Committee report Technical Committee on Feasibility of Establishment of Infra-dock for Concrete Structures

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Abstract: It is a prime task to establish technologies and systems for maintaining, inspecting and diagnosing existing concrete structures. However, inspection methods currently available, which mainly involves visual inspection and diagnostic measures might be insufficient. Therefore, a technical committee that aims for establishment of "infra-dock", which is referred to "ningen (human)-dock" in concept, was proposed toward sustainable maintenance of concrete structures. The committee consisted of three working groups, which worked on 1) improvement of in-situ measurement methods as inspection technologies for construction of the infra-dock (WG1), and 2) organization of inspection methods for the infra-dock and production of scenarios (WG2). A working body at the infra-dock was proposed, and application of authorized concrete diagnosis engineers as "doctors" in charge was investigated (WG3). The results are summarized below.

Keywords: Nondestructive inspection, monitoring, field survey, mechanism of deterioration and damage, maintenance

1. Introduction

The 21st century is an era of sustainable society. The concept of elongating the lifespan should be applied not only to people but also to infrastructures. For the future, which also includes total restoration from the Great East-Japan Earthquake, technologies and systems need to be established for maintaining, inspecting and diagnosing existing concrete structures. However, current inspection relies on mostly visual examination and not sufficient for maintenamce, for judging the time of reconstruction. Therefore, establishment of "infra-dock", which is referred to "ningen(human)-dock" for human, is proposed toward sustainable maintenance of concrete structures.

In medical treatment, diagnosis is an act of specifying the cause of a disorder or disease after onset. On the other hand, prognosis implies examinations for preventing diseases as known as ningen-dock. Thus, the infra-dock is proposed aiming to evolve diagnosis into prognosis in order to cope with future increases of deteriorated and aged concrete structures.

Toward construction of "Infra-dock" for concrete structures, the committee has worked on improvement of in-situ measurement methods as inspection technologies, organized and proposed useful inspection technologies and methods, and surveyed and investigated a working body to establish a system of "doctors" in charge. All achievements have been summarized

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in a final committee report.

In the concept of the infra-dock proposed, measures for preventing and/or mitigating damage during an earthquake or other disasters, which may correspond to accidents and diseases in human body, are to be established. This is because the ningen-dock does not aim at preventing such accidents and diseases, but at detecting problems that may lead to them. This concept is introduced into the infra-dock as detecting deteriorations and defects that may affect the durability in the future and as proposing recuperation measures.

Nondestructive inspection methods for a concrete structure are compared with examinations during ningen-dock in Fig.-1. This is just a conceptual illustration but could present a clear overall vision of infra-dock.

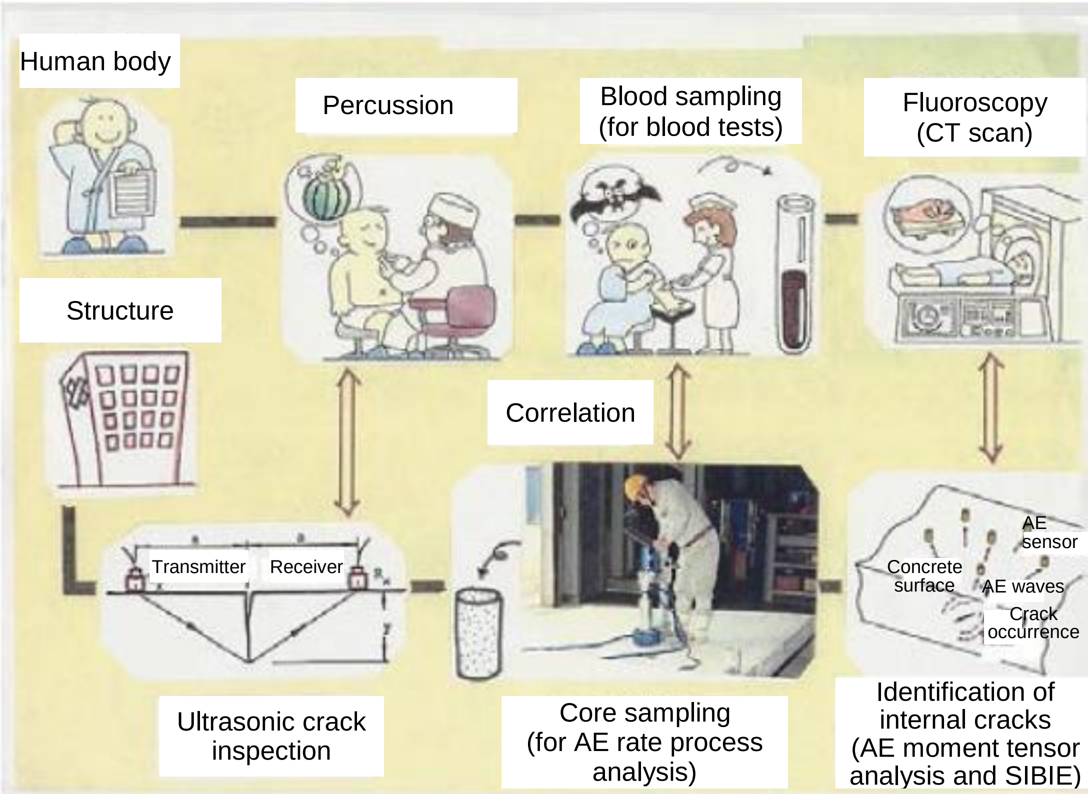


Fig.-1 Comparison between ningen-dock and infra-dock.

The committee worked with secretaries listed in Table-1 by establishing three working groups. The themes of the working groups were as follows:

WG1: To develop and organize nondestructive in-situ inspection methods for evaluating defects in concrete,

WG2: To select in-situ measurement methods and propose scenarios in the process of in-situ infra-dock, and

WG3: To establish an inspection system and to apply authorized concrete engineers to inspectors.

At the time of establishment of the FS committee in FY2012, we asked Dr. Nagayama to join as a secretary of WG2, and he played an active part. In the present committee, his position changed to an observer due to his work schedule. As described later, overseas corporate members have played very important roles at international conferences, etc.

The results of the committee activities are overviewed below, including the forefront of monitoring techniques useful for in-situ inspections (WG1), field surveys to prepare scenarios for the contents of inspection (WG2), and construction of the system and human resource development (WG3). For the details, please see the full committee report that is issued in July.

Table-1 Constitution of the committee

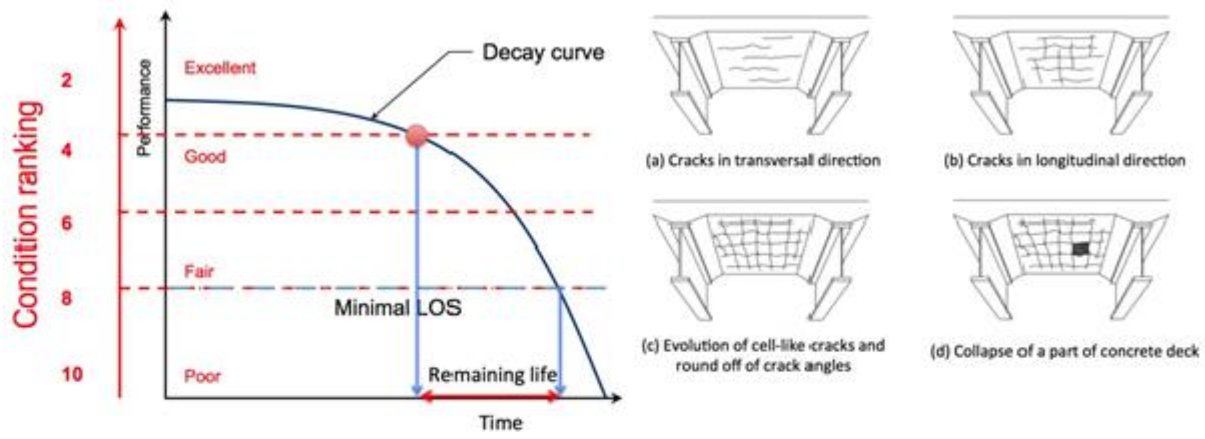
Chairman	M. Ohtsu
Secretary WG1	T. Shiotani, K. Imamoto, T. Watanabe
Secretary WG2	Y. Ueda, H. Hamazaki
Secretary WG3	A. Okamoto, K. Yokozawa
Member	K. Morihama, T. Suzuki, K. Matsuyama S. Kobayashi, Y. Watanabe, T. Nishiwaki E. Kato, H. Matsuda, S. Momoki N. Okude, K. Ohno, K. Koga N. Masui, K. Niimura, T. Minematsu
Observer	M. Nagayama, S. Yuyama, T. Komiyama
Overseas Corporate Member	C. Grosse, M. Forde

2. Forefront of monitoring techniques for infra-dock

2.1 Evaluation of defects and damages in concrete

WG1 conducted a questionnaire survey prior to organizing methods for assessing defects in concrete. From the results, it is confirmed that the concept of “preventive maintenance”, which is to be an aim of infra-dock, is different depending on management bodies.

According to the Diagnosis Technique for Concrete 2014 : Application published by the Japan Concrete Institute, preventive maintenance of a building is defined as a “method for executing maintenance to keep of damage” and that of an infrastructure is defined as a method for “predicting deterioration based on inspection and surveying and performing appropriate diagnosis”. Therefore, it is clear that concrete structures need to be inspected and monitored, but current practices mainly focus on compensative (not predictive) maintenance and various definitions are adopted by organizations. For example, grades (degrees) have been set for the damage to the external appearance of a structure. However, grading itself is qualitative, and quantitative evaluation or deterioration prediction based on the detailed inspection has been rarely performed. So far, the life-span of a structure is conventionally judged by grading the external appearance and referring to the performance curve as shown in Fig.-2. An important concept related to remaining life is a service life. In the case of a building, three kinds of lives as physical, functional and social lives are taken into account. In general, the physical life is longer than the other two and rebuilding requires much costs. The life of a building is to be judged based on the relationship between the value (Vt) of the building and the necessary costs (Ct) for retaining the building [2]. The building is to be retained when Vt > Ct and demolished and rebuilt when Vt < Ct. Since Ct is easy to be calculated, the key to life evaluation and prediction is how to quantify the value Vt.



(a) Grades for soundness evaluation based on the performance curve

(b) Visual evaluation of concrete deck

Fig.-2 Example of performance evaluation by visual inspection

2.2 Present states of in-situ inspection methods

Toward development and organization of in situ inspection methods, targets of inspections are classified into defects at the surface and those inside concrete. The methods are applied for understanding the properties of concrete surface, visualization of defects inside concrete structures, corrosion of reinforcing steel, and so forth.

Inspection methods for cracks and defects on the surface are summarized in Table-2 along with the approximated cost of inspection and time required. Concerning the methods applicable to inspecting internal concrete structure, acoustic emission (AE) method, tomography, and SIBIE analysis of the impact echo are discussed in the committee report. The next step to be taken into consideration is how to incorporate them in the inspection scenario at an infra-dock.

Table-2 Cost and measurement time of typical inspection methods

Method applied	Approximate cost*	Measurement time*
Laser scanning method	1.5 million yen / km	2.0km / day
CCD line camera method	1.5 million yen / km	2.0km / day
Ultrasonic wave method	2 thousand yen / measuring line (21 lines) to 26 thousand yen / measuring line (6 lines)	1 to 2 days / structure
Impact elastic wave method	8 thousand yen / measuring line (30 lines) to 21 thousand yen / measuring line (6 lines)	1 to 2 days / structure
Thermography	500 thousand yen / day	Similar to the time required by a digital camera on the market
Spontaneous potential method	20 thousand yen / m^2	20 m^2 / day
FBG optical fiber sensing	24 million yen	5 years
	・Displacement measurement over a surface of about 3,000 m^2 ・5 measuring lines, 50 base points (10 base points / line) ・Continuous monitoring over 5 years	

2.3 Deterioration phases and performance-based maintenance

The basic method for inspecting a concrete structure available is a visual inspection. It can inspect a large number of structures and members in a short period of time, but the results much depend on the skills, experience and knowledge of the inspector. Nondestructive tests (NDT) are useful to aid the results of visual inspection, and available for quantitative evaluation of a structure. Applications of NDT have gradually increased but are still insufficient. Lately various NDT methods have undergone remarkable development. Particularly, visualized NDT techniques have progressed strikingly. However, all decisions on which methods, when and how are dependent on the engineers' knowledge and skills.

Deterioration of concrete depends on time, but there has existed no scenario specified about "which phase of deterioration to be taken into account", "which inspection method to be strategically used for a structure", and "members of which dimensions". Therefore, the committee has investigated the cases where NDT methods are applicable, depending on the phases of deterioration.

The progress of deterioration of a reinforced concrete structure can be classified into four phases of incubation, progressive, acceleration and deteriorated periods. Due to carbonation, salt damage and chemical attack, these external factors cause deterioration of concrete cover, lower the pH near reinforcing steel, break passive layers and the reinforcing steel-bars (rebars) corrode. Then, expansion pressure due to corrosion products results in cracks on the concrete surface, as the deterioration of the concrete becomes visible. The performance level of a reinforced concrete structure is closely related to the corrosion state of reinforcing steel. The durability starts to decrease at the time when rebar starts to corrode and progresses into the acceleration phase, nucleating cracks. A deterioration model can be illustrated as shown in Fig.-3, which shows the decrease in the durability with the passage of time. In the model, during the periods prior to development of visible cracks at the concrete surface, no special inspection is currently conducted. Detailed inspection is executed only after cracks and other deterioration appear on the surface. Conventional NDT methods are employed in detailed inspections, and can quantitatively grasp the state of the concrete surface layer, but are known to be difficult to detect the damage in internal concrete structure. Therefore, the committee has surveyed

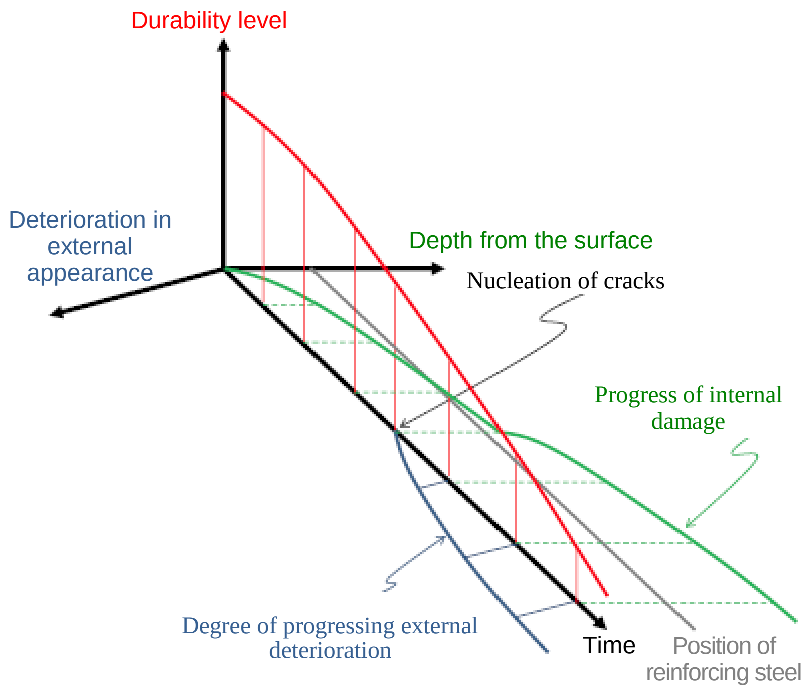


Fig.-3 Deterioration model in performance-based design of a sound reinforced concrete structure

the state-of-the-art on NDT methods applicable to inspection of internal concrete structure as summarized in the report.

A structure is kept in the sound condition by drawing up maintenance plans, which are normally based on the expected service period determined at the time of designing the structure. For an existing structure, the estimated remaining period is determined by subtracting the period of the structure in service to be maintained. Today, elongating the life-span of infrastructures is an emarging social topic, and the expected service period is going to be elongated from the initial design. Since the life-span of an existing structure is often elongated without determining clear service period, it is very difficult to determine the estimated remaining period. In Fig.-3, the values of the maintenance limit values are not shown not only because of a social background but also because it is deemed not appropriate to evenly set the maintenance limit values. This is because expected service period or estimated remaining period differs by manager and structure and the methods for determining the maintenance limit values are not common.

2.4 Nondestructive tests for evaluating the progress of deterioration

Nondestructive tests play very important roles in detailed inspection of a concrete structure. Technical Committee 331 in Japan Society of Civil Engineers (JSCE 331) has shown the

Table-3 Progress of deterioration induced by alkali-silica reaction and inspection methods [3)]

Inspection item	Inspection method (nondestructive)	Progress of deterioration			
		Latent period	Progressive period	Acceleration period	Deteriorated period
Crack (width, density, depth)	Digital image analysis (using a digital camera)	↔	↔	↔	
	Ultrasonic method		↔	↔	
	π-shaped displacement meter, crack displacement meter			↔	↔
Position of steel and state of corrosion	Spontaneous potential method, polarization resistance method		↔	↔	↔
Presence or absence of damage to steel	Elastic wave method, electromagnetic wave pulse emission			↔	↔
	Eddy current flaw detection method			↔	↔
	Electromagnetic induction method + ultrasonic method			⇠⇢	⇠⇢
	Wave propagation and pattern detection			⇠⇢	⇠⇢
Discoloration and exudation of ASR gel	Digital image analysis (using a digital camera)	↔	↔		
Strength and modulus of elasticity of concrete	Rebound hammer method			↔	↔
	Ultrasonic method			↔	↔
	Elastic wave method, AE method			⇠⇢	⇠⇢
Deformation and displacement	Fiber optic laser displacement measurement			↔	↔
Temperature, humidity, solar radiation, exposure to rain	Meteorological observation	↔	↔		
Effects of sea water and antifreezing agent	Near infrared spectroscopy	⇠⇢	⇠⇢	⇠⇢	
Solidity index (ultrasonic propagation velocity, etc.)	Ultrasonic method	↔	↔		

↔ : Quantitative to a certain extent ⇠⇢ : Quantitativity unknown and/or under investigation relationship between the progress of deterioration and inspection method for the three major kinds of deterioration, i.e. salt damage, fatigue cracks on floor slab and alkali-silica reaction (ASR) [3). As an example, the relationship between the progress of ASR deterioration and inspection method is shown in Table-3. The durability of the structure could be properly evaluated by selecting NDT methods appropriate to the progress of deterioration.

Deterioration of concrete materials is mostly affected by external factors (such as chloride ions) and then internally it leads to the deterioration of such a member as concrete cover to reinforcement, resulting in the damage of external appearance. Due to expansion of corrosion products (micro-scale), cracks in concrete (meso-scale) take place during the incubation and progressive periods. Then, visible cracks (macro-scale) are nucleated with the acceleration period. Nowadays, it is known that NDT methods are not effective to detect micro-level deterioration at the site, but are capable of detecting meso- and macro-level deterioration.

It is desirable to collect time-series data by combining two or more inspection methods based the relationship between the progress of deterioration and the level of available information to select appropriate NDT methods to the target phase and the degree of deterioration.

3. Field survey in infra-dock

3.1 Scenarios and procedure of field survey

The committee has investigated scenarios for the infra-dock, taking into account environmental conditions and the level of maintenance of each structure to be maintained. In order to make the maintenance effective with limited budgets and human resources, a good scenario needs to be prepared for each individual structure instead of inspecting and examining all structures in a uniform manner.

The committee has surveyed diverse issues to maintain infrastructures and aimed to provide engineers with reference materials, in which actual maintenance works could be performed individually. In addition, the cases that are not assumed in the scenario or has never been foreseen might occur during the long service period of an infrastructure. Consequently, examples of advanced maintenance by engineers and surveys for supporting technical judgment are also included. The committee also includes the state-of-the-art technologies for evaluating the soundness of a structure and estimating the causes of deterioration along with continuous monitoring of a structure.

In order to effectively use the inspection results at an infra-dock, the aim of each inspection needs to be clarified. Engineers, who are involved in maintenance of a concrete structure, need to acquire the following knowledge about the target structure among others.

(i) Any problem in the in-service structure at the moment
(ii) Any problem in the in-service structure in the future
(iii) Possible solution(s) if there exist any problems
(iv) Effectiveness of the measure if any countermeasure has been implemented

To acquire knowledge about these issues, it is necessary to evaluate the current conditions of the concrete structure and also the deterioration state of the components. Then, scenarios need to be prepared for such severe deterioration as structural failure and impeding damage of the structures in service. The progress of deterioration should be realized following the prepared scenarios. The usefulness for preparing a scenario would be upgraded by clarifying which inspection to be performed at the infra-dock, providing what knowledge to be demanded by engineers and by sharing the information among parties concerned.

3.2 Importance of preparing a scenario

Preparation of a "correct scenario", i.e. understanding or estimating the mechanisms of deterioration and/or performance decrement of the target structure, is particularly important in acquiring the knowledge on "(ii) Any problem in the in-service structure in the future" and "(iii) Possible solution(s) if there exist any problems" among the others mentioned in the previous section. The following steps are considered:

(1) Preparing a scenario of problems,

(2) Applying the scenario to solve problems, and

(3) Estimating future conditions

Investigation for estimating the causes of deterioration is one of means to solve problems. Detection of first signs of deterioration is often dependent on the ability of engineers, in such cases as visual inspection, detecting abnormal sound, detecting abnormal vibration, and having a feeling of "something wrong" about the structure. For maintenance of a concrete structure, noticing such an abnormality is crucial. Cases in which abnormal data are obtained during monitoring are possible to increase in the future, but the analogue senses of engineers would play the major roles, requiring engineers to have high skills. After detection of first signs, machine-based inspection should also be performed when necessary to correctly estimate the causes. General inspection items for such machine-based inspection are difficult to be dictated, because each structure should be examined for items that are appropriate to estimate its actual condition. Estimating a scenario (such as corrosion of steel by salt damage and resultant performance decrement of the structure) for solving the current problem helps extracting general inspection items up to a certain degree (such as measuring the amount of chloride ions to estimate the progress of salt damage in this example).

Means of solving future problems include deterioration prediction and monitoring of various kinds of damages. Deterioration prediction includes not only quantitative prediction but also prediction based on the abilities of engineers.

Scenarios for the problems in a concrete structure that lead to failure of the structure and difficulty of continuing service or maintenance, including broken members and accessories, can be classified, as follows:

(i) Scenario similar to the assumed scenario at the time of construction

(ii) Scenario known today but was not known at the time of construction

(iii) Scenario that was not assumed

(iv) Others

(i) The scenario corresponds to such cases as that the possibility of salt damage was assumed and the damage has progressed as predicted. In the committee report, maintenance activities in a concrete platform for underwater oil field development are exemplified, including monitoring for salt damage.

(ii) The scenario corresponds to, as an example, alkali-silica reaction in structures that were built before 1975. Alkali-silica reaction was difficult to predict at the time but are fully predictable with current technologies. Therefore, a concrete structure should be well maintained by considering deterioration progress along with this scenario.

(iii) The scenario includes actual cases in which kieselguhr was added to concrete to save cement. They were found in concrete structures that were built in early Showa era (1926 to 1989) and deteriorations of concrete due to thaumasite were reported. Thus, deterioration via un-assumed scenario sometimes occurs in a structure, and detection of signs by engineers is important.

(iv) The scenario includes the cases that cannot be clearly classified into (i) to (iii). For example, salt damage by use of sea sand that have been insufficiently desalinated and corrosion of steel and exfoliation of concrete due to insufficient concrete cover depth fall in the category of both (i) and (ii). Deterioration of concrete and steel corrosion by water, alkali-silica reaction in a new structure, and delayed ettringite formation (DEF) can be either (ii) or (iii) depending on the situation.

Those that belong to (i) are easily set up as scenarios. However, countermeasures are possible to delay for scenarios for which prediction technologies have not been fully developed. It is noted that un-assumed scenarios ((iii)) may occur, revealing that the correct scenario is not the one to apply deterioration mechanisms in the past, but the other for engineers to think.

3.3 Procedure of field survey

There are various ways of proceeding inspection of an actual structure, which can be considered as a scenario at the infra-dock, but the inspection is generally performed by conducting daily and periodical procedure at the beginning, followed by primary examination, which is executed when an abnormal event is detected or at a certain time intervals, and secondary and tertiary examinations for evaluating the degree of deterioration and damage. These are conducted for identifying the cause, predicting the future and investigating countermeasures. There are also inspections and examinations executed by an accidental factor, after an accident and during a disaster. Examining method differs depending on the phase of the examination. Daily inspection and primary examination mainly involve visual inspection and simple measurement for supplementing the visual inspection. Secondary and tertiary examinations are for estimating the cause and quantifying damage. At an early stage, NDT and partially-destructive methods are applied, but there are cases in which core sampling and/or chipping are required to secure examination accuracy depending on method of analysis or evaluation used.

The area of inspection and number of samples undergo changes during the process. In visual inspection, not only the face side part but an area as large as possible is inspected. The area to be inspected is reduced in the primary examination and is further limited to suspicious points in the secondary and tertiary examination. The number of samples is limited to the least necessary number, and is added only when it is inevitable. The method, range and quantity of examination change depending on the level of inspection. In other words, examinations to be performed at the infra-dock could be of various levels and be executed by different executors.

In the case of an apartment building, the primary examination may be performed by a building engineer who is not necessary to be an expert of concrete engineering. Particularly a building requires inspection on such various elements, as the concrete skeleton, finishing materials, and equipment, and is thus frequently inspected not by an expert of concrete engineering but by an architect. At the stage of secondary and tertiary examinations, the structure is often examined by an expert, such as a professional inspector and diagnostician and an expert from a major construction company. When the cause is unique or when an advanced countermeasure is required, investigation is sometimes performed by an expert who has advanced knowledge and experiences.

3.4 A simple case of infra-dock

Road maintenance by residents in Nagasaki Prefecture is known as activities by *Michimori*[4]. While Nagasaki Prefecture promotes tourism and has a number of tourist resources, such as vista points and churches, it consists of peninsulas and isolated islands. Thus, oversea bridges connect the islands, harbors and other infrastructures, which are aging. To solve the issue, Nagasaki University and the prefectural government of Nagasaki have jointly started an education program for cultivating engineers to maintain infrastructures, which is funded by the Strategic Program for the Promotion of Science and Technology. The education program is shown in Fig.-4.

A “Michimori portal” system has also been implemented in which a local resident could report any abnormality of a nearby infrastructure to the road administrator via smart phone or PC, contributing to formation of safe and secured society in the prefecture. The activities are implemented originally in Nagasaki Prefecture to address the lack of human resources in maintaining the infrastructures and are highly pioneering in Japan.

The Center for Sustainable Infrastructures of Nagasaki University has established an abnormality information system for graduates of Michimori course, which can inform the abnormality upon finding a problem or deformations in road structure to the center via facsimile or e-mail. Upon receiving the information, the center transmits it to the administrator. Right after repair is completed, the administrator informs of the completion to the center, and transfers the issue to the first communicator. Such a feed-back system is epoch-making from the viewpoint of local residents participating in public services of maintaining infrastructures.

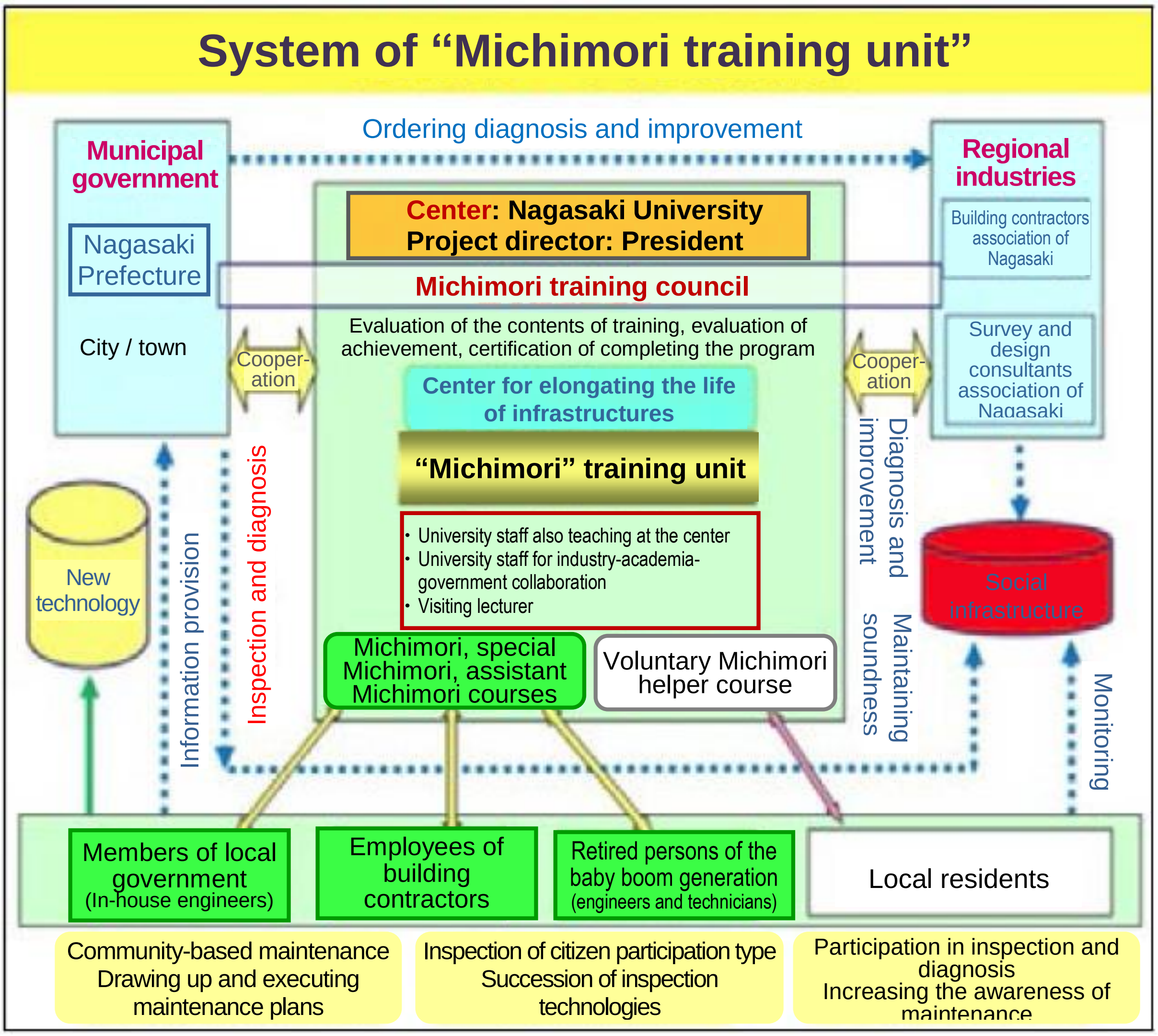


Fig.-4 System of Michimori training program

3.5 Scenarios at infra-docks

In order to make scenarios at the infra-dock, the committee has analyzed and organized the cases from the viewpoints of "detection by an engineer", "survey and analysis", and "monitoring".

In the case of buildings, they are inspected mostly before a large-scale repair project. This is because it is necessary to understand the conditions of deterioration and acquire basic data for the repair project. Precise investigation by experts becomes necessary when causes of damage such as cracks are to be identified.

Examples of inspection items in a building are shown in Table-4 for the first time (about 10 years after completion) and the second and later times (20 years or more after completion) inspections.

By referring to the information surveyed, the committee has examined scenarios at infra-dock for several cases and investigated a list of such constituents as inspection system, methods and time (we call a "menu") for each scenario as summarized in the committee report.

Table-4 Examples of inspection items of a building

Inspection item	Time of inspection	
	First (about 10 years after completion)	Second and later (20 years or more after completion)
Document survey, questionnaire survey	●	●
Visual inspection (including hammering)	●	● (Use of scaffold)
Adhesion	●: Paint (○:Tile)	●
Concrete compressive strength	–	○
Depth of concrete carbonation	○ (●:Cover concrete)	●
Corrosion of steel	–	○

●: To be performed always or in most cases
○: To be performed depending on necessity (on state of deterioration and/or damage)

Issues to be included in a menu:

・Assuming a building (apartment building) and civil engineering structure (oversea bridge, etc.) based on the standard specifications)

・Cases of scenarios

(i) Relatively slow progress of deterioration (deterioration factors such as carbonation and drying-shrinkage cracking)

(ii) Being in an environment prone to deterioration (for example, harbor structure exposed to salt)

(iii) Maintenance of a structure with already apparent deterioration (cracks caused by corrosion of steel, etc.)

The committee also has investigated timings of inspection, inspection contents and scope

Table-5 Example of menu at infra-dock of a building

Kind of field inspection	(i) Visual inspection mainly	(ii) Physical inspection included
Contents	One-day course	Two-days course
Example of inspection items	1) Document survey, hearing survey 2) Visual inspection and hammering 3) Data organization and report preparation	1) Document survey, hearing survey 2) Visual inspection and hammering 3) Concrete compressive strength (9 lines) 4) Depth of concrete carbonation (9 lines + 3 points) 5) Salt content in concrete (3 specimens) 6) Corrosion of steel (3 points) 7) Data organization and report preparation
Approximate cost	■ 300 thousand yen	■ About 1.4 million yen

for each timing, responses upon finding deformations, responses upon encountering an unassumed event, long-term inspection plan for future, and costs. The menu shown in Table-5 was proposed by the FS committee as a reference.

4. Construction of the infra-dock system and development of certified doctors

4.1 Overview of the infra-dock system proposed

The infra-dock proposed is a system to inspect, diagnose and evaluate a concrete structure upon receiving an order by the manager of the structure. As shown in Fig.-5, the organization consists of regional branches, which are to perform the actual inspection works and located in each region, and Social Infrastructure Maintenance Control Center, which coordinates the branches. Regional branches would introduce advanced technologies and treatment technologies to promote computer-based daily inspection and organize evaluation meetings by inspectors or doctors. The doctors certified might be teaching staff of regional universities and technical high schools, staff of municipal government, engineers of building contractors and staff of the branches to prepare a soundness certificate of the inspected structure.

There have been a number of organizations like aforementioned "*Michimori* (literally 'road guard')" and "*Hashimori* (literally 'bridge guard')" formed in all parts of Japan by reflecting the sense of crisis about infrastructures in municipal governments in recent years. By organizing these and other small local groups as non-profit organizations, it is probable to achieve "gaining understanding and cooperation with the people".

4.2 Problems to be solved by infrastructure dry-dock

An existing background to deal with aging social infrastructures is insufficient engineers and decreasing investments although the maintenance costs are increasing. Thus, the results

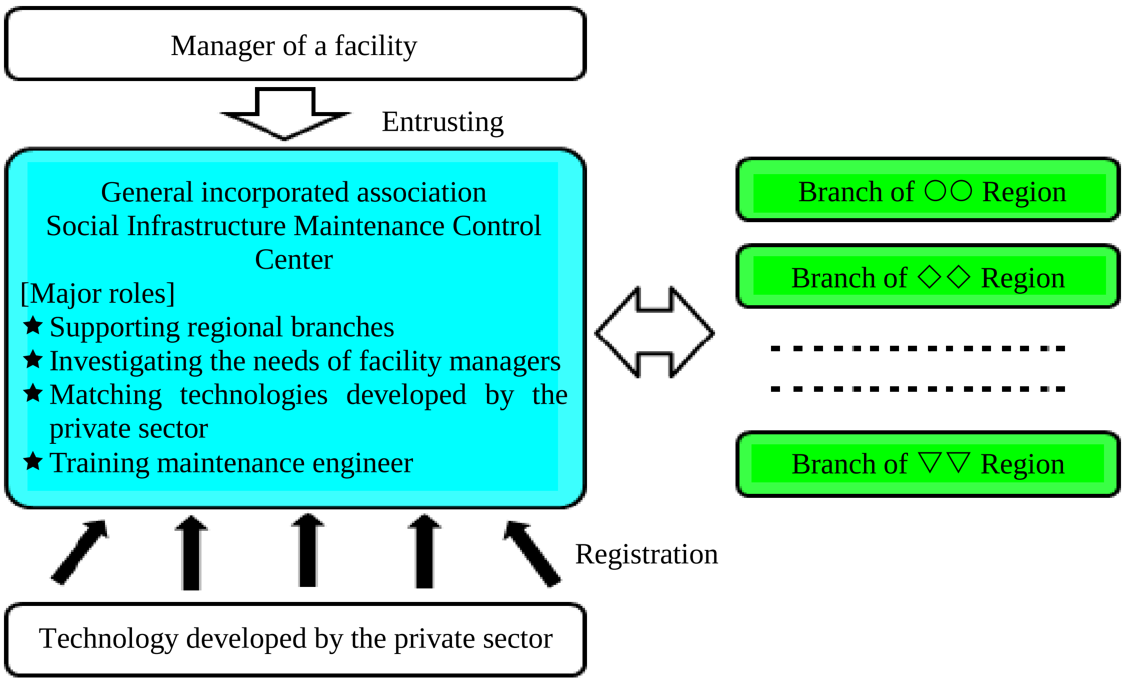


Fig.-5 Organization of infra-dock (a plan)

of a survey on people's attitude about the fact that a large sum of tax is expected for maintaining infrastructures are discussed.

Fig.-6 shows the recognition of the people about aging of infrastructures. As shown in the figure, about 70% of the respondents are not fully aware of it in January 2012. After the ceiling collapse of Sasago Tunnel on December 2, 2012, people's interest in aging on infrastructure increases, but more than a half of the people are not aware of the problem in February 2014 yet.

Up to present, many infrastructures have been constructed in Japan and enriched the life of people. However, many of them are aging and will soon require renovation. Did you know that infrastructures are facing the problem of aging? (Select one)

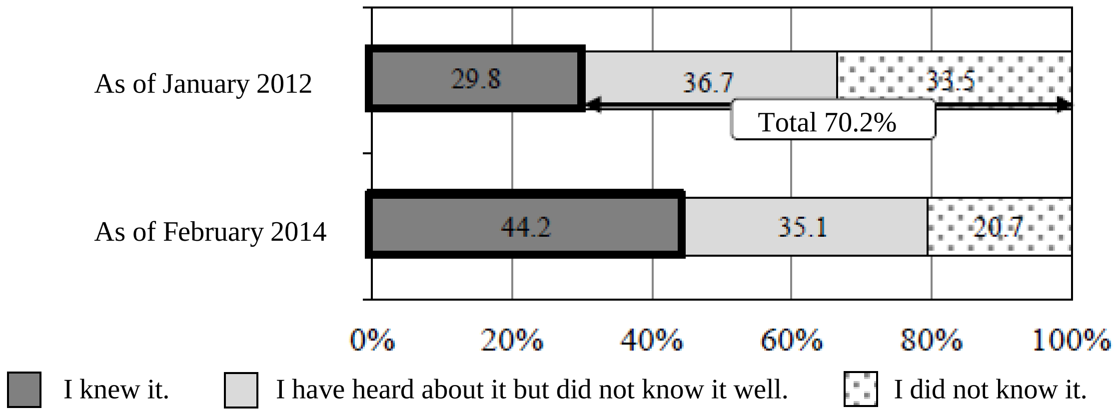


Fig.-6 Recognition of the aging problem of infrastructures [5)]

On the other hand, Fig.-7 shows the concern of people on the future of aging infrastructures. The percentage of people who worries about the future of infrastructures also increase to more than 70% after the ceiling collapse of Sasago Tunnel.

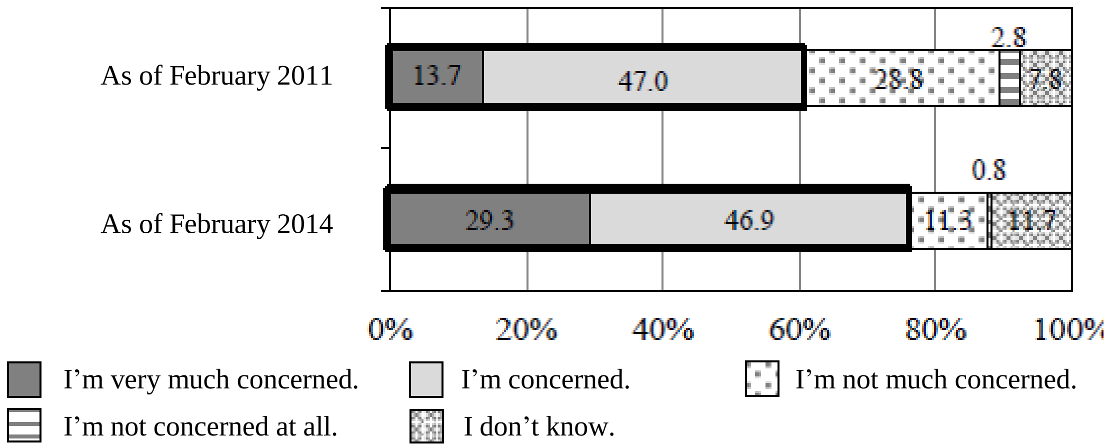


Fig.-7 Concern about the future of social infrastructures [5)]

Actually, there was an accident before the ceiling collapse of Sasago Tunnel that aroused people's awareness on the importance of concrete structure maintenance. It was the exfoliation accident of lining concrete in Fukuoka Tunnel on Sanyo Shinkansen line in 1999. West Japan Railway Company attributed "insufficiency of experts on maintenance of concrete" as a cause.

Therefore, for the purpose of improving the quality of materials and methods for repairing concrete, a system of concrete repair works execution management engineers was started, who have a certain level of knowledge at construction sites. So far, about 1,000 qualified engineers[6)] have been enrolled. As these accidents suggest, human resource development is indispensable for constructing the infra-dock system.

4.3 Issues of the authorized concrete diagnosis and maintenance engineer system

Japan Concrete Institute started the qualification system of Authorized Concrete Diagnosis and Maintenance Engineer in 2001, and there existed no such a system in 1999 when the accident of Fukuoka Tunnel occurred. Until April 1, 2014, 10,500 authorized concrete diagnosis and maintenance engineers have been appointed. Even if there had been authorized concrete diagnosis and maintenance engineers at the time of Fukuoka Tunnel accident, West Japan Railway Company was likely to have started the system of certified engineers for concrete repair works and execution management. Here a problem underlies on the authorized concrete diagnosis and maintenance engineer system.

Authorized concrete diagnosis and maintenance engineers are very likely to possess the expertise knowledge on maintenance of concrete required to a concrete repair works and execution management. However, the required performance to a concrete structure varies depending on the kind of structures, in-service states, ambient conditions, and so forth. A manager of a facility is desirably to be an engineer who has worked on similar structures or has experienced a large number of structures. It may also be difficult to find an authorized concrete diagnosis and maintenance engineer without knowing who to contact. Thus, the system should take into account the following two issues.

[Issue-1]

It is necessary to prepare a systematic and practical program to acquire qualifications required to facility manager, which are predicted to be updated further, based on his or her skills of concrete diagnosis.

[Issue-2]

Since the Social Infrastructure Maintenance Control Center and its regional branches offer the infra-dock, an organization for supporting authorized concrete diagnosis and maintenance engineers is to be needed. This role is expected to be played by the Japan Society of Concrete Diagnosis and Maintenance Engineers. A key to achieve this goal is development of human resources who have superior executive and management abilities.

So far, there exists the automobile inspection system, which could be informative for creating the system of infra-dock on track. In Japan, automobiles are required to receive inspection by a qualified mechanic once every two or three years otherwise the vehicle is not allowed to run on a public road. Car owners may feel troublesome, but the system is in partial charge of ensuring safe and secured driving and has taken a part in propelling the formation of the market. Like the automobile inspection system, infra-dock would provide safety and security to social infrastructures and buildin and is desirably to be systemized like the automobile inspection system.

There are building constructors, manufacturers of concrete products and other companies of the construction industry in all parts of Japan. The infra-dock aims at revitalizing local economy via the construction industry. It is hopeful to initiate the system of infras-dock on a trial basis in pioneering areas where *Hashimori* and/or *Michimori* are acting. The areas are then to be improved into an ideal model area by providing supports from the national and local governments.

5. Concluding remarks

The technical committee on the establishment of the infra-dock was first established in 2012 as the feasibility (FS) committee, and became a regular committee in 2013. Thus, the committee has acted over a total period of three years. In March 12, 2013, a JCI forum entitled “Prospect for infra-dock system” was held at the Tokyo Office of Kyoto University as a summary of the FS committee, where future activities were discussed in panel discussion.

During the period, several international activities were conducted, in collaboration with Prof. C. Grosse (Technische Univesitat Munchen) and Prof. M. C. Forde (The University of Edinburg), who are overseas corporate members. The 6th Kumamoto International Workshop on Acoustic Emission Fracture and NDE in Concrete - KIFA-6 was held in September 2013 in Kumamoto. In July 2014, the chair, M. Ohtsu, gave a keynote lecture entitled “Toward Establishment of Infra-Dock for Concrete Structure” at Structural Fault & Repair 2014, London, organized by Prof. M. C. Forde. Moreover, the chair was invited to deliver a plenary lecture entitled “Basics and Applications of NDE based on Elastodynamics toward Infra-Dock for Concrete Structures” at the 6th International Conference on Emerging Technology in Nondestructive Testing (ETNDT6), held at Vrije Universiteit Brussel (Belgium) in May 2015.

In conclusion, the committee has actively published the results in and outside Japan. The final meeting was held at Morito Memorial Hall of Tokyo University of Science on July 30 (Thursday) jointly with the “Symposium on Innovative Inspection Technology for Concrete Structures” organized by JCI.

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