

5. Social Significance and Development Potential of the Technology

Our proposed technology makes it easy for facility managers to obtain damage prediction information and make decisions on whether to continue using the facility or to repair or reinforce it, thereby enabling a shift to rational and planned "preventive maintenance". This is of great social significance as it contributes to national land resilience and economic development. As we can construct AI models for structures other than port piers, this system can be used as a maintenance management technology for various structures in the future.

6. Track Record of Application of the Technology

Annual inspection of quays and port piers owned by Nippon Steel Kobelco Shearing Corporation, September 2021 to November 2021., and 1 other.

7. Contact Information

Technology Developer:
Kunihiko Uno , Dr.Eng. , Manager
Civil Engineering R & D Division,
Institute of Technology,
Penta-Ocean Construction Co., Ltd.

E-mail: kunihiko.uno@mail.penta-ocean.co.jp
TEL: +81-287-39-2109
FAX: +81-287-39-2131
HP: http://www.penta-ocean.co.jp/

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IDI provides consulting services to facilitate international assistance to developing countries, to promote international exchange of information and human resources, and to support globalization of project implementation systems targeting both developed and developing countries in the field of infrastructure.

IDI has been publishing a free quarterly journal called “IDI Quarterly” since1996 to introduce information related to public works and construction technologies developed in Japan, to foreign countries. We have distributed the journal to administration officials in more than 90 countries around the world via e-mail.

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