# Report of SIP Infrastructure Regional Implementation Support Teams: Promoting Innovation in Regional Infrastructure Maintenance

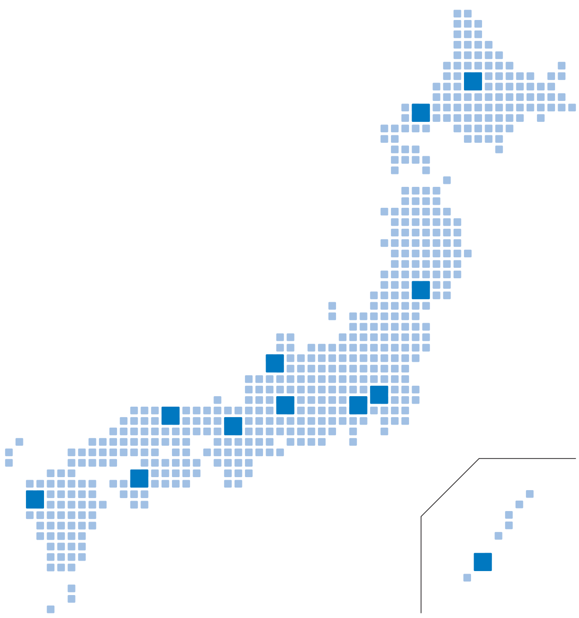
**Compiled by:**

**SIP Infrastructure Regional Implementation Support Teams**

**Cross-ministerial Strategic Innovation Promotion Program (SIP)**
**- Infrastructure Maintenance, Renovation and Management -**

**Issued by:**

**Subcommittee on Promoting Regional Implementation of New Technologies**
**SIP Infrastructure Program Coordination Committee**
**Organization for Promotion of Civil Engineering Technology, JSCE**



SIP

# Report of SIP Infrastructure Regional Implementation Support Teams:

## Promoting Innovation in Regional Infrastructure Maintenance

# Foreword

**Yozo FUJINO**

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SIP Infrastructure Program Director (PD)

The Strategic Innovation Promotion Program (SIP), led by the Council for Science, Technology and Innovation (CSTI) of the Cabinet Office, was begun in FY 2014 as a five-year plan to address ten challenges. Infrastructure maintenance, renovation and management technology (referred to below as the SIP Infrastructure Program) was selected as one of these areas, and I have served as its program director (PD) from the start. I am very happy to be able to issue this report on the activities of the regional implementation support teams, which began in FY 2016, the third year of the SIP Infrastructure Program. I would like to express my sincere gratitude to everyone who has participated in the activities of the regional implementation support teams, including the persons who have written papers for this report. To Dr. Keitetsu ROKUGO, who has worked very hard on its compilation, I would like to extend special thanks.

A portion of the SIP Infrastructure Program was directly administered by the Ministry of Land, Infrastructure, Transport and Tourism, but for the majority of the program, R&D topics were submitted in response to a public invitation and selected after reviewing presentations. The program was launched with a total of 60 topics. Compared to other areas of SIP, this is a very large number, involving a wide range of fields, and with participation from many small businesses and universities located outside the Tokyo metropolitan area. Well over 1,000 researchers and engineers were involved, and nearly half of them came from fields other than civil engineering, making interdisciplinary collaboration possible. I believe that this was the first infrastructure-related project to be performed on such a large scale with participants from such a wide variety of fields.

I am writing this foreword exactly four years after the kickoff conference, which was held in December 2014 at the University of Tokyo, in Takeda Hall. At that time, I called on all of the participants to develop the kinds of technologies and systems that they would want to use, combining different fields from the basics through to implementation in an interdisciplinary approach, with the goal of achieving innovation. I still feel the same way today, and I have continued to repeat this appeal.

Soon after the launch, along with the members of the program promotion council, I began engaging in efforts to ensure results such as providing advice on individual topics and locating partners to fill any gaps. Each of the R&D teams has worked with dedication to achieve valuable results. The efforts devoted to this project have gradually grown into the form of useful technologies that that people will truly want to use.

The governing board of SIP, an organization under the Council for Science, Technology and Innovation (CSTI) ), is composed of experts and CSTI legislators. This governing board (two meetings per year) has the important role of providing oversight of SIP, including rigorous evaluation of all topics under SIP and determination of the annual budget. Ever since its first meeting, the governing board has always demanded input on steps toward implementation and prospects of implementation, in addition to the results of R&D.

To be honest, my attitude toward implementation was initially somewhat lax. I felt that these technologies could be put to some use by the network of the Ministry of Land, Infrastructure, Transport and Tourism, as well as by highway corporations, which have solid groups of engineers.

However, approximately 70% of road infrastructure is managed by local governments, which have institutionalized the use of close-up visual inspection in bridge and tunnel inspections, and I learned about a variety of pressing needs that they are facing. The conservation of local infrastructure is of great importance in the sustainability of local communities, and this is an extremely significant issue that will help to determine the future of Japan. Sub-Program Director Toshihiro WAKAHARA, along with Dr. Yusaku OKADA, whom I invited to serve as sub-PD starting in the second year, proposed the concept of regional implementation support teams as organizations that would be necessary to enable the SIP Infrastructure Program to help ensure the soundness of infrastructure managed by local governments, thereby contributing to regional revitalization.

The actual users of technologies and systems developed under the SIP Infrastructure Program may include private consultants and construction companies, but the work is generally contracted from government offices as the facility administrators, so it is essential to obtain the understanding of administrators. However, it is a reality that communication between government and the private sector tends to be difficult in a context of contractual relationships. We anticipated that universities and public research institutions could play an important role in the regional deployment of technologies developed under the SIP Infrastructure Program, because of their ability to act as intermediaries to connect the public and private sectors.

Regional implementation team applications were solicited in FY 2016, and nine regional implementation support teams were adopted, ranging from Hokkaido in the north to Okinawa in the south, as well as one regional implementation strategy team. I am glad that these teams included not only national universities, but also private universities. With the addition of teams at the University of Tokyo and Kanazawa University, which were already playing a role in regional representation, there are 12 regional implementation support teams, forming a system that covers all of Japan. The teams of Gifu University and Nagasaki University, which have been involved in regional infrastructure maintenance for many years, were asked to play the role of compiling the overall report. Some teams had no previous experience in such involvement and needed guidance, including Ehime University and Tottori University, and this guiding role was played by Keitetsu ROKUGO (Gifu University) as representative and Hiroshi MATSUDA (Nagasaki University) as deputy representative of the regional implementation collaboration council of the SIP Infrastructure Program. The newly minted teams made rapid progress while learning from and exchanging information with the more experienced teams.

A large number of events of various kinds have been held regionally, starting with seminars to introduce the SIP Infrastructure Program itself, and including regional lectures and demonstrations to let people know about the developed technologies, including drones to support bridge inspection, and actual applications of the developed technologies in the field. I am glad that it was possible to involve local consultants and construction companies, in addition to prefectural and municipal governments, in holding these events. Many persons from fields other than civil engineering have performed R&D under the SIP Infrastructure Program. We have received many comments from these persons to the effect that they were able to learn a great deal by hearing from regional implementation support teams about demonstration sites, trying out their own technologies, and listening to a variety of opinions from people who are involved in actual maintenance operations.

I was born and raised in Tokyo, and I was constantly surprised and impressed by the activities of the regional implementation support teams. I got the sense that significant developments have begun in other parts of the country, which previously found it difficult to make their voices heard by the Cabinet Office in far-off Kasumigaseki, Tokyo. It seems to me that regional universities have gained a higher profile through these kinds of activities.

This report covers various aspects of the activities of regional implementation support teams, and I anticipate that it will provide a useful reference in future activities for regional revitalization. It is my hope that this report will be utilized in a variety of situations.

FY 2018 has been a year of numerous occurrences of damage in rural regions due to torrential rains, earthquakes, and the like. The question of how to improve regional resilience is an important challenge for Japan today. I believe that the approach of regional implementation support teams developed in the SIP Infrastructure Program is also effective with respect to resilience. I anticipate new developments in this regard as well.

Last, I would like to conclude this foreword by expressing my sincere appreciation to all those who have worked with dedication to guide and support the activities of the regional implementation support teams in various respects, including the project promotion council members, JST fellows, and those at related organizations under the Cabinet Office, JST, and NEDO.

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# How to find reports containing the information you need

When you or a family member are troubled by illness or pain, you'll look for a way to treat it. For example, if you get a headache, you might go to the drugstore for a bottle of medicine. But how can you choose from among all the different headache medicines on the shelf? It would be very helpful to have some kind of recommendation by pharmacists based on case studies of patients where a medicine was effective, user reviews about effectiveness, or survey results on medicines administered to many people.

| Category | Information needed (topic) | No. | Main key words in title of report | Application cases | Comments and reviews | Surveys |
|---|---|---|---|---|---|---|
| Introducing technologies | Future outlook on regional infrastructure maintenance | A-1 | Infrastructure maintenance, future outlook, innovation | | | |
| | | A-2 | Infrastructure maintenance, future outlook, regional implementation | | | |
| | Ways to introduce new technologies in a region | A-3 | Infrastructure maintenance, open innovation | | | |
| | | A-4 | New technology applications, obstacles, countermeasures | | | ○ |
| | | A-5 | New technology applications, municipalities, installation method | ○ | | |
| | | A-6 | Seeds and needs, business development, management | | | |
| | | A-7 | Seeds and needs, management of technical development, issues and recommendations | | | |
| | | A-8 | SIP, general public, awareness, questionnaire surveys | | | ○ |
| | | A-9 | Social science, institutional policy theory, policies to promote diffusion of technologies | | | |
| Technologies | New technologies of SIP | B-1 | SIP development technologies, introduction decision, implementation status | | | ○ |
| | | B-2 | SIP development technologies, guidelines for periodic inspection of bridges, damage types | ○ | | |
| | | B-3 | New technology applications, technical lecture participants, countermeasures, obstacles | | | ○ |
| | Cases of bridge inspection | B-4 | Close-up visual inspection, hammering test, flying robots | ○ | ○ | |
| | | B-5 | Application of new technology to actual bridge, RCT-girder bridge, bending test of cut girders | ○ | | |
| | Cases of corrosion measurement | B-6 | High-sensitivity magnetic non-destructive inspection, light pole bases, damage detection | ○ | | |
| | | B-7 | Underwater structures, damage, surveys, countermeasures | ○ | | |
| | Cases of slope monitoring | B-8 | Wireless sensor networks, slope monitoring, collaborative experiment | ○ | | |
| | Cases of road surface inspection | B-9 | Mobile profilometer, road surface inspection, regional implementation | ○ | ○ | |
| | Cases of embankment inspection | B-10 | River embankments, monitoring technologies, regional implementation | ○ | | |

In this document, administrators who maintain infrastructure are analogous to people shopping for medicine. We have prepared the table below to help administrators discover where to find the kinds of information they need. In addition, we have added circles to identify those reports which also include case studies of maintenance using new SIP technologies, comments on new technologies or reviews after using new technologies, or survey results on new technologies.

| **Category** | Information needed (topic) | No. | Main key words in title of report | Application cases | Comments and reviews | Surveys |
|---|---|---|---|---|---|---|
| **Regions** | Needs related to maintenance | C-1 | Road bridges, maintenance, municipalities, needs | ○ | | |
| | | C-2 | Regions, technical needs, engineers, approaches | ○ | | |
| | Database utilization | C-3 | Collaboration among industry, government, and academia, bridge maintenance, integrated database systems | | ○ | |
| | Reasonable systems | C-4 | Municipalities, infrastructure, regional characteristics, constructing asset management systems | ○ | | |
| | | C-5 | Local community, water infrastructure, maintenance, municipalities, role allocation | ○ | | |
| | Cases of advanced bridge maintenance (robotic technologies including drones) | C-6 | Robotic technologies, bridges, periodic inspection, advancement | ○ | ○ | |
| | | C-7 | Robotic technologies, steel bridges, periodic inspection, approaches | ○ | | |
| | | C-8 | Robotic technologies, municipalities, infrastructure maintenance | ○ | | |
| | | C-9 | UAV, photographed images, remote island bridges, crack inspection | ○ | | |
| **Deployment** | Cases of broad-area collaboration | D-1 | Infrastructure management platform, construction and deployment | ○ | | |
| | | D-2 | Kyushu Association for Bridge and Structural Engineering (KABSE), collaboration, evaluation of new technologies | ○ | | |
| | | D-3 | Hokuriku, municipality officers, human resource development, technology exhibitions | ○ | | |
| | Cases of maintenance engineer training | D-4 | Implementation of new technologies, Super Michimori concept | ○ | | ○ |
| | | D-5 | Bridge inspection personnel, technical skill development, bridge inspectors | ○ | | |
| | | D-6 | Collaboration among industry, government, and academia, bridge conservation masters, training | ○ | | |
| | | D-7 | Engineers, educational materials, infrastructure museum | ○ | | |
| | Cases of international deployment | D-8 | Maintenance technologies and systems, international deployment, human resource development | | | |
| | | D-9 | JICA, SIP Infrastructure Program, collaboration, international deployment | ○ | | |
| | Afterword | D-10 | Infrastructure maintenance, future, regional implementation | | | |

# Introducing technologies

# Future vision for infrastructure maintenance: Innovation in inspection, monitoring, and diagnostic technologies

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## Categories of inspection, monitoring, and diagnostic technologies

Among the R&D topics of the SIP Infrastructure Program, technologies related to inspection, monitoring, and diagnostics are divided into four categories of technologies that can replace or support close visual inspection by inspection engineers: inspection support tools, screening, permanent monitoring, and detailed inspection technologies. In this paper, we will describe the changes that these technologies can bring to inspection practices and mention current challenges which need to be addressed for the diffusion and widespread adoption of these technologies. It is not possible to present all of the technologies in this journal, but more information is available on the website of the Japan Science and Technology Agency (JST)[1].

## Inspection support tools

Tools that support inspection and diagnosis by engineers are technologies that can easily be brought into the field, are capable of recording inspection data as well as location information, and can function as high-precision sketch machines in the field.

Optical technologies include the latest image processing technologies for high-sensitivity camera images, and technologies using AI for high-precision detection of cracks in concrete surfaces. With technologies that use high-sensitivity magnetic sensors (small, portable superconducting quantum interference devices (SQUIDs) and magneto-resistive elements (MR)) to explore corrosion and cracking in steel, it is possible to inspect not only the top surface of a structure, but also the interior and back surface. This category also includes AI hammers, in which acoustic sensors are added to hammers used in hammering tests, and damage determination based on hammering sounds is supported by deep learning.

## Screening

Bridges, tunnels, and other infrastructure subject to inspection are scattered far apart, and it is extremely challenging for inspection engineers to thoroughly identify every location of damage by close visual inspection. Therefore, it is desirable to have technologies that can reliably discover deterioration and damage at a predetermined level of precision and perform automatic visualization and mapping with location information.

Therefore, technologies are being developed that will use advanced signal processing technologies to detect deterioration and damage while moving at high speed, using the latest sensors (high-sensitivity cameras, lasers, 3-D radar, synthetic-aperture radar, etc.) mounted on dedicated vehicles, aircraft, robots, or satellites. Examples include technology to detect surface properties, cracking, lifting, peeling, etc. in the covering concrete of a tunnel using vehicle mounted sensors (high-sensitivity cameras, radar, and lasers) while traveling through a tunnel at a speed of 60 km/h, technology to identify damage (crumbling and cracking) in the upper parts of reinforced concrete floor slabs of expressways while traveling at a speed of 80 km/h (3-D ground penetrating radar, Fig. 1), technology to measure 3-D data of riverbed topography by airborne laser bathymetry (ALB) and determine scouring of bridge piers with high accuracy, and technology to measure annual changes in the vertical displacement of revetments, dams, river and embankments, bridges, etc. from images distributed by satellite mounted synthetic-aperture radar (SAR).

## Permanent monitoring

In permanent monitoring, large numbers of networked sensors are installed on the relevant kinds of infrastructure, including infrastructure with a high level of importance, large-scale structures (such as long span bridges and long length tunnels), and slopes expected to be at risk in disasters.

## Detailed inspection technologies

When damage has been identified by inspections or screening, detailed data must be obtained in cases where an accurate determination is absolutely necessary because the safety of using a structure has been called into question, or to determine whether large-scale reinforcement and renovation is needed. For purposes such as these, development is underway on technology to visualize breakage of steel wire inside precast concrete bridges with high-precision transmission imaging devices using high-output X-ray sources (Fig. 2), and technology for detailed visualization of moisture, voids, crumbling, and other conditions inside concrete using compact neutron sources. Both of these are being developed for in-situ use in the field and will be mounted on dedicated vehicles.

## Future image of infrastructure maintenance and current issues

Each of the technologies described above will make it possible to perform inspections with a high level of accuracy and efficiency through the use of cutting-edge technologies that did not exist in the past. Inspection support tools will help to improve inspection accuracy and reduce variability among the results of inspections performed by people. Screening may improve the efficiency of inspection work by narrowing the scope for close visual inspection. Permanent monitoring will make it possible to monitor the conditions of structures and provide early damage detection, based on suitable thresholds for sensor data. In addition, detailed inspection carries the potential for identification of deterioration factors and damage in the interior of structures, which has not been easily discoverable in the past.

Inspection information (deterioration and damage) obtained through screening and monitoring with advanced technologies will be mapped onto three-dimensional models of infrastructure with geographical location information, and this will be registered and stored in an infrastructure information database. This data will be used to compare past inspection records with current inspection records in order to determine the progress of deterioration and damage. In addition, damage mapping will be incorporated into structural analysis models by means such as data assimilation, and the performance deterioration curves of structures will be quantified through coordination with detailed remaining lifetime analyses. This will provide the basis for calculating the asset value and life cycle cost of infrastructure, facilitating effective infrastructure asset management.

However, when using advanced technologies to perform inspection, in many cases, some of the data that is gathered may not be necessary under the current inspection procedures and technical standards, etc. Therefore, at the same time that these technologies are being adopted and deployed, it will also be necessary to consider the handling of such data under these procedures and standards.


[Reference]
1) Infrastructure maintenance, renovation and management technologies under the Strategic Innovation Promotion Program (SIP): website of the Japan Science and Technology Agency (JST), URL: http://www.jst.go.jp/sip/k07.html

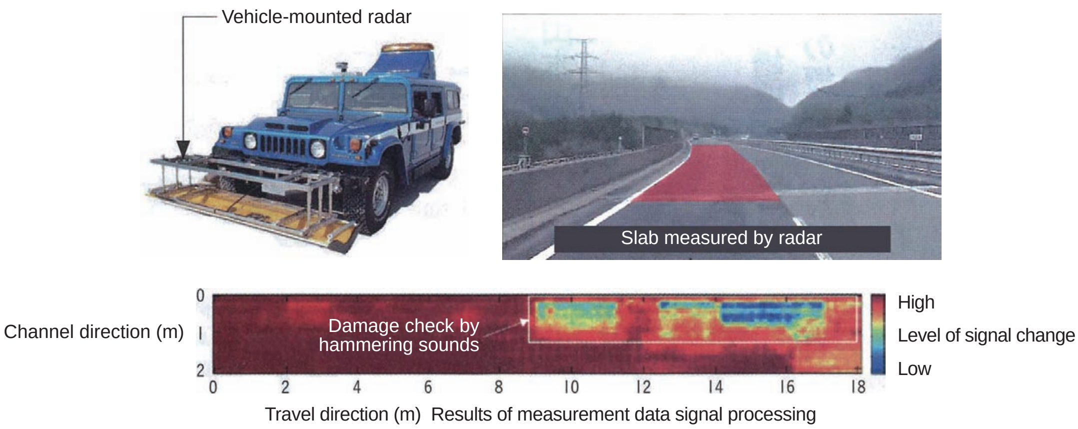
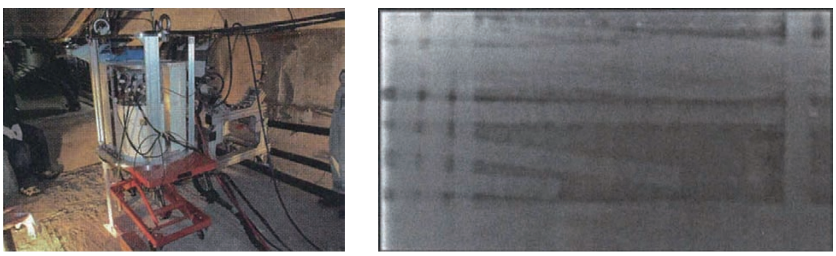




**Fig. 1** Example of screening technology (3-D ground penetrating radar)



Measurement inside a box girder    Visualization of internal steel wire and rebar

**Fig. 2** Example of detailed inspection technology (high output X-ray)

A-2

# How regional implementation activities can shape the future: Outlook on infrastructure maintenance

**Pang-jo CHUN**

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## Visualizing the future based on regional implementation activities

SIP regional implementation teams engage in a variety of activities according to the characteristics and needs of each region. This paper is based on comments obtained from regional implementation teams concerning areas where improvement is needed for more appropriate infrastructure maintenance and opinions on desirable directions for society and infrastructure maintenance.

## Information disclosure and public relations

One major problem at present is that the importance of infrastructure maintenance is not being fully communicated to residents and citizens. In order to provide an understanding of factors including the importance of maintaining an enormous stock, in addition to building infrastructure, and the concept of infrastructure depreciation, it is necessary to disclose information regarding the current condition of infrastructure, the results of future predictions, and costs. For example, it is necessary to share objective, scientific facts with regard to the amount of funding that needs to be budgeted for infrastructure maintenance, and the level of risk.

One means to this end is to prepare something like a health chart detailing the current health status of infrastructure. For example, the infrastructure health reports issued by JSCE are useful, but these deal with infrastructure all over Japan, and it is also necessary to have health charts limited to specific local governments and health charts limited to specific structures. It is also necessary to create the kind of platform and environment that is needed for appropriate sharing of such health charts.

## Links to depopulation and compact cities

Infrastructure maintenance will become more challenging in the future as the population declines in most regions, as shown in Fig. 1. Therefore, unless infrastructure maintenance is considered as part of a changed model, including more compact cities in light of a grand design for municipalities, communities, and settlements, it would be easy to worsen the overall condition even while accomplishing local improvements, or to falsely assume that a benefit for some portion will necessarily lead to an overall benefit, and this could actually result in higher overall administrative costs instead of the intended savings. This can be addressed by means such as active collaboration between the field of urban engineering and the field of building construction.

A declining population also means a smaller number of engineers. It is necessary to develop technologies to make it possible to perform inspection, diagnosis, and repair work with fewer engineers. Similar to the process in the SIP Infrastructure Program, it can be very effective for persons who are in a position to understand the relevant needs, such as a regional implementation team, to propose ideas to developers at companies that could provide potential solutions and take steps to promote improvements.

pursuing a high, uniform level of quality management nationwide, it is necessary to establish frameworks for management quality at a level that is suited to the structure and the region.

## Systems

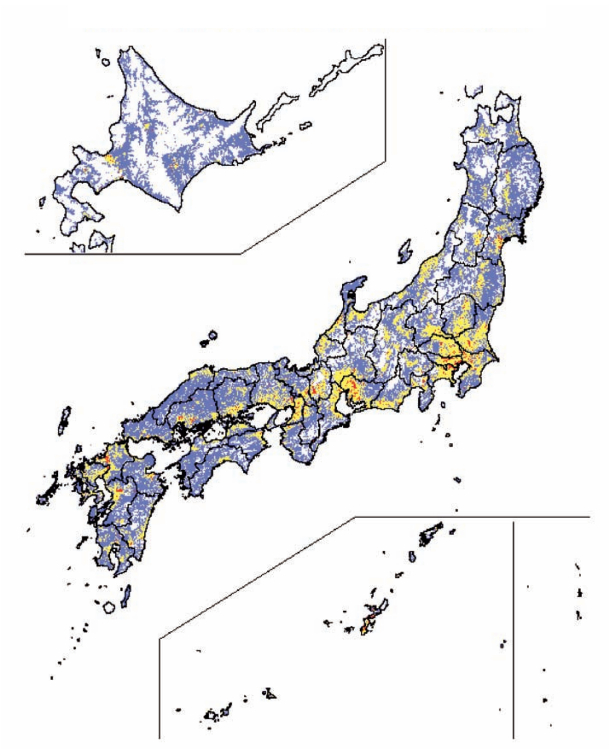
Further consideration is needed with regard to mechanisms such as comprehensive consignment systems for overall maintenance services and introduction of PFI approaches including concessions. For example, if maintenance contracts for several decades at a time are feasible, is preventive maintenance really appropriate? This could provide an opportunity for examining the numbers to seriously consider whether an excess of preventive measures can actually result in higher costs. Consideration should also be given to a directional mechanism for matching between those who benefit from maintenance and those who bear the costs of maintenance. In this way, the importance of infrastructure maintenance will be keenly felt, and real moves will be made on abolishing unnecessary infrastructure, a difficult issue in infrastructure maintenance.

It is also necessary to promote establishment of a national certification system for engineers who can implement appropriate measures with regard to the kinds of damage that truly need to be fixed. At the same time, we should endeavor to foster an environment where this is recognized.

## Raising awareness

Persons involved in infrastructure maintenance need to have a better awareness of crisis management. The attitude of turning a blind eye to potential trouble and doing no more than is required by the rules is widespread among persons involved in infrastructure maintenance. It is necessary to correct this attitude and raise awareness among persons related to infrastructure maintenance so that they will take initiative in their respective positions and take steps to achieve better infrastructure maintenance. Each one should proactively do what he or she is able to do; this may include more thorough description of inspection guidelines like those recommended by the Ministry of Land, Infrastructure, Transport and Tourism, while ensuring accuracy in new endeavors, along with information disclosure; clarification of organizational policies by local governments, use of new technologies by contractors in their contracted services, innovations by technology developers to reduce the burden on ordering parties, advice by university personnel as a basis for decisions, and providing opportunities for introducing new technologies.

The widespread attitude of turning a blind eye to trouble leads to the problem that cases of failure, which are essential to the PDCA cycle, are not recorded and shared due to fear of liability issues. The result is that the same failure is repeated in different places, or over and over at the same place. One means of preventing



Key: Ratio to 2010 population
- Decline of at least 50% (including relocation)
- Decline of less than 50%
- Population increase

**Fig. 1** Population decline from 2010 to 2050 (2010 population = 100%)

## Management frameworks

In infrastructure maintenance, an imbalance is considered to exist in the allocation of engineers and maintenance funds, due to structural problems in management frameworks. For example, national highways, prefectural roads, municipal roads, farm roads, forestry roads, and the like are managed separately, and although this separation is not in itself a bad thing, it does result in inadequacies when the responsible management entity lacks the necessary capabilities and resources. Classification according to the characteristics of a bridge, rather than the management entity, could be used to resolve this situation. For example, it would be necessary to develop management standards and inspection guidelines according to the importance of the route and the class of bridge, such as large-scale bridges, medium bridges, and small bridges.

Especially in rural areas, it will be necessary to develop new, low-tech technologies according to the local situation (inadequate levels of funding, human resources, and technology). (New, high-tech technologies will be used on expressways and national highways.) In the maintenance of small bridges, it is effective to involve local residents in cleaning, simple inspections, and “Michimori” road maintenance programs. It is also important to train and hire in-house engineers who can determine the condition of local infrastructure and devise countermeasures. Instead of this could be for an independent engineer to conduct diagnosis, establishing a qualification system for such engineers as described in the preceding paragraph. It is also urgently necessary to construct a mechanism for data sharing.

The attitude of turning a blind eye prevents the development of an enterprising spirit. It is necessary to build awareness that the region will be improved by having an enterprising spirit through efforts to improve the motivation and awareness of stakeholders. For example, SIP regional implementation teams are engaged in meaningful efforts such as events to introduce, learn about, and demonstrate new technologies. ME training courses at Gifu University, Ehime University, Yamaguchi University, and Niigata University, “Michimori” road maintenance courses at Nagasaki University, and other recurrent education in human resource training endeavors also contribute to raising awareness.

## Desirable directions for society and infrastructure

Different people have different ideals for society and infrastructure, depending on their own perspectives. For example, users of infrastructure value comfort and peace of mind; administrators value a long life span and low maintenance costs; local residents value revitalization of the local economy; and people who work in infrastructure maintenance feel that their job is worthwhile when it improves disaster resilience. People involved in infrastructure maintenance should work to promote these kinds of ideals.

Considering the cultural factors and origins by which communities and villages are established, infrastructure should support these communities and settlements in a role similar to the blood vessels of our bodies, from the standpoint of continuity and reflecting the characteristics of the community. Therefore, it is necessary to break away from conventional ideas, taking steps such as introducing ICT technologies in appropriate forms.

The matters discussed in this article include both bottom-up factors that require a steady approach of gradual improvement, and top-down factors that require innovative change. With the urgency of problems related to aging infrastructure, neither approach is sufficient on its own, and changes will need to come in both directions, bottom-up as well as top-down. It is extremely important to continue the activities of regional implementation teams led by regional universities as an engine to promote this process.

[References]
1) Japan Society of Civil Engineers: 2017 Infrastructure Health Report, http://www.cbr.mlit.go.jp/kawatomizu/kousyukai/pdf/4_sindansyo_kouhyou.pdf, 2017. (Accessed Oct. 14, 2018) (in Japanese)

# Why is open innovation used in infrastructure maintenance?

**Masato ABE**

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Executive Committee, Japanese Congress for Infrastructure Maintenance

## What is open innovation?[1)]

Interest in open innovation is growing in the field of infrastructure maintenance, and with the establishment of platforms such as the Japanese Congress for Infrastructure Maintenance,[2)] there is increasing activity in this area.

In conventional research and development (closed innovation, left side of Fig. 1), the entire process would be handled by the same organization, from planning to implementation and product development. In this process, R&D is initially conducted to seek a wide range of technical seeds, and the assumed needs are gradually narrowed down as implementation is pursued. Capturing technologies and needs and being the first to market them results in exclusive benefits, based on the advantage of being first.

In contrast, in open innovation (right side of Fig. 1), even during the R&D process, the aim is to incorporate newly discovered needs and develop new markets while exchanging technologies and needs beyond the boundaries that separate different organizations and disciplines. Factors contributing to the rise of open innovation include the fact that advances in information technology have made knowledge universally available, making it more difficult to capture a technology; as well as the fact that it is becoming easier to commercialize a business model due to diversification in forms of investment and financing.

## The difficulty of infrastructure maintenance

Infrastructure consists of built-to-order structures that are geographically dispersed and have a wide range of ages, from new to old. Therefore, infrastructure maintenance sites involve a wide range of needs, making it difficult to standardize operations. In addition, the needs and markets are fragmented and subdivided because infrastructure maintenance consists of operations which are individually small in scale, such as inspection, repair, and reinforcement. Because it is not necessarily efficient to conduct individually self-contained R&D for each of these aspects, this continues to be highly labor-intensive. Therefore, there are high expectations with regard to open innovation which would incorporate external technical seeds and needs.

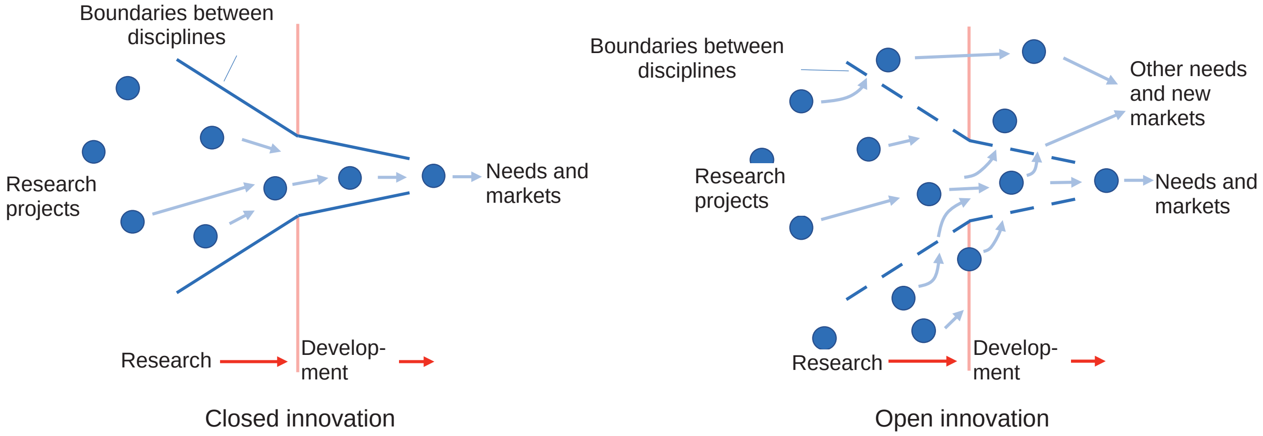


**Fig. 1** From closed innovation (conventional self-contained R&D and implementation) to open innovation

**Table 1** Examples of needs submitted by local governments to the Kinki Forum of the Japanese Congress for Infrastructure Maintenance

| Need | Conditions, situation, etc. |
|---|---|
| Close-up visual inspection and sounding inspection of bridges, or technologies to support movement of inspection staff | □ Depending on conditions under the bridge, it may be difficult to use aerial work platform vehicles, ladders, or scaffolding.<br>□ Some roads cannot be closed to traffic (although brief temporary closures are possible).<br>□ There is not enough space below the bridge to allow close-up visual inspection by inspection staff. |
| Technologies for cleaning under side panels and removal and prevention of standing water | □ Access to narrow spaces behind side panels and ceiling panels, etc. is obstructed by obstacles (such as bird nests, bird droppings, or standing water). |
| Technologies to support measuring the thickness of cavities under road surfaces | □ It is generally possible to confirm the depth, location, and extent of a cavity using probe vehicles, etc., but boring is needed to determine cavity thickness. |
| Technologies to support close-up visual inspection of dedicated sewer line ducts in multipurpose tunnels | □ Workers can only go in and out briefly to place equipment, etc. |
| Technologies to support inspection of underwater portions of submerged river and harbor structures | □ Divers perform this work, but visibility is limited by murkiness and floating objects, and aquatic organisms adhere to structures and must be removed. |

To actually advance open innovation, it is necessary to share technologies and needs to some extent. The needs of administrators are often made public, as shown in Table 1, because infrastructure is public property.

However, simply disclosing the needs is often not enough to obtain a solution, because there is some distance between the “raw” needs as stated and existing seed technologies. In addition, different disciplines and different industries having technologies commonly lack the technical capabilities related to infrastructure that would enable the selection of appropriate fields. Even in the implementation of field tests, consultation and coordination with stakeholders is often inadequate, or there is a lack of expertise concerning outdoor work, etc., and this poses a barrier to entry.

Therefore, for open innovation to work, there has to be some intermediary matching function between needs and seeds. This matching function needs to offer the ability to understand the insights and challenges of both the needs side and the seeds side, gain their trust, and make it possible to create new technologies together. The Japanese Congress for Infrastructure Maintenance and SIP regional implementation teams are important platforms for this kind of matching because of their knowledge and neutral status.

## For sustainable innovation

Although open innovation is an effective approach in infrastructure maintenance, many different entities are involved, and there is a strong tendency to adopt situation-dependent, ad-hoc measures. Therefore, in addition to discussion and coordination regarding technologies, this calls for advanced management and direction, including the development of trust. For example, even among technologies that may superficially appear to be in competition with each other,

**Fig. 2** Similar needs of different local governments: Demonstration of simple inspection scaffolding (left: Kinki Forum, right: Ehime University)

there may be mutual advantages in the sharing of basic technologies, data, and so on, so it is effective to develop rules and frameworks for collaboration, based on an awareness of the areas of competition as well as the areas of collaboration. Japanese organizations have typically tended to be highly self-contained, making it difficult for this sort of capability to develop spontaneously. Therefore, the universities involved with SIP regional implementation teams can play an important role by training human resources such as innovation architects, in addition to their ongoing regional engagement.

Fig. 2 shows the demonstration of a simple inspection scaffolding that makes it possible to efficiently inspect small to medium bridges while minimizing road closure. This illustrates the fact that different regions often share the same needs. Collaboration based on needs shared by different regions is also an effective means of market development.

For the advancement of sustainable innovation, it will be necessary to go beyond merely offering support and establish functions that will actually promote the development of new businesses in the area of infrastructure maintenance, such as evaluating business feasibility when funding is provided, or establishing functions for hands-on investment funds. In addition, it is hoped that technologies originating in the area of infrastructure maintenance will also be used to meet needs in other fields by means of open innovation, resulting in new market development.

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A-4

# Obstacles and measures when adopting new technologies for maintenance of infrastructure: Based on a hearing survey


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## Surveys on obstacles and measures when adopting new technologies

The Gifu University SIP implementation team conducted questionnaire and hearing surveys of the following engineers in order to clarify what are the obstacles to the application of new technologies to infrastructure managed by local governments and what measures are effective in overcoming such obstacles[1]:

- Ordering parties: 16 civil engineers of local governments on the ordering side,
- Developers: 8 engineers developing new technologies in the maintenance field,
- Contractors: 7 civil engineers of construction companies and construction consulting companies on the contractor side.

## Results of the questionnaire survey

The questionnaire consists of description-type questions No. 1, 2 and 6 and selection-type questions No. 3-5 as shown in Table 1. In the selection-type questions, options were prepared beforehand, and the respondents made a plurality of selections and the most fitting one. This questionnaire on the application of new technologies covers not only maintenance but also all processes including survey, design, construction, and maintenance of civil engineering projects. “Conventional technologies” are defined as those described in the current technical standards and manuals in addition to data for the cost calculation. Technologies other than these are defined as “new technologies”.

### (1) Obstacles

Figure 1 shows the results of question No. 3 regarding the obstacles to the promotion of new technologies for each position. The numbers in those graphs represent the number of respondents. “Fairness is not guaranteed” and “Burden over the explanation for account audit” were the main obstacles for the engineers from the ordering parties. The obstacles for the engineers from the developers and contractors were “Insufficient ascertainment of needs” and “Performance and precision are not assured,” respectively. About 40% of the engineers from the developers and contractors chose “Standards or manuals are not satisfied”, but only 20% of the engineers from the ordering parties made that choice. Therefore, we can say that the new technologies that do not satisfy the standards or manuals can

**Table 1** Contents of questionnaires.

| No. | Questions | Contents |
|---|---|---|
| 1 | Image of new technologies | - How do you feel about utilizing new technologies for your work?<br>- When you hear “new technologies”, what comes to mind? |
| 2 | Experience in utilizing new technologies | - Have you ever adopted new technologies in your past work?<br>- What kind of new technologies did you adopt?<br>- Was the adoption a success or failure?<br>- What do you think was the reason for the success or failure? |
| 3 | Obstacles to the utilization of new technologies | - What are the reasons why you cannot or are averse to using new technologies? (Selection-type question) |
| 4 | Measures to promote utilization of new technologies | - What are effective the measures to make it easier to utilize new technologies? (Selection-type question) |
| 5 | Key points in utilizing new technologies | - What are the key points when utilizing new technologies? (Selection-type question) |
| 6 | Others | - Free description. |

be accepted by the ordering parties, provided the main obstacles, "Fairness is not guaranteed" and "Burden over explanation for account audit," are removed. Japan's account audit system that rigorously checks appropriate use of tax revenue at local governments may form the background of these answers

## (2) Measures

Figure 2 shows the results of question No.4 regarding measures for the promotion of new technologies. Many engineers of all positions chose "Encourage adoption of new technologies in manuals." Engineers from the developers and contractors chose "Provide application examples of new technology" and "Create neutral evaluation systems for new technologies."

## (3) Key points

Figure 3 illustrates the results of question No.5 regarding key points to be considered when utilizing new technologies. Many engineers from the ordering parties and developers chose "Respect participation of local companies." Many engineers from the ordering

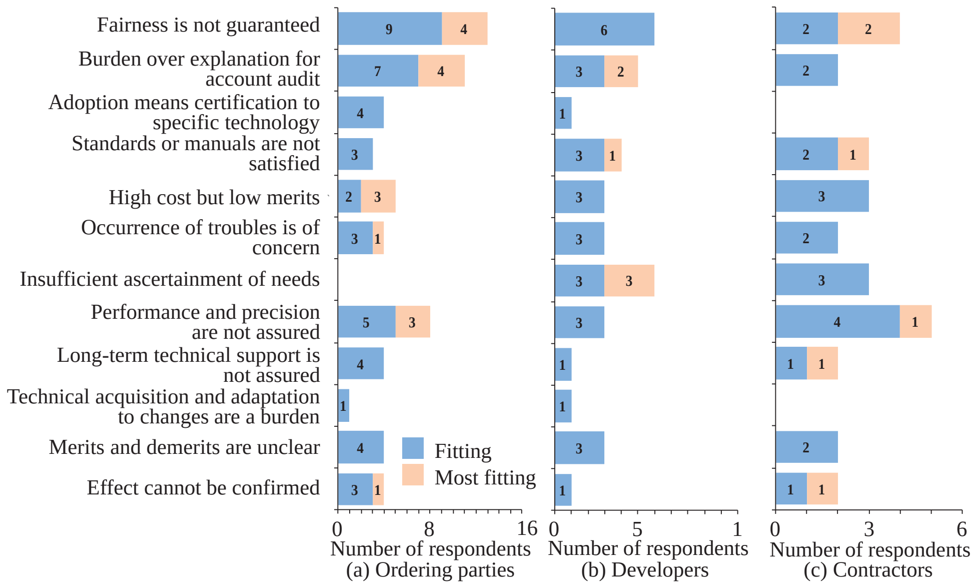


**Fig. 1** Results of questionnaire survey regarding obstacles.

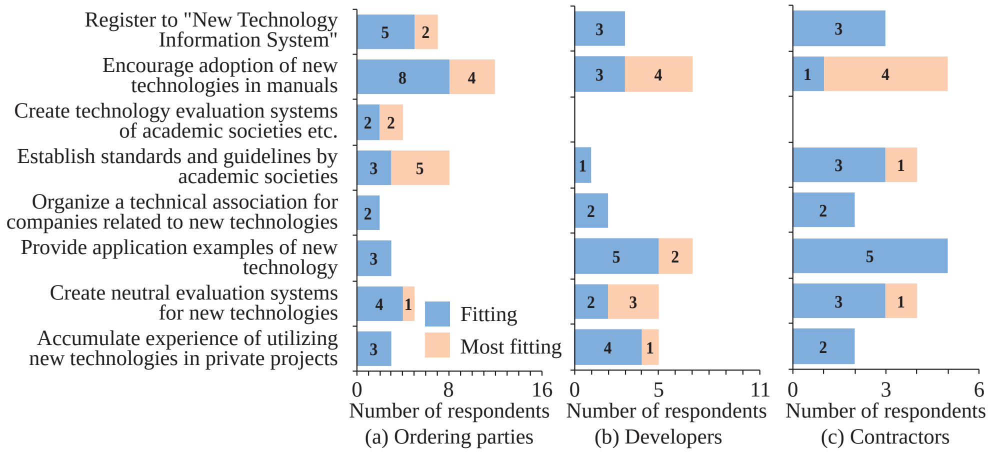


**Fig. 2** Results of questionnaire survey regarding measures.

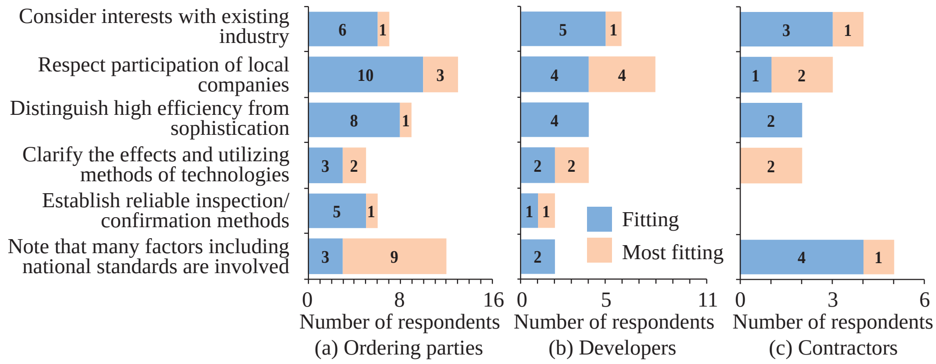


**Fig. 3** Results of questionnaire survey regarding key points.

**Table 2** Obstacles viewed from different positions.

| Positions | Major obstacles | | Major causes |
|---|---|---|---|
| Ordering parties | Lack of incentives | Attitudes of people in charge widely vary | - The organizational mission is unclear.<br>- Enthusiasm gap between head and local offices.<br>- Resistance to changes. |
| | | Significant energy and effort are required for introduction | - Fairness should be ensured.<br>- Basis for external explanation (account audit) is necessary.<br>- Basis for internal explanation (organizational consensus) is necessary. |
| | | Great risks in the events of trouble | - Who takes responsibility is unclear.<br>- Certainty and continuity of support by developers are not assured. |
| Developers | Difficult to build a business model | Investment decision for development is difficult | - First-mover advantage from development is not assured.<br>- Investment recovery in a short time is difficult.<br>- It is difficult to grasp the market (scale, continuity). |
| | | Required specifications are unclear | - Needs for new technologies (required performance/precision) are unclear.<br>- Appropriate cost for ordering parties is unknown.<br>- Content and period of technical support required are unknown. |
| | | Government's situation is unknown | - Each organization or local government is in a different situation.<br>- Methods of order placing and introduction conditions are difficult to understand.<br>- Attention to industry officials is required. |
| Contractors | Lack of incentives | No direct benefit | - Technical proposals do not lead to increase in orders received. |
| | | Great risks in the events of defects | - Who takes responsibility is unclear. |
| | | Cost of technical proposal is high | - Needs should be grasped and seeds should be collected.<br>- Documents supporting the validity of introduction should be formulated. |

**Table 3** Examples of measures taken to promote the use of new technologies.

| Goal | Measures | Orientation of measures |
|---|---|---|
| Raise incentives for order-placing staff | Define the mission of introducing new technologies | - Mandate introduction by law<br>- Agree on the introduction policy within the organization |
| | Raise the consciousness of individual staff members | - Exchange personnel with other organizations |
| | Reduce the labor of order-placing staff | - Increase the explainability of necessity for introduction<br>- Increase the explainability of performance, accuracy, and effect<br>- Increase the explainability of cost adequacy |
| | Reduce the risk in case of trouble | - Clarify the defect liability |
| Support developers to create a business model | Support investment decision | - Find areas where introduction in a short time is possible<br>- Formulate a system to facilitate introduction of new technologies |
| | Match seeds with needs | - Clarify public needs (required specifications)<br>- Clarify the seeds of developers<br>- Make proposals that are easy for order-placing staff to explain |
| | Support ascertaining the administrative situation | - Cooperate with appropriate developing partners |
| Raise incentives for contractors | Clarify the advantages for contractors | - Create a system by which proposals lead to increases in orders<br>- Show concern for local companies |
| | Deal with the risk of defects | - Clarify the defect liability |
| | Raise the awareness of the necessity for introduction | - Introduce new technologies suitable for the competence levels of contractors |

parties and contractors chose "Note that many factors including national standards are involved".

## Results of interview survey following the questionnaire survey

The interview survey was carried out in line with the questionnaire items filled in by the interviewees. The interviewers paid attention to extracting possible causes along with the apparent obstacles. After the interviews, keywords in the transcripts were extracted and analyzed. Table 2 gives the items recognized as major obstacles and their causes.

As seen from this table, engineers from the ordering parties and contractors feel a lack of incentives to use new technology for various reasons and perceive this as an obstacle. On the other hand, those from the developing parties feel it difficult to create a business model when developing a new technology, due to the special nature of the public works market, and perceive this as an obstacle.

Table 3 shows examples of promising measures taken by each position, which were ascertained through the interviews.

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# Scenarios for the introduction of new technologies in infrastructure maintenance by local governments

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In this paper, I will describe the issues faced by local governments when introducing new technologies developed by the SIP Infrastructure Maintenance, Renovation and Management Program (SIP Infrastructure Program), etc. and present potential approaches that they can take regarding the introduction of new technologies in the form of scenarios.

## Issues related to the introduction of new technologies by local governments

Although local governments call for the use of new technologies in their repair plans for extending the lifespan of infrastructure, the introduction of new technologies in infrastructure maintenance involves the following three issues, in addition to shortages of human resources and finances.

First, inspection work is conducted on the basis of various periodic inspection guidelines including periodic bridge inspection procedures, and local governments do not necessarily have much need to consider making the work more efficient and more advanced from a technical standpoint.

Second, inspection work is often entrusted to private operators who are not in a position to make choices and decisions concerning the introduction of new technologies or equipment. Although a local government can indicate new technologies in special notes on specifications or as design integration standards, decisions on the use of such technologies are ultimately up to the operator performing the work.

Third, local governments not only need to pursue solutions for technical issues and cost savings, but also must seek to avoid raising the bar too high for local companies to receive orders and improve their technical capabilities.

## Scenarios for introducing new technologies

Based on the issues described above, I will present six scenarios of approaches that local governments can take when seeking to actively utilize new technologies.

Five of these approaches can be taken when the use of new technologies is being promoted as part of the normal work of the local government's civil engineering department: (1) Top-down, (2) External committee, (3) Local management and human resource development, (4) Construction technology center led, and (5) Wide-area cooperation. (The fourth and fifth approaches are possible in the case of prefectural governments or small-scale local governments.) A sixth approach can be taken if the use of new technologies is being promoted in cooperation with other departments besides the civil engineering department: (6) Industrial promotion.

### (1) Top-down approach

This approach promotes infrastructure maintenance and the use of new technologies as a focus area, based on policy decisions by the heads of local governments or directors of civil engineering departments.

For example, in the top-down approach, a local government could conclude an agreement with a local university to pursue collaboration in infrastructure maintenance. Even if university faculty members are already involved as experts, it is meaningful to specify that the local government and the university will be working on infrastructure maintenance in an inter-organizational manner. According to Asaoka et al.,[1] 920 out of 1,914 organizations have concluded comprehensive collaboration agreements with universities as of 2016, and this is a scenario that could be applied by many local governments.

As shown in Fig. 1, local governments obtain knowledge

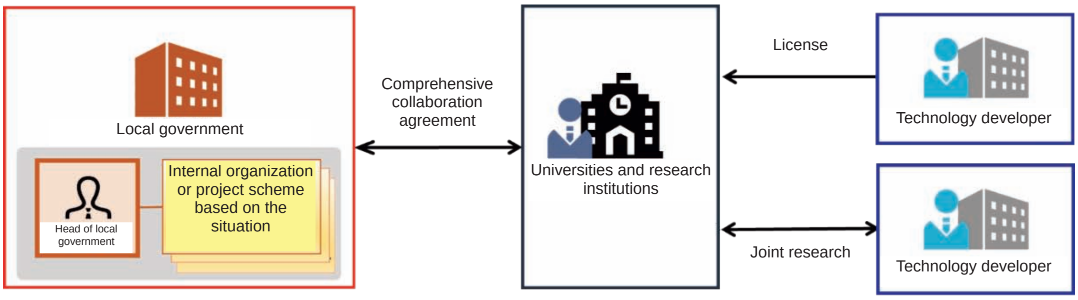


**Fig. 1** Example of a scheme for introducing new technologies under the top-down approach

and advice concerning new technologies by way of universities with which they have agreements, and the universities serve as hubs with the general public and companies. The universities are to make use of their own research findings, findings from joint research with companies, licenses obtained from companies, and so on for deployment in the region.

Examples of agreements focusing on infrastructure maintenance include the agreements on cooperation and collaboration for effective and efficient infrastructure maintenance that have been concluded by the civil engineering department of Miyagi Prefecture and the city of Sendai, respectively, with the infrastructure management research center of the Tohoku University Graduate School of Engineering; as well as a collaborative agreement on cooperation in research and investigation toward the utilization of drones and other construction robots that has been concluded by the city of Kakamigahara with the Center for Infrastructure Asset Management Technology and Research of Gifu University's faculty of engineering.

## (2) External committee approach

In this approach, expert committees on new technologies and techniques are established in order to promote the introduction of new technologies, and these committees provide guidelines and conduct reviews of new technologies as a stamp of approval. The approach of committee-based decision-making has also been used in other fields besides civil engineering, and this scenario is easily applied in cases where the issue under study and the new technology to be introduced are clear, because the points for discussion are clearly defined.

One example in the SIP Infrastructure Program is a study at Gifu University on proposed guidelines for local governments regarding the use of robotic technologies in bridge inspection.

## (3) Local management and human resource development approach

In this approach, infrastructure is maintained locally with the participation of local residents and companies, etc. while training human resources. This scenario is applicable to small-scale infrastructure that can be maintained adequately through daily patrols and relatively simple repairs.

As shown in Fig. 2, local governments provide the technologies and tools that local human resources who reside in the area can use to handle maintenance. Universities are to promote introduction by developing human resources for regional infrastructure maintenance and offering advice on the scope of work that can be handled by local human resources.

Examples include the program for small-scale bridge inspection and repair by infrastructure maintenance experts (ME) in Gifu Prefecture, and the Kamigoto council on general management of local infrastructure in Kamigoto-cho, Nagasaki Prefecture. In addition, Nagasaki University (Michimori program), Gifu University (ME program), universities and technical colleges in the Hokuriku region, Kansai University, Hiroshima University, Tottori University, Ehime University, Yamaguchi University, the University of the Ryukyus, and other institutions are engaged in human resource development in their respective regions.

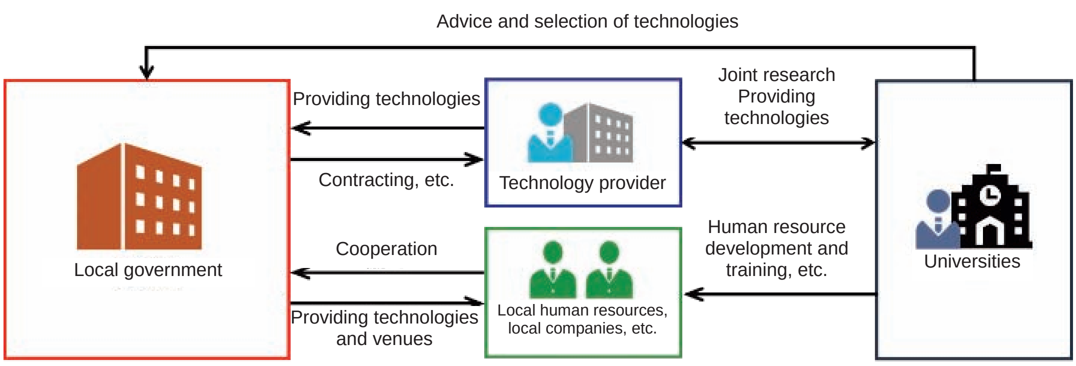


**Fig. 2** Example of a scheme for introducing new technologies under the local management and human resource development approach

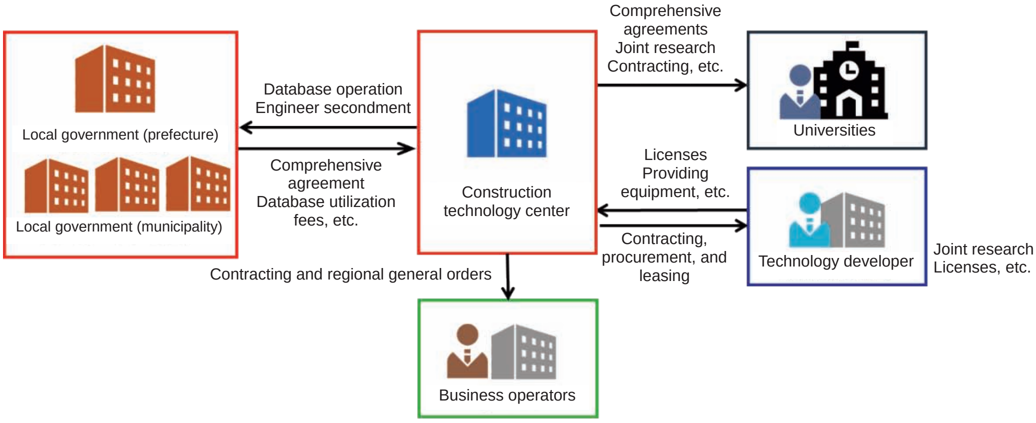


**Fig. 3** Example of a scheme for introducing new technologies based on the construction technology center led approach

## (4) Construction technology center led approach

In this approach, construction technology centers (or similar external organizations) play a leading role in providing technologies and placing orders based on the introduction of new technologies for prefectural governments and the municipalities whose infrastructure they manage. Construction technology centers differ from place to place with regard to their corporate status and content of operations, but they offer support to prefectural municipalities in areas such as database operation, combined regional order placement, technical certification, and comprehensive evaluation systems. The aim in this scenario is to make use of existing systems and frameworks to reduce the burden on prefectural municipalities in various ways.

As shown in Fig. 3, local governments assume costs and promote the introduction of technologies by way of a construction technology center. The construction technology center obtains licenses from the technology developers, procures the equipment, and deploys these technologies to local governments. Universities are to address the needs of local governments and construction technology centers through joint research and advice from a professional standpoint based on agreements with respect to construction technology centers, as well as joint research with companies.

One example is database operation by Tohoku University and the Yamagata Prefecture Construction Technology Center.

## (5) Wide-area cooperation approach

In this approach, councils are established for certain regions or to address specific technologies and issues, sharing information and seeking solutions to problems. Maintenance councils, liaison conferences with prefectural and municipal governments, and the like already exist in the area of regional cooperation, and under the Japanese Congress for Infrastructure Maintenance, local government support forums and regional forums, etc. have been established and are beginning to function.

## (6) Industrial promotion approach

This approach makes use of support measures for industry and business, such as promotion of regional industry, enhancement of technical capabilities, and technology transfers from universities, to promote capital investment and the introduction of technologies at regional companies. According to the Ministry of Land, Infrastructure, Transport and Tourism, most of the funding for infrastructure maintenance by regional governments is based on the use of government grants for infrastructure maintenance; and while prefectural governments are increasingly using multi-year implementation and making use of private sector funding, these trends are not being seen among small-scale local governments.[2] Therefore, this could include scenarios making use of industrial support measures for small and medium enterprises,venture businesses, and the like, pursuing cooperation with planning

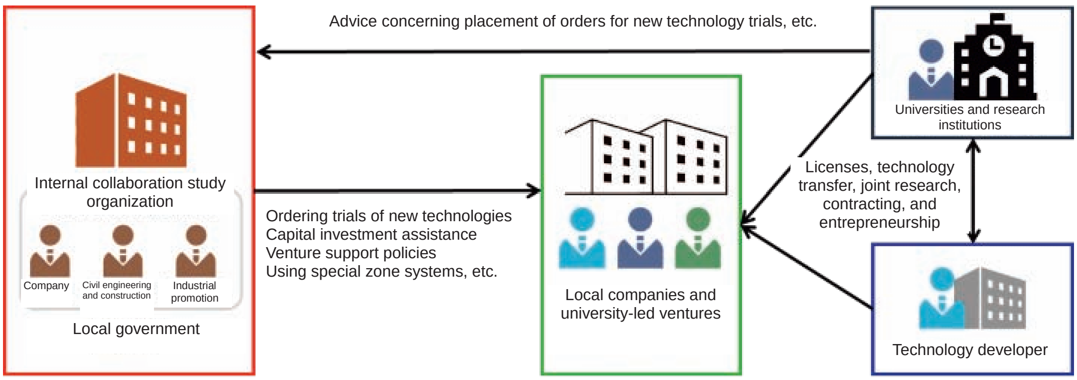


**Fig. 4** Example of a scheme for introducing new technologies based on the industrial promotion approach

departments and industrial promotion departments in addition to obtaining funding for the civil engineering sector.

As shown in Fig. 4, local governments support business activities in conjunction with measures by the national government targeting small and medium enterprises and venture businesses, such as the Small Business Innovation Research (SBIR) program, ordering trials of new technologies, and providing special zones and demonstration venues under sandbox programs. In addition to giving advice to the recipients of new technology trial orders, universities pass along the results of joint research with technology developers and other research findings. Universities could also take the role of promoting the introduction of new technologies through technology transfers and by establishing venture businesses and engaging in business development themselves.

Examples in the SIP Infrastructure Program include the RIKEN Venture system which has been established by the Institute of Physical and Chemical Research (RIKEN), and the identification of damage locations on bridges with drones based on a trial ordering program in Saga Prefecture.

## Introducing new technologies in the future

The introduction of new technologies in infrastructure maintenance is not an end but a means. In cases where a local government wishes to introduce and use new technologies for a certain purpose, it will be necessary to use new approaches from the standpoints described in this paper, in addition to conventional approaches. The industrial promotion approach, in which infrastructure maintenance is advanced in conjunction with regional industrial promotion measures, and the construction technology center led approach, which identifies technologies to be promoted for small-scale local governments, are expected to be especially helpful in opening paths for introduction of new technologies in the future.

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# Development of new technologies from a "seeds and needs" structural perspective: Promoting innovation and implementation through management

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In this paper, I will propose a structural model of “seeds and needs” and discuss ways that management can promote the implementation of new technologies. Initiatives for the implementation of new technologies are generally driven by either “needs” (unmet demand) or “seeds” (potential solutions). Although both types of initiatives are necessary for the implementation of new technologies, the management approaches best suited to each type are not the same. It is important to distinguish between these different management approaches and ensure that both are promoted, without overemphasizing either the needs type or the seeds type.

## “Seeds and needs” structure (business structure model)

Fig. 1 depicts the basic structure by which the needs of society are satisfied by seeds, which include technologies, services, and goods. In this figure, each S is a seed, and N is a need. The seeds on the left-hand side of the arrow are combined to meet the need on the right-hand side. For example, the transportation needs of a region are met through a combination of seeds such as road infrastructure, vehicles, and driver manpower. Fig. 2 shows this example in terms of the basic structure.

Looking at it in more detail, road infrastructure, as one of the seeds of Fig. 2, includes roads, bridges, tunnels, and so on. Bridges need components and maintenance services, etc. in order to be usable. This means that a structure in which seeds are combined to meet needs is hierarchical, as illustrated in Fig. 3. The structure shown in Fig. 3 is made of multiple connected instances of the basic form shown in Fig. 1.

In Fig. 3, the notation “N/S” indicates that the same thing can be a need when seen from the left side, and a seed when seen from the right side. Taking the example of a bridge, when seen from the left-hand perspective of components and maintenance, the bridge represents the need for the functions required of a bridge. However, when seen from farther to the right, the bridge is one of the seeds that serve as infrastructure. In other words, both seeds and needs are relative concepts, indicating the same things from two different perspectives.

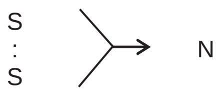


**Fig. 1** Basic form of the business structure model

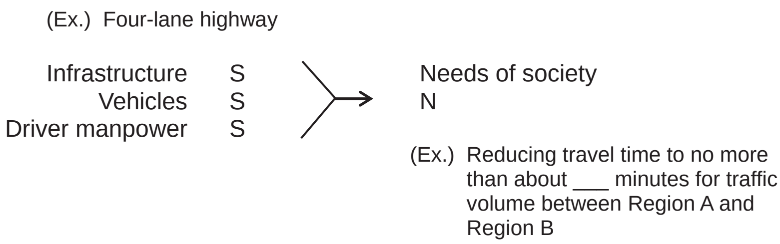


**Fig. 2** Example of a basic form of the business structure model

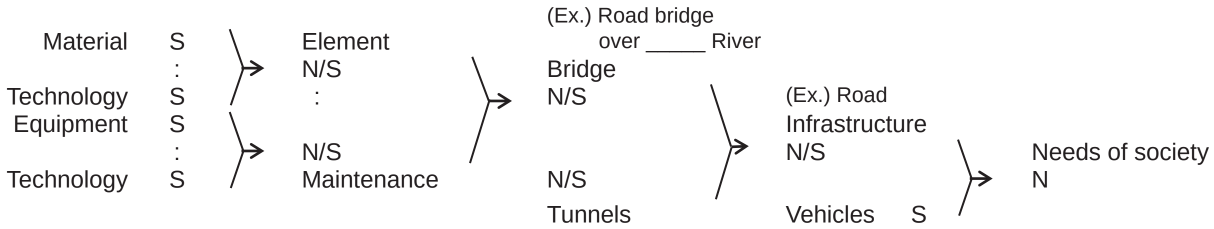


**Fig. 3** Example of the business structure model

## Innovation and implementation

Expressed in terms of this business structure model, innovation means creating or changing several instances of the basic form. This definition makes it easy to express the concept of new combinations which was proposed by Joseph Schumpeter. The implementation of a technology can be expressed as adoption of a technology within a business structure to fulfill some need of society.

For a new technology to be implemented, it is necessary to put not only that technology into practical use, but also a whole set of other seeds to satisfy a need of society. In other words, the technology is implemented only when that entire set of seeds is complete. Until the other seeds are put into practical use, the new technology cannot be implemented. In general, a new technology is implemented sometime after it becomes practicable. In addition, the person who performs development to make the technology practicable is often not the same as the person who implements the technology.

Next, we will express the process of technical development using the business structure model. The process of implementation of a single technology often involves multiple innovations of different types, both needs-driven and seeds-driven. We will consider the process for each type and appropriate management approaches.

## Needs-driven development

Needs-driven development, which is conducted to meet a specific need of society, can be generally expressed as shown in Fig. 4. Its purpose is to seek combinations of seeds that can satisfy a specific need.

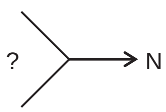


**Fig. 4** Needs-driven development

In some cases, it is possible to find a way to meet the need through some combination of existing seeds. In other cases, new seeds are developed and then combined with existing seeds to meet the need. In those cases, the performance required of the newly developed seeds constitutes a new need.

The development of a large system involves designing a set of components that will serve as the seeds for meeting needs of society, and determining the functions that each of these components should have. This is needs-driven development on a large scale. The next step is to design combinations of seeds such as technologies, goods, services, and data to provide the functions that each of the components should have. In other words, large-scale needs-driven development is structured in a way that incorporates needs-driven development on a smaller scale. The overall structure may be as shown in Fig. 3, for example.

The problem-solving approach to development is one example of needs-driven development. This includes the development of machines for the automation of specific tasks and the development of information systems. The construction of infrastructure and the development of maintenance technologies are also typical categories of needs-driven development.

## Management suited to needs-driven development

In needs-driven development, it is important to appropriately select the needs to be met and determine appropriate development goals on that basis. The more appropriate the development goals that are set, the more likely it becomes that the results of development will actually be used once these goals have been met.

When new infrastructure is to be constructed, the needs to be met are often spelled out in specifications indicated by the administrator, along with various regulations and standards. In this sense, it is easy to set development goals and implement needs-driven development. However, in infrastructure maintenance, the needs will not be expressed appropriately unless the administrator has adequate knowledge. If the administrator is unable to express the needs appropriately, it is necessary for developers or third parties to analyze the needs.

In needs-driven development, the more significant the needs, the more urgent it is to surely meet those needs. Therefore, it is more effective to make use of existing seeds. If the seeds have been proven effective, are technically stable, have been used by many people, and are widely understood, this makes it much easier to complete development reliably and without delay. The amount of work and the uncertainty of development can be reduced by relying on existing seeds as far as possible, and developing new seeds only when no existing solution is adequate.

A good example in technical development under SIP Infrastructure Maintenance is the combination of three SIP robotic technologies and two non-SIP robotic technologies by the Gifu University team to meet the need of reducing the costs of periodic bridge inspections.

## Seeds-driven development

Development is not always driven by needs; there is also seeds-driven development. A great deal of basic R&D is seeds-driven in nature. Some basic R&D is conducted with the idea of meeting needs of society, but even so, the purpose of development is often not very well defined. In other cases, R&D is performed with the aim of obtaining some "interesting" result, instead of a specific purpose.

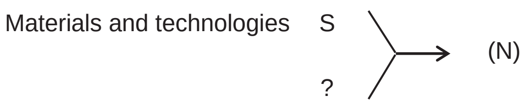


**Fig. 5** Basic R&D on seeds

Fig. 5 shows a business structure model representation of basic seeds-driven R&D. In this figure, (N) in parentheses indicates a need that is assumed in a general way but has not been specified in detail. For example, standards exist for evaluating the results of academic research, but these are general in nature, and may not necessarily have a direct bearing on specific needs of society.

The development of applications for new technologies and new materials, etc. is also seeds-driven. Needs are explored on the basis of a specific seed. Fig. 6 shows a business structure model representation of the development of applications for seeds. Other seeds for potential combinations are explored, in addition to needs. When relevant needs are identified, the nature of development changes to needs-driven. The lower diagram in Fig. 6 shows the stage of final coordination of seeds in needs-driven development.

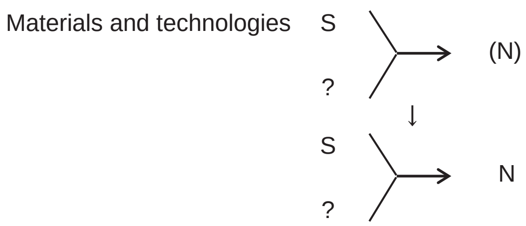


**Fig. 6** Developing applications for seeds

The diversion of existing seeds for use in meeting other needs is also seeds-driven development. Fig. 7 shows a business structure model representation of the diversion of seeds. In Fig. 7, a seed, represented as S, is diverted for use in a pipeline. Diversion is a type of seeds-driven application development, but after a need has been identified for diversion, the nature of development changes to needs-driven.

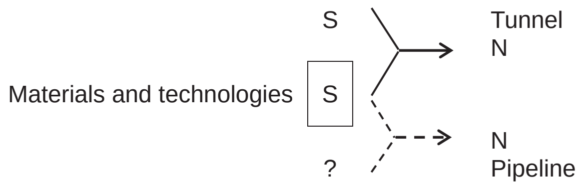


**Fig. 7** Example of utilizing seeds for different purposes

## Management suited to seeds-driven development

Seeds-driven development changes to become needs-driven after the needs to be met have been identified. However, in the stage of seeds-driven development up to that point, there is no development goal directly connected to a specified need, so there may be frequent changes in the assumed needs and development goals. This generally requires persistence and repeated trial and error.

Seeds that have high quality and versatility can be diverted to many needs and used to support a great deal of needs-driven development. To suit a variety of needs, a seed may be standardized in its design or interface, or it may have the nature of a platform.

Research areas with a high proportion of seeds-driven development include databases, in addition to new materials and innovative technologies. A good example in technical development under SIP Infrastructure Maintenance is the development of a consolidated database and dissemination to local governments by the Tohoku University team.

## Challenges and recommendations

The following article presents challenges and recommendations regarding management for promoting the implementation of new technologies, based on a structural analysis of seeds and needs.

A-7

# Management of technical development from a "seeds and needs" perspective: Challenges and recommendations

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From the preceding paper, "Development of new technologies from a 'seeds and needs' structural perspective," it is understood that both seeds-driven and needs-driven development are involved in the processes whereby new technologies are implemented, and it is important to promote both of these types of development, rather than relying on only one or the other. However, different management approaches are suited to each of these types of development, as shown in Table 1. In this paper, I will present challenges and recommendations concerning management for promoting the implementation of new technologies.

## Separate seeds-driven and needs-driven development

The implementation of new technologies is accomplished by needs-driven development to satisfy the needs of society. However, a great deal of seeds-driven development is needed prior to that in order to make many seeds usable. In general, it often happens that there are several years between seeds-driven development, which makes new technologies usable, and needs-driven development, in which new technologies are implemented. Also, in many cases, different people handle seeds-driven and needs-driven development in their respective fields.

Therefore, R&D programs such as SIP may separately handle proposals of seeds-driven and needs-driven topics.

In the needs-driven category, the topics are intended to solve specific problems (such as devices to reduce the costs of periodic bridge inspection). The seeds to be combined may consist of previously existing seeds. Fig. 1 is a business structure model representation of this approach.

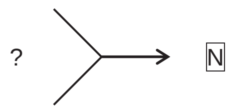


**Fig. 1** Needs-driven development

**Table 1** Comparison of seeds-driven and needs-driven development

| Seeds-driven | Needs-driven |
|---|---|
| Example: Innovative research | Example: Development close to implementation |
| Characteristics:<br>The requirements of needs are unclear<br>The goal may change<br>Results will not emerge for quite some time | Characteristics:<br>The requirements of needs are clear<br><br>Relatively short-term |
| Criteria:<br>Versatility rather than problem specificity<br>Separate efforts in individual fields<br>Deep cultivation of seeds<br>Evaluation of novelty and difficulty<br>Evaluation within a specialized field | Criteria:<br>Solving a specific problem<br>Multidisciplinary efforts<br>Wide range of seeds<br>Use of existing seeds is more convenient<br>Multidisciplinary, multidimensional evaluation |
| Remarks:<br>Problem solutions that are currently impossible | Remarks:<br>— |

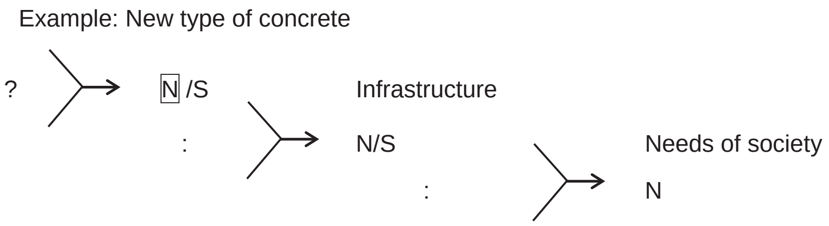


**Fig. 2** Development of specified seeds (needs-driven)

In another approach, requirements are defined for the seeds that are missing to solve a problem, and proposals are sought for forming those seeds (such as concrete that has at least a certain level of durability and can be installed at no more than a certain cost) as a need. A business structure model representation is shown in Fig. 2. The new concrete which is the missing piece in the overall structure is developed as a need, N.

In the seeds-driven category, R&D is conducted for seeds that will make it possible to solve problems that currently lack solutions, and implementation does not necessarily have to happen within a short period of time. (An example is AI to estimate and predict structural deterioration based on crack patterns and changes over time.) A business structure model representation is shown in Fig. 3.

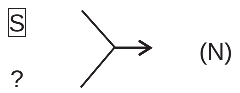


**Fig. 3** Seeds-driven development

## Different management approaches and criteria

Management for seeds-driven and needs-driven development differs in the following points. On the needs-driven side, the purpose is to solve specific problems, not necessarily to develop new seeds. It is actually preferable to solve problems through combinations of existing seeds, because this makes it possible to solve problems faster and more reliably. In contrast, on the seeds-driven side, technical novelty and versatility of application are among the criteria for evaluation. If a seed is new, this may make it possible to solve problems that previously lacked solutions. If a seed is versatile instead of being specific to a certain application, it can be used to solve many problems.

Overcoming these differences in criteria for evaluation poses a challenge for innovation where both seeds-driven and needs-driven development are required. If only one of these types is emphasized, the other type of development will not be promoted. With needs-driven development alone, refinement of existing results tends to be overemphasized, and radical breakthroughs are unlikely. With seeds-driven development alone, new technologies may be created but not implemented.

It should be noted that shifts between seeds-driven and needs-driven phases may occur until a technology is implemented. Distinctions need to be made in management and developer criteria depending on whether development is in a seeds-driven or needs-driven phase. If it is difficult to draw those distinctions within a single organization, it is possible to collaborate with a partner having experience in each phase, or to divide up the development work to some extent.

## Developer evaluation and incentives

Differences in criteria have an impact on the motivation and career paths of developers. Seeds-driven development is generally similar to academic research. That is, evaluation is conducted separately for each field of specialization, and the emphasis is placed on novelty, technical difficulty, and addressing the problems recognized within that field. Meanwhile, needs-driven development is multidisciplinary in nature, coordinating and combining seeds from different fields of specialization according to the individual problems to be solved. Evaluation is based on the extent of contribution to solving specific problems.

The scope of seeds that are mobilized to address needs of society is wider than the scope involved for development of individual seeds. A business structure model representation is shown in Fig. 4.

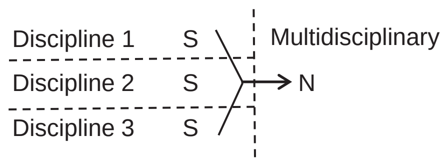


**Fig. 4** Scope of evaluation

It takes work and creativity to coordinate and combine seeds across multiple fields of specialization, but due to the specificity of individual problems, the results may not have versatile applicability. Frequently, in multidisciplinary development, technologies that are simple and already popular are more practical than new technologies having a high level of difficulty. Therefore, for people who wish to pursue careers in specialized fields, working in needs-driven development may offer a low potential for recognition within their area of specialization, in comparison to the amount of effort required.

It is easier to pursue a career as an expert by working in seeds-driven development and building a reputation within an area of specialization. Therefore, developers have an incentive to prioritize seeds-driven work within their area of specialization, rather than working in needs-driven development.

For people having knowledge in specialized fields to actively engage in needs-driven development, there must be systems in place whereby contributions to solving individual problems can also result in recognition within specialized fields. A typical project of needs-driven, problem-solving development lasts for a few years, not as long as career of developers. Therefore, it should be possible to obtain recognition and career advancement in academia and research institutions based on contributions in needs-driven development. Along with such systems, it is also important to have evaluators who are able to appropriately assess contributions in needs-driven development. If no suitable evaluators are available, record of being selected as a member of needs-driven development teams could be taken as a form of evaluation. Contribution in needs-driven development may result in repeated invitation of the developer to needs-driven development teams.

## Characteristics of needs in infrastructure maintenance

Needs in infrastructure maintenance are characterized by a high degree of specificity for each project. However, even when maintenance needs are highly individual, it may be possible to identify partial commonalities. A business structure model representation is shown in Fig. 5. As partial common needs are identified, seeds are developed for them, and these are used for many specific needs. This is a promising approach to innovation in the area of infrastructure maintenance.

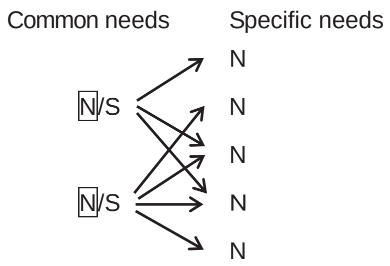


**Fig. 5** Identification of common needs N

However, in the present situation, the local governments that manage small and medium-scale infrastructure do not have adequate experts, and because each local government handles only a small quantity, it is difficult for them to identify standard types of needs. Local contractors who receive orders for maintenance work also tend to be small or medium enterprises, lacking the capability to develop new technologies. Therefore, the kinds of maintenance needs that emerge tend to be biased toward large-scale infrastructure managed by the national government or major operators. Japan has a great deal of small and medium-scale infrastructure, and in order to advance the maintenance of this kind of infrastructure, it would be effective to obtain the cooperation of academic societies, specialized conferences, and other expert groups to compile maintenance needs on a nationwide scale and identify typical development goals.

# Survey of the general public concerning SIP


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In November 2018, with the cooperation of MyVoice, an online survey company, we conducted a science and technology related questionnaire survey of 3,520 persons in order to assess understanding and awareness among the general public concerning the pros and cons of selection and concentration with regard to large-scale competitive R&D projects, which have given rise to controversy in recent years.

We confirmed that the majority of respondents were interested in science and technology, with 20% describing themselves as "interested" and 48% stating that they were "somewhat interested." Survey respondents showed an unexpectedly high level of trust in scientists, with 10% stating that scientists are "very trustworthy" and 76% describing scientists as "somewhat trustworthy."

Concerning the fields that should be particularly targeted for contributions from science and technology, the field of resource energy was specified by the greatest number of respondents (41%), followed by life and medical care (40.6%), the global environment (39%), food (35%), and disaster and crime prevention (32%).

Regarding the key question of awareness of SIP among the general public, as shown in Table 1, 66% stated that they did not know of any specific sources of research funding, and only 22% were even aware of grants-in-aid for scientific research. However, SIP was tied with AMED for first place in awareness of large-scale competitive R&D programs, as both of these were recognized by 8.2% of respondents, far more than those recognizing PRISM, ImPACT, and FIRST, which are also large-scale competitive R&D programs.

For further details concerning opinions about SIP, we asked respondents whether they feel that SIP is making contributions to science. We found generally positive perceptions, with answers of "yes" (22%), "somewhat" (37%), "not sure" (37%), "not very" (2%), and "no" (2%). Similarly positive perceptions were expressed with regard to the industrial competitiveness of SIP and its degree of contribution to resolving problems of the general public. Respondents generally indicated a higher opinion of SIP than of ImPACT or FIRST, although the differences were slight. The above results indicate that there is generally high awareness and a positive perception of SIP among the general public. In the future, we plan to conduct detailed quantitative analyses including individual attributes and news/publicity.

**Table 1** General public recognition of research funding

| | |
|---|---|
| Grant-in-Aid for Scientific Research Project | 21.9% |
| NEDO | 14.5% |
| AMED | 8.2% |
| SIP | 8.2% |
| Security Technology Research Promotion Program | 7.7% |
| Health Labour Sciences Research Grant | 7.6% |
| JST Basic Research Program | 7.0% |
| Funds for Promotion of Environmental Research | 5.4% |
| Strategic Basic Technology Upgrading Support Program | 5.4% |
| PRISM | 5.2% |
| ImPACT | 4.7% |
| R&D Promotion Program for National Task | 2.6% |
| FIRST | 2.5% |
| Nothing to Know | 66.4% |

A-9

# Measures to promote adoption of technologies from an institutional and policy perspective

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In this paper, I will take a social sciences approach to examine measures for promoting the regional implementation of SIP technologies from an institutional and policy perspective.

## Current status and challenges of infrastructure stock in Hokkaido

### (1) Infrastructure stock by region

The communities of Hokkaido are dispersed over the prefecture's very large land area. Among the prefectures of Japan, Hokkaido has a high level of infrastructure stock as well as per capita infrastructure stock. Fig. 1 shows the relationship between the land coefficient (square root of the product of a region's area and its population) and share of national infrastructure stock. The level of infrastructure stock is correlated not only with population, but also with land area.

Infrastructure stock can be classified into four categories: urban infrastructure (housing, water and sewer, urban parks, waste, education, etc.), land conservation infrastructure (flood control, afforestation, and coastline), transportation infrastructure (roads, harbors, and airports), and agricultural infrastructure (farming, forestry, and fisheries). Hokkaido has a high proportion of agricultural infrastructure stock, but a low proportion of urban infrastructure stock. Hokkaido also has a high proportion of transportation infrastructure stock, as its harbors and airports serve an important role in connecting Hokkaido with the main island of Japan and its large land area requires a large network of roads.

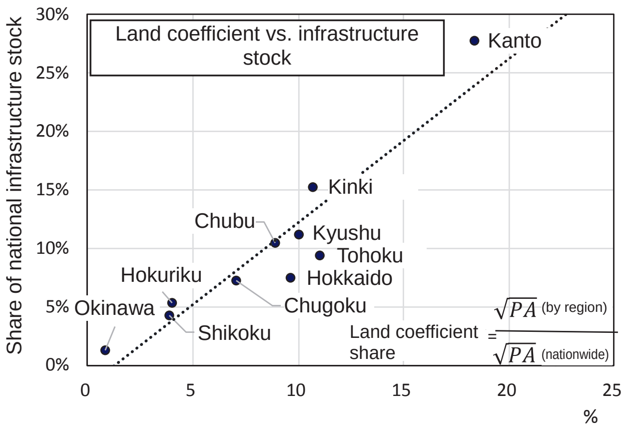


**Fig. 1** Land coefficient vs. infrastructure stock

### (2) Regional economy

The economy of Hokkaido is currently driven by industries related to tourism and food, backed by primary industries. Infrastructure supports trade and interchange among the geographical areas and industries of Hokkaido, which have thriving activity and an active economic structure. Eastern Hokkaido has a trade surplus with regions outside Hokkaido and contributes to the rest of the country as a food supply base.

### (3) Population trends

Population decline is more advanced in Hokkaido than the rest of Japan. The birthrate continues to decline, and increasingly, the population is becoming (relatively) more concentrated in Sapporo for reasons such as higher education and finding employment. In rural regions, competitiveness is improving as farms become larger in scale; and no serious problems such as abandonment of villages have occurred, although the amount of farmland per farming family has increased. In the 2015 national census, Hokkaido's population was approximately 5.38 million persons, distributed over an area of 20,230 square kilometers. Fig. 2 shows the population distribution per square kilometer of land area over the past 20 years. As this graph indicates, urban populations have become increasingly dense, at the same time that sparsely populated regions of farming villages have expanded in area.

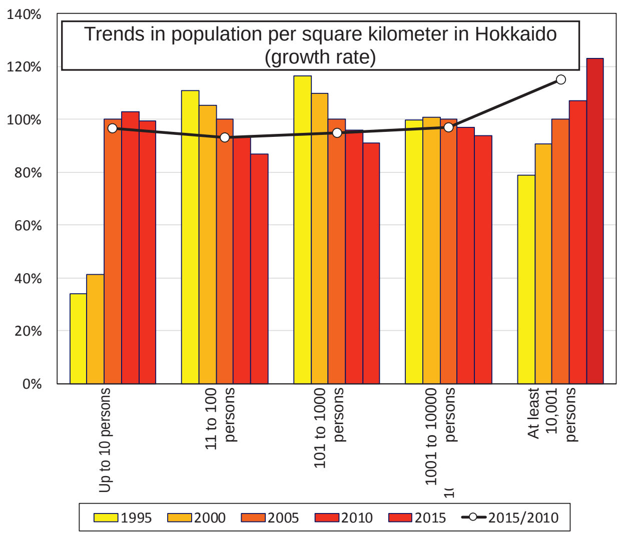


**Fig. 2** Population trends in Hokkaido (population per square kilometer)

(4) Regional finances

Municipalities face severe financial challenges, and fiscal adjustment measures including distribution of tax revenues to local governments are indispensable for the sake of infrastructure maintenance. Some of the infrastructure managed by municipalities as a local public asset does not only benefit a limited geographical area, but also provides noncompetitive spillover benefits to other regions. This effect is called the spillover of benefits.[1)] It is reasonable to allocate financial assistance and subsidies as a means of adjusting the financial burden commensurately.

In towns and villages with small populations and sparsely populated areas, total per capita expenditures are high, and expenditures related to civil engineering are also higher than those of large cities.

## Infrastructure stock management in cities and rural areas

In the preceding section, I gave an overview of Hokkaido as a whole. Next, it is necessary to take a more detailed look at the situations of individual areas.

Fig. 3 shows changes in the Hakodate metropolitan area in population density per 500 meters compared to five years ago, according to the national census. The city of Hakodate is engaged in urban development aimed at keeping the city compact and revitalizing the city center, but there is a pattern of urban sprawl as residents move into the suburbs. The convenience of road transportation is improving in areas near junctions of national and regional high-grade arterial highways, and commercial facilities are increasingly located in areas that offer high levels of convenience. Basically the same tendency is also seen in the cities of Hokkaido other than Sapporo.

Key regional cities such as Hakodate are bases of economic activity and life for their surrounding areas. Because of underdeveloped public transportation,

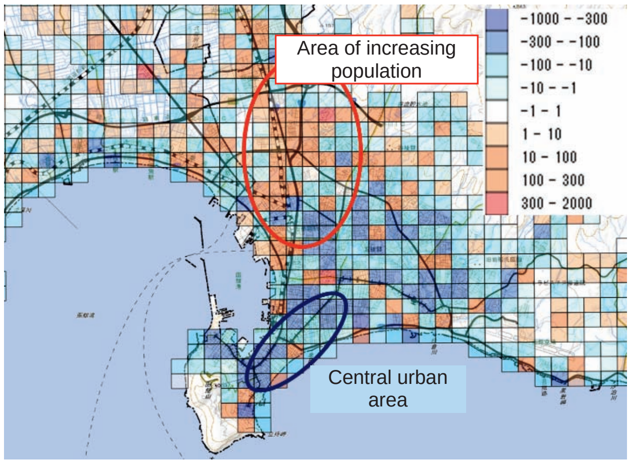


**Fig. 3** Population trends in Hakodate (per 500 m)

many residents of the areas surrounding these cities arrive by car, and it is difficult to realize the ideal of a compact, walkable city. Snowfall in wintertime is also a factor, and the Hokkaido standard for a compact city needs to include cars as well as walking. This diminishes the feasibility of measures to reduce the amount of road infrastructure. For basic infrastructure that supports the regional economy and livelihoods, infrastructure management must be performed in effective ways by using options other than consolidation.

As the population is rapidly declining, there will be increasingly severe problems of vacant lots and vacant buildings in city centers and other urban areas unless the sprawl of residential districts is halted. Therefore, it is important to hold discussions including directions for urban structures in the future.

Fortunately, much of Hokkaido's infrastructure is still relatively new because it was constructed at later times. Fig. 4 shows the age distribution of bridges. Hokkaido's bridges are newer than those of the rest of Japan by nearly 10 years, and this margin of time before infrastructure deterioration becomes more severe should be used for high-quality discussions.

I will also mention housing, because public housing can be included as part of the infrastructure stock.

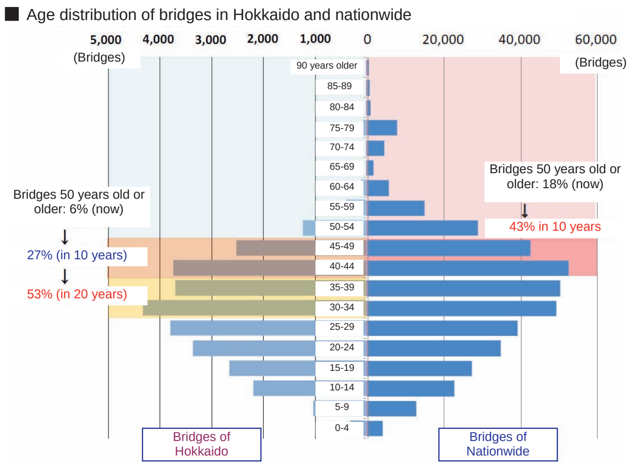


**Fig. 4** Age distribution of bridges in Hokkaido and nationwide

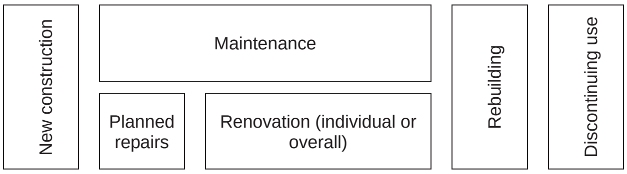


**Fig. 5** Plans for extending the lifespan of public housing, etc. (selecting an approach)

Local governments are to develop plans for extending the lifespan of public housing. As a preliminary step before establishing plans for extending the lifespan of such infrastructure, local governments are to determine the situation of their stock as a basis for plan development. To determine the stock situation, they are to select approaches for all public housing, etc. as shown in Fig. 5 and conduct inspections in residential buildings as needed. One of the approaches that can be selected is to discontinue use of a building as housing, reducing the stock. This plan development method combines technical and policy perspectives.

## Promoting local engagement in technology implementation

The management of aging infrastructure is a serious problem, especially among local governments in areas with small populations or sparsely populated areas.

Local government officials are interested in hearing about new technologies that can help to solve their problems. However, it is difficult for them to move forward with implementation because of issues such as budget problems, technical certification, and equipment transportation costs. This can result in missing good opportunities for resolving problems, so it is necessary to develop an environment that will minimize these kinds of hurdles.

I would like to propose expansion of local autonomy and discretion as one such measure. The current handling of standards of the Ministry of Land, Infrastructure, Transport and Tourism is as follows.

| | |
|---|---|
| [Laws and regulations] | Applicable to all |
| [MLIT Standards] | |
| National application: | Those applicable to facilities managed by the national government |
| Local government advice: | Those known as technical advice for local public organizations, etc. |
| Local government reference: | Those provided as reference information for local public organizations, etc. |
| Business application: | Those applicable to facilities managed by businesses, etc. |
| Business advice: | Those known as technical advice for businesses, etc. |
| Business reference: | Those provided as reference information for businesses, etc. |

The relevant organizations are permitted to make independent decisions with regard to those standards that are handled as advice or reference. Decisions concerning facility reorganization or abolition are subject to independent decision-making. In relation to legally mandated inspections as well, it is possible for interpretations such as partial substitution to be handled with independent discretion and responsibility, and this kind of independence in decision-making could become an incentive for the use of new technologies. (This approach is depicted in Fig. 6.)

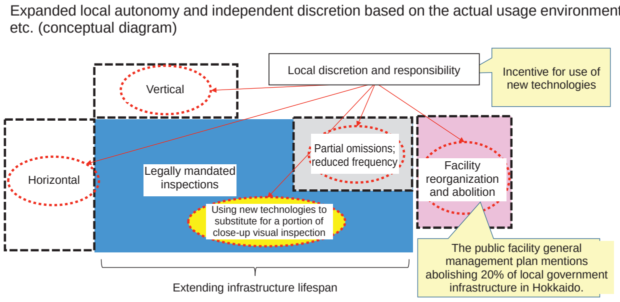


**Fig. 6** Local independent decision-making based on the actual usage environment

**Fig. 7** Joint lecture by SIP and Hokkaido Forum (group discussion)

Many local governments are facing problems such as declining populations, and efforts are underway for problem resolution and regional revitalization. It is important to consider the relationship between infrastructure management and the future of local communities in discussions.

SIP research groups have undertaken various initiatives in collaboration with the Hokkaido Forum, a national council, in FY 2018 in Hokkaido. Even after SIP ends, the Hokkaido Forum will continue to promote the regional implementation of technologies. At a second group discussion (Fig. 7) that was held on August 22, 2018 as part of a commemorative lecture on establishment of the Hokkaido Forum, information was shared among multiple local government organizations that are facing similar problems as they are beginning to actively confront issues of infrastructure management, including lively exchanges involving both local government officials and members of private companies.

Some indicated that they would like to try using a mobile profilometer (MPM) which is currently being developed at the Kitami Institute of Technology under SIP. This venue is expected to help to develop momentum for the introduction of new technologies.

[References]
1) Takero DOI: Introductory public economics, second edition, p. 202, Nippon Hyoron Sha [in Japanese]

# Technologies

B-1

# Regionally easy-to-use technologies and implementation status

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In this paper, I will give examples of technologies that are easily accessible for regional implementation, along with determination of the information needed for selection of SIP technologies by local governments, which are users, and key universities, etc. which deploy SIP technologies regionally. For specific endeavors by regional implementation support teams, please refer to Regions Category in this report.

## Criteria for regionally easy-to-use technologies

For the future implementation of SIP technologies, based on interviews with local governments and private business operators, etc., we have identified criteria for introducing the use of "regionally easy-to-use technologies," which are defined as technologies that could easily be introduced in a region, or technologies that could be selected for introduction. Specifically, we have determined criteria in four areas: the targeted scope and processes, constraints on introduction, benefits of introduction, and cost savings (Table 1). This does not include operability, such as user interfaces of equipment or systems.

**Table 1** Criteria for introduction

| Item |
|---|
| [Applicable scope and processes]<br>○ Applicable structures and components<br>○ Applicable inspection and repair processes |
| [Constraints on introduction]<br>○ Limited applicability based on infrastructure size, structure, etc.<br>○ Limited equipment usability based on weather or other conditions<br>○ Limited quantity of equipment, costs of transporting equipment, etc.<br>○ Need for technical expertise (qualification or license) to operate equipment, etc.<br>○ Need for procedures such as permit applications to use equipment, etc.<br>○ Difficulty in determining the acceptability of using equipment that is not covered in periodic inspection guidelines |
| [Benefits of introduction]<br>○ Safety, simplicity, efficiency, quality and accuracy |
| [Cost savings]<br>○ At time of introduction and during ongoing utilization |

## Trends in technical development in the SIP Infrastructure Program

To enable local governments to select the technologies they wish to introduce from among the SIP technologies, we performed a questionnaire survey of technical development teams on matters related to the criteria for introduction.

Based on this survey, in general trends concerning technologies that are applicable to bridges and tunnels, most respondents expect that the introduction of these technologies will lead to improvements in quality, accuracy, and efficiency (Fig. 1). When asked about constraints that would limit the introduction of

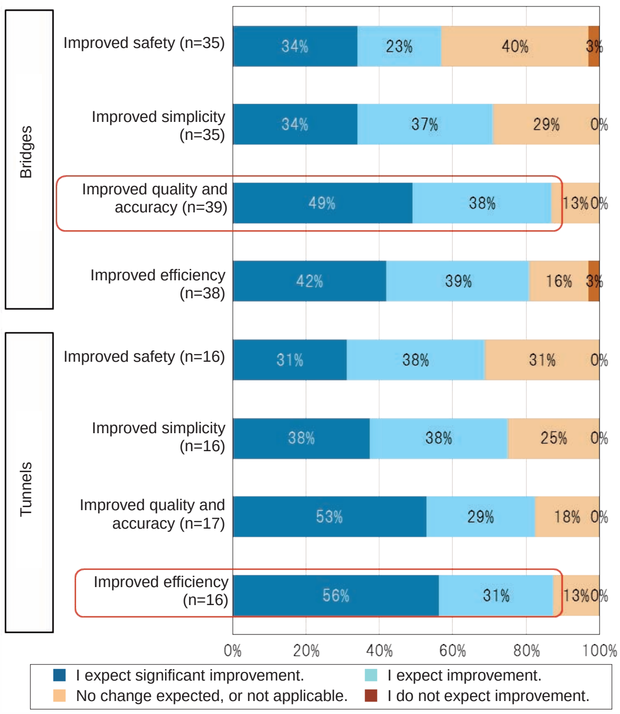


**Fig. 1** Benefits of introducing bridge and tunnel related technologies

technologies, many respondents cited "limited applicability based on infrastructure size, structure, etc.," "limited equipment usability based on weather or other conditions," and "need for technical expertise to operate equipment, etc." (Fig. 2).

With regard to costs, respondents tended not to expect any cost savings at the time of introduction of new technologies (Fig. 3).

## Cases of implementation of easy-to-use technologies

For the implementation of SIP technologies, it is necessary to clarify the criteria for introducing the use of such technologies, and to provide opportunities for users to actually see and experience the technologies for themselves through field demonstrations and the like. Therefore, regional implementation teams hold technology information sessions and field demonstrations and offer explanations and advice concerning SIP technologies.

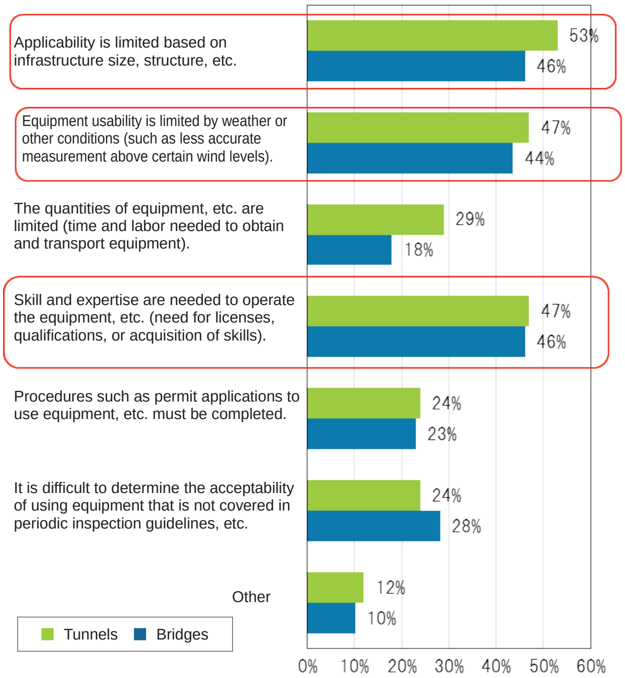


**Fig. 2** Constraints for bridge and tunnel related technologies

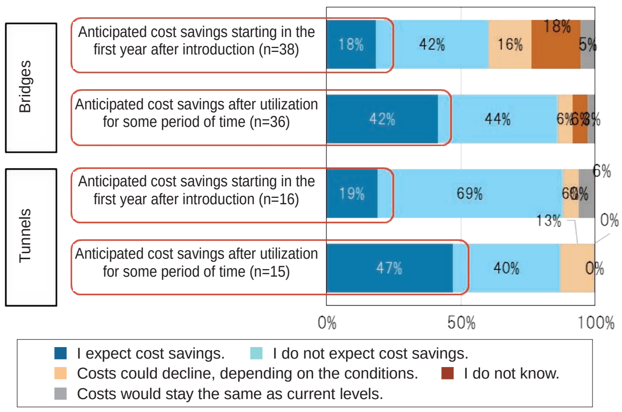


**Fig. 3** Cost savings from bridge and tunnel related technologies

**Table 2** Bridges: Examples of technologies implemented by regional implementation support teams

| Name of R&D project | Technical characteristics | Region of implementation | Portion targeted | | | Inspection processes | | |
|---|---|---|---|---|---|---|---|---|
| | | | Superstructure | Substructure | Foundation | Close-up visual inspection | Nondestructive inspection | Other |
| Creating a monitoring system that uses robotic cameras and other devices for bridge inspection | Robotic camera and monitoring system | Gifu University<br>Kansai University | ◎ | ◎ | ◎ | ○ | | |
| Constructing a system that uses image analysis technology for quantitative evaluation of deck slab cracks from a distance | Image analysis technology and remote monitoring system | University of the Ryukyus | ○ | ○ | ○ | ○ | | |
| R&D on a flying robotic system to replace sounding and close-up visual inspection of bridges | Drone and sounding mechanism | Tohoku University<br>Gifu University<br>Nagasaki University | | ○ | ○ | ○ | ○ | |
| R&D on a flying robotic inspection system that uses close-up visual inspection and sounding, etc. | Drone, image analysis, sounding mechanism, and sounding test analysis | Tottori University<br>Nagasaki University | ◎ | ○ | | ○ | ○ | ○ |
| R&D on a robotic system to support bridge inspection that is capable of acquiring close-up images with geo-tagging, using a two-wheeled multi-copter | Drone, image analysis, and 3D-CAD modeling | Gifu University<br>Tottori University<br>Nagasaki University | | ○ | ○ | ○ | | |
| R&D on a flying robotic system for sounding tests of bridges and tunnels | Drone (sounding mechanism) and pole sounding device | Gifu University<br>Nagasaki University | ○ | ○ | | | ○ | |
| R&D and implementation of road surface and bridge screening technology based on large-scale sensor data integration for preventive maintenance of infrastructure | Infrastructure sensing data management | Tottori University | ◎ | ◎ | ◎ | | | ○ |
| Nondestructive ultrasensitive magnetic inspection for assessment of infrastructure deterioration and maintenance planning | Nondestructive ultrasensitive magnetic inspection | Kansai University<br>Ehime University<br>University of the Ryukyus | ● | ● | ● | | | ○ |
| Development of a device to inspect for rebar corrosion inside concrete | Nondestructive rebar magnetism evaluation by acoustically stimulated electromagnetic method | Ehime University | ● | ● | ● | | | ○ |

Applicable locations:
◎: Concrete members and steel members ○: Concrete members ●: Steel members
Source: Value Management Institute, Inc.

**Table 3** Tunnels: Examples of technologies implemented by regional implementation support teams

| Name of R&D project | Technical characteristics | Region of implementation | Portion targeted | | Inspection processes | |
|---|---|---|---|---|---|---|
| | | | Main work | Ancillary | Close-up visual inspection | Nondestructive inspection (sounding) |
| R&D on high-performance, nondestructive technology to diagnose infrastructure deterioration using lasers | Frequency-shifted feedback laser; diagnostic (sounding) technology using laser-induced vibration waves | Kansai University<br>Nagasaki University | ○ | ○ | ○ | ○ |
| Development of an integrated diagnostic system that uses high-speed moving noncontact radar technology to detect internal defects in tunnel lining | Image analysis technology; high-speed moving noncontact radar and lasers | Gifu University<br>Nagasaki University | ○ | ○ | ○ | |
| Constructing a system that uses image analysis technology for quantitative evaluation of deck slab cracks from a distance | Image analysis technology and remote monitoring system | University of the Ryukyus | ○ | | ○ | |
| R&D on a full-surface inspection and diagnosis system for tunnels | System for full-surface inspection and diagnosis of tunnels | Nagasaki University | ○ | | ○ | |
| R&D on a flying robotic system for sounding tests of bridges and tunnels | Drone (sounding mechanism) and pole sounding device | Gifu University<br>Nagasaki University | ○ | | | ○ |

Source: Value Management Institute, Inc.

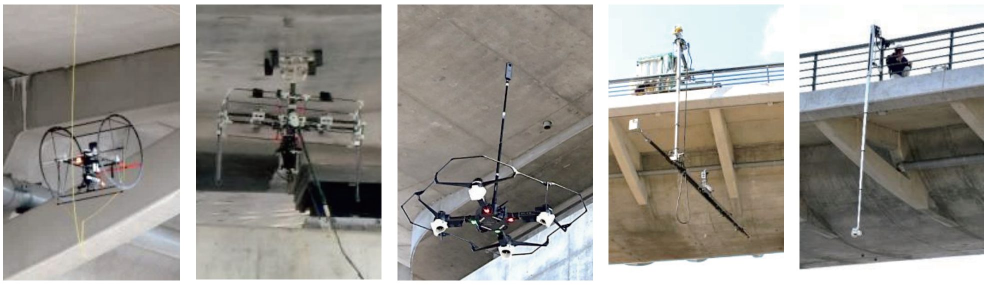

**Fig. 4** UAV and robotic technologies developed under the SIP Program (Source: Examples of outcomes under the SIP Infrastructure Maintenance, Renovation and Management Program, JST/Gifu University)

Below, I will present examples of technologies that are regionally easy-to-use for future introduction in areas such as bridges, tunnels, and road pavement, based on information related to these criteria for introduction and field demonstrations, etc.

## Bridges: Technologies for locations where close-up visual inspection is difficult and technologies for preliminary investigation

Technology information sessions and field demonstrations have been held by regional implementation support teams for many bridge-related SIP technologies, as shown in Table 2.

Although these SIP technologies are unable to substitute for close-up visual inspection and sounding tests at present, robots and UAV are expected to be used to identify damage in hard-to-see locations and perform preliminary investigation (screening) prior to close-up visual inspection (Fig. 4).

For example, robotic cameras for bridge inspection provides equipment portability and versatility, along with simplicity and efficiency for inspection workers. In addition, cost savings are anticipated because the use of bridge inspection vehicles can be omitted.

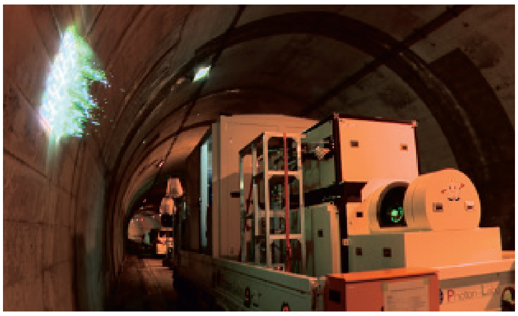

**Fig. 5** Demonstration of laser sounding (Source: Photon-Labo Co., Ltd.)

Next, UAV technologies differ in factors such as flight operation methods, scope of applicability, and processing methods for captured images, depending on the equipment that has been developed. In addition, it is necessary to select and combine technologies for introduction, such as equipment that is capable of sounding tests, based on the locations to be inspected.

## Tunnels: Technologies for inspection without lane closure or scaffolding

Technology information sessions and field demonstrations have been held by regional implementation support teams for the tunnel-related technologies shown in Table 3.

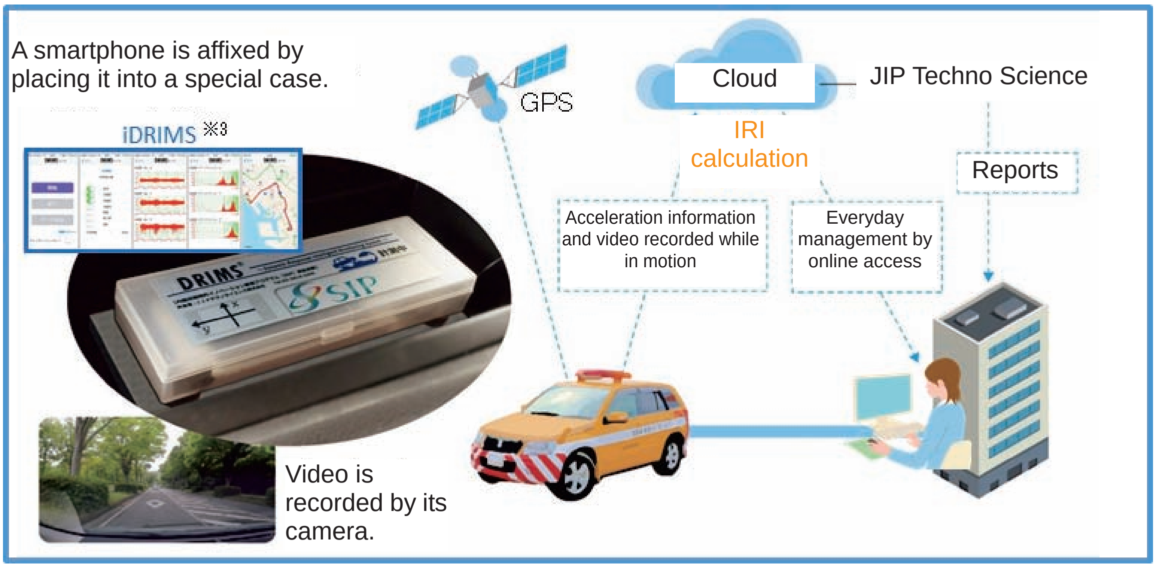


**Fig. 6** Mechanism for road surface inspection using smartphones (Source: JIP Techno Science Corporation)

These SIP technologies are not capable of substituting for close-up visual inspection and sounding tests at present, but technologies capable of measuring cracks, etc. in tunnel walls from vehicles moving at high speeds and technologies using lasers for sounding tests are promising.

In the former, a special vehicle is capable of simultaneously measuring cracking, deformation, lifting, rear face cavities, and so on in a tunnel while moving at high speed. Because road closures are not needed, this method has a high level of safety and efficiency in contrast to conventional aerial work vehicles, and it is also highly versatile, being applicable in practically all tunnels.

In the latter, or laser sounding tests (Fig. 5), measurement cannot be performed during high-speed motion, but no scaffolding is needed for work in high places, and sounding can be performed at 20 times the speed of a human worker, so practical use of this technology is anticipated.

## Road pavement: Technology for simple, inexpensive IRI evaluation

In the area of technologies related to road pavement, a technology that uses smartphones to evaluate road surface conditions is expected to be utilized.

With this technology (Fig. 6), a smartphone is simply affixed to a service vehicle, etc. and held in a special case, making it possible to verify locations of damage and to calculate the International Roughness Index (IRI) of the road surface based on acceleration, angle, image data, etc. This can be accomplished at 1/20 of the cost of a conventional maintenance control index (MCI) evaluation. This technology involves a low level of capital investment because it only requires equipment on the order of smartphones and Wi-Fi routers, resulting in considerable cost savings.

## Database management and utilization for operational efficiency

This is a system in which the results of bridge inspections and other types of data are jointly used and managed by prefectural and municipal governments. It has been reported that the time needed to prepare a bridge diagnosis (health report) is reduced to 1/60 by database introduction.

Operational frameworks are formed to improve usability so that the accumulated information can be better utilized as data, instead of merely improving the efficiency of record-keeping for inspections; for example, a university can provide support in the area of data analysis, as in the case of Yamagata Prefecture and Tohoku University. (See No. C-3 in this report)

Also, asset information on locally managed water supply systems in Hokkaido is managed using tablet computers and GIS, etc., and this has had the effect of improving simplicity, making it more easily handled by local residents, students, and other users. (See No. C-8)

## Developing easy-to-use technologies

In the future, the criteria for easy-to-use technologies will become more clearly defined if constraints (acceptability of use) are indicated for the implementation of SIP technologies and the use of new technologies in periodic inspection procedures and guidelines, etc.

Local governments and universities can play an important role in providing demonstration venues, determining the needs of users, and obtaining evaluation by developers of technology, in order to help make new technologies more accessible for use. Networks such as regional implementation support teams and regional forums of the Japanese Congress for Infrastructure Maintenance are important.

B-2

# Correspondence of SIP development technologies to 26 types of damage under periodic bridge inspection guidelines

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## Comments during SIP technology information sessions and demonstration tests

The main pillars of the activities of the regional implementation support team at Nagasaki University have been as follows: (1) to familiarize a wide range of infrastructure maintenance engineers with SIP development technologies; (2) to determine the current needs in maintenance overall from local government infrastructure administrators and private maintenance engineers; and (3) to provide developers with feedback concerning those needs. The comments shared by infrastructure administrators and private maintenance engineers generally correspond to the following two types of questions: "Which technologies are immediately usable in inspections?" and "How can these technologies be introduced into our current maintenance operations?"

## Periodic inspection of bridges by national government and local governments

At present, the methods for inspection and diagnosis of bridges directly managed by the national government and those managed by local governments are separately specified by the respective periodic inspection guidelines. There are some differences regarding the types of damage, criteria for countermeasure classifications, and so on, but both are the same in the sense that national or local government administrators are to perform appropriate maintenance work. For example, the periodic inspection guidelines for bridges directly managed by the national government include the 26 types of damage shown in Table 1, while the guidelines for use by local governments only indicate the 7 types of damage indicated with asterisks. For each of these types of damage, inspections can identify up to five stages (a – e) of damage, based on close-up visual inspection, sounding tests, etc.

However, especially in the case of inspection and diagnosis of bridges by local governments, the fact is that merely confirming the types of damage indicated in these guidelines is not enough to enable effective use of the results. Also, many areas are not accessible to visual inspection, including narrow portions at the ends of girders; and in reinforced concrete deck slabs, multiple types of damage such as leakage and free lime are frequently present in addition to cracking.

## Correspondence of SIP development technologies to 26 types of damage under the national government's inspection guidelines

Table 1 shows the specific types targeted by SIP development technologies out of these 26 types of damage.1) As the table indicates, the technologies under development are focused on specific types of damage such as cracking, deck slab cracks, lifting, etc., but no technologies are being developed for damage categories such as water leaks and free lime, damage in repair and reinforcement materials, or water leaks and standing water. Meanwhile, the 7 types of damage included in the road and bridge periodic inspection guidelines for local governments are all covered, except for the "other" category.

## Trends in critical damage to major members

Table 2 shows an example of the top three types of high-frequency damage in major members having a health diagnosis of Class II (stage of damage requiring preventive maintenance) and Class III (stage of critical damage requiring urgent measures), which are C1 and C2 in an administrative organization's countermeasure categories.

For example, with steel main girders, members in classes C1 and C2 made up 5% of all members, and

**Table 1 Correspondence** of SIP development technologies to 26 types of damage

| Type of damage | | Development issue numbers | Type of damage | | Development issue numbers |
|---|---|---|---|---|---|
| (1) | Corrosion* | 1, 7, 12 | (14) | Uneven road surface | 39 |
| (2) | Fissures* | 2, 3, 36 | (15) | Pavement abnormalities | 39 |
| (3) | Loosening and falling | | (16) | Functional impairment of supports* | 54 |
| (4) | Breakage* | 1, 7 | (17) | Other* | |
| (5) | Degraded anticorrosion protection | 1, 12 | (18) | Fixation abnormalities | |
| (6) | Cracking* | 22, 44, 45, 47, 50, 51, 52 | (19) | Discoloration and deterioration | |
| (7) | Peeling and rebar exposure | 12 | (20) | Water leaks and standing water | |
| (8) | Leakage and free lime | | (21) | Abnormal noise or vibrations | 8, 21, 24 |
| (9) | Falling out | | (22) | Abnormal flexure | 25, 33 |
| (10) | Damaged repair or reinforcement materials | | (23) | Deformation and deficits | |
| (11) | Deck slab cracking* | 7, 12, 22, 23, 33 | (24) | Dirt and sand clogging | |
| (12) | Lifting | 11, 48, 50, 51 | (25) | Settlement, movement, or inclination | |
| (13) | Expansion gap abnormalities | | (26) | Scouring | 21 |

* Included in the road and bridge periodic inspection guidelines

**Table 2** Critical damage tendencies in major members

| Type of damage ((1)-(26), see the type of damage in Table 1) | Steel main girders, 5% | Concrete main girders, 2% | Concrete deck slabs, 5% | Substructure, 2% | Type of damage ((1)-(26), see the type of damage in Table 1) | Steel main girders, 5% | Concrete main girders, 2% | Concrete deck slabs, 5% | Substructure, 2% |
|---|---|---|---|---|---|---|---|---|---|
| (1) | No. 1 | | | | (14) | | | | |
| (2) | No. 3 | | | | (15) | | | | |
| (3) | | | | | (16) | | | | |
| (4) | | | | | (17) | | No. 3 | No. 1 | |
| (5) | No. 2 | | | | (18) | | | | |
| (6) | | No. 2 | | No. 1 | (19) | | | | |
| (7) | | No. 1 | No. 2 | No. 2 | (20) | | | | |
| (8) | | | No. 3 | | (21) | | | | |
| (9) | | | | | (22) | | | | |
| (10) | | | | | (23) | | | | |
| (11) | | | | | (24) | | | | |
| (12) | | | | No. 3 | (25) | | | | |
| (13) | | | | | (26) | | | | |

* Included in the road and bridge periodic inspection guidelines

the most frequent type of damage was corrosion, followed by degraded anti-corrosion protection in second place, and fissures in third place. With concrete main girders, the most frequent type of damage was peeling and rebar exposure, followed by cracking in second place, and "other" in third place. With concrete deck slabs, the most frequent type of damage was "other," followed by peeling and rebar exposure in second place, and leakage and free lime in third place. With substructures, the most frequent type of damage was cracking, followed by peeling and rebar exposure in second place, and lifting in third place.

As an example, although reinforced concrete deck slabs show a high frequency of peeling and rebar exposure, as well as leakage and free lime, not much development is aimed at detection of these types of damage, as shown in Table 1.

## Expectations for new technologies

The technologies most desired by maintenance engineers are maintenance technologies that would contribute to accuracy in diagnosis and final countermeasures. There is high demand for new technologies that would handle preliminary screening or complement human senses (close-up visual inspection) for the sake of reliable inspection and diagnosis without missing critical damage, and we expect that these could be implemented immediately.

B-3

# Questionnaire result report on SIP technical lectures by the University of the Ryukyus

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## 1.Summary of SIP technical lectures

SIP technical lectures were held at the University of the Ryukyus on February 21, June 16, and October 16, 2018. We performed a questionnaire survey during this program to assess familiarity with SIP and determine needs related to bridge inspection and maintenance technologies.

## 2.Questionnaire results and discussion

• Ages of SIP lecture participants

The ages of participants in the SIP technical lectures are shown in Fig. 1. About 20% of participants were 29 or younger, but more than half were between the ages of 40 and 59.

• Occupations of SIP lecture participants

Occupations are shown in Fig. 2, with 7–9% working in government agencies, and 2–8% working at construction companies. Consultants accounted for over 70% of participants at every lecture.

• Familiarity with SIP

Fig. 3 shows the proportion of participants in the SIP technical lectures who knew about SIP. Fewer than 40% were familiar with SIP at the second lecture, but over 50% knew about it at the third lecture, indicating that the level of familiarity with SIP increased with repeated lectures.

• New technologies that participants want to use

Table 1 shows the new technologies that participants said they would like to use. The results indicate a high level of interest concerning the use of UAV and a new technology for detecting cracks from images, which were used in verification testing.

• Obstacles seen by participants concerning the use of new technologies

Table 2 shows comments by participants on obstacles concerning the use of new technologies. Participants cited several types of obstacles to the use of new technologies, including costs, personnel, a lack of standards or guidelines for new technologies, track record, and level of awareness of new technologies among ordering parties.

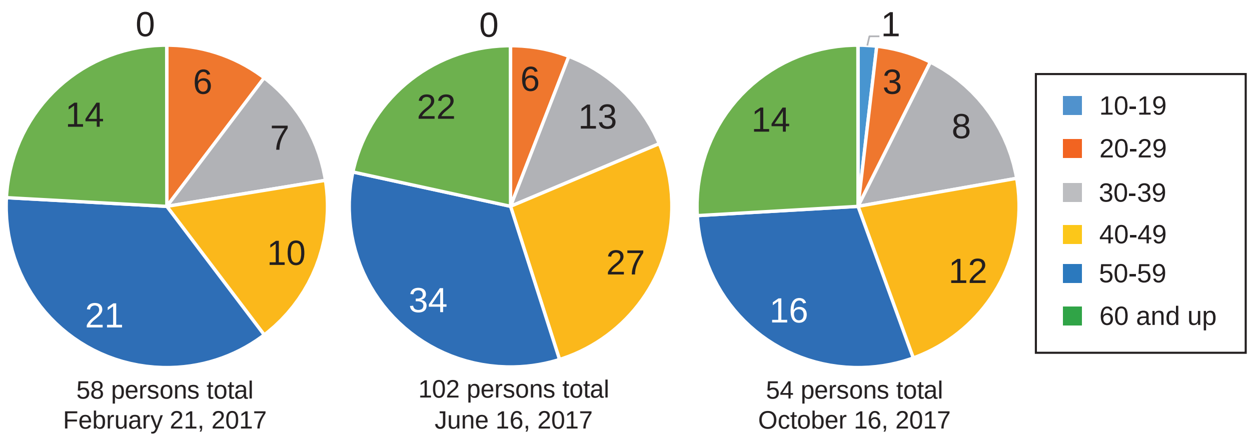


**Fig. 1** Ages of SIP lecture participants

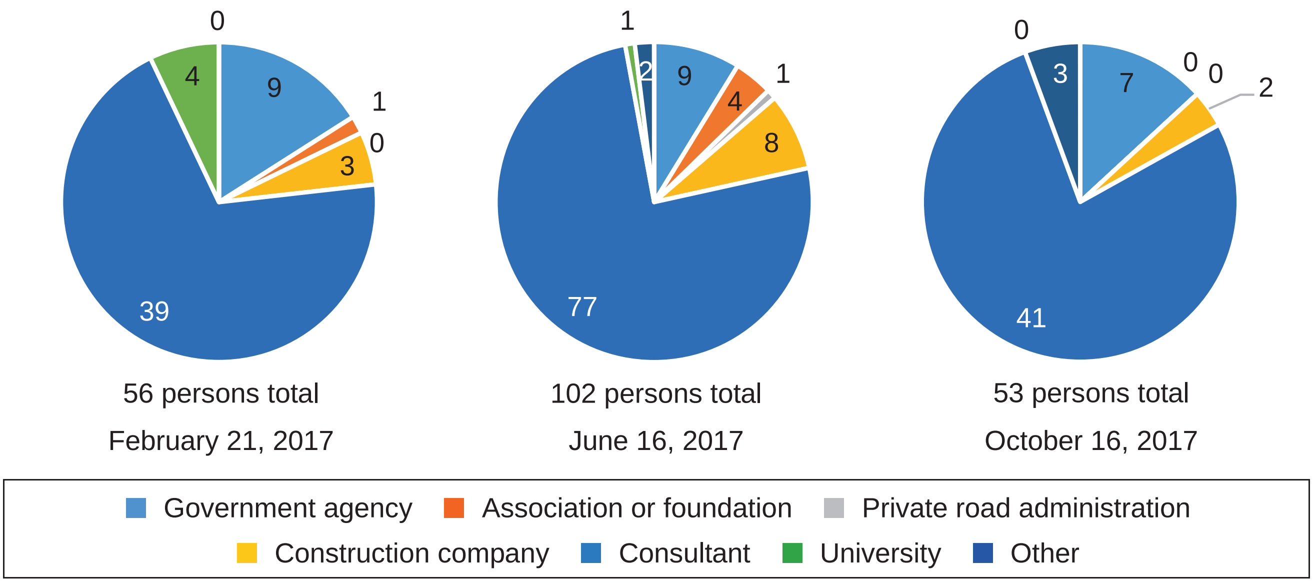


**Fig. 2** Occupations of SIP lecture participants

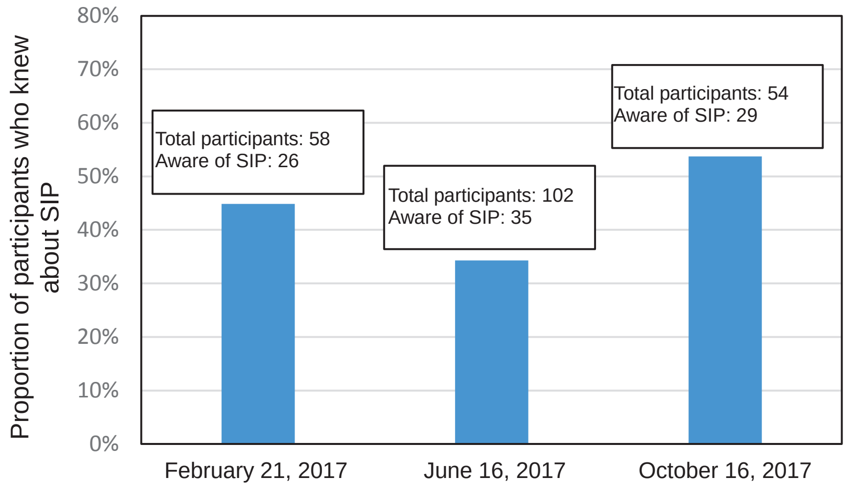


**Fig. 3** Familiarity with SIP

**Table 1** New technologies that participants want to use

[February 21, 2017 survey results:]

- If it becomes possible to use crack image analysis technology with general-purpose programs soon, I think this will improve the efficiency of work.
- Crack image analysis technology
- Crack analysis technology seems to be at a practical level. I hope this technology will be made available to the public soon.
- Crack analysis technology is promising. I think this will be very useful as the number of engineers declines.
- Remote diagnostic technology
- Technology related to diagnostic standardization
- I want to study and propose countermeasures against salt damage by using additives such as fly ash for concrete used in coastal structures.
- Using omnidirectional video to produce images of bridge aging
- Drones, robots, and AE
- Innovations in construction of cast-in-place floor slabs
- I think image analysis technology would be effective for structural inspections with limited working time. It would be ideal if my company could use this.
- Development of inspection and diagnostic technologies for harbor structures
- Underwater drones
- Inspection using drone technology in cavities below girders, such as in bridges
- Technology for diagnosing the state of corrosion of rebar in concrete in a completely nondestructive manner. In the case of visual inspection, the internal condition can only be inferred by hammer sounding and the like, so it would be enough for the technology to

provide a simple determination of the internal condition.
- Crack image analysis technology for structures
- Technology to prepare crack drawings from photographs
- Analysis of 3D point groups and crack images
- Crack image analysis technology
- Crack images for structures
- Shorter working period
- Image analysis technology using wavelet transform
- Diagnostic technology for structures such as bridges using UAV
- None at present
- Traditionally, if a technology has been fine-tuned by someone who is an authority in that field of infrastructure, it can be introduced into the workplace with confidence.
- I am interested in the re-use of materials including concrete.
- Technologies that would make up for the disadvantages in work that tends to be costly, such as diving work, or places that are difficult for people to investigate and inspect, as discussed in this lecture (distant and narrow locations)
- Technology to measure corrosion in steel

[June 16, 2017 survey results:]

- Constructing a system for quantitative evaluation of floor slab cracks from a distance, using image analysis technology
- Alternative methods to close-up visual inspection of bridges
- R&D on flying robotic systems for hammer sounding tests in bridge and tunnel inspection
- R&D on infrastructure structures and inspection devices that are suited to more sophisticated inspection of infrastructure
- Development of technologies for automating the inspection and diagnosis of pavement and embankment structures
- Inspection of pavement and embankment structure, development of automation technologies for diagnostic
- Technology for highly precise and efficient monitoring of manmade structures for displacement over time
- Demonstration testing of a surface collapse prediction and detection method based on driven-in water level gauges with inclination sensors
- R&D on monitoring system technologies for detecting river embankment deformation, etc.
- Using satellite observation for more efficient river embankment monitoring
- A system for monitoring the internal state of embankments using geophysical exploration and groundwater observation technologies
- R&D on a wide variety of data storage, management, and utilization technologies related to infrastructure maintenance and updating
- Development of an infrastructure maintenance system for local governments based on multi-tiered diagnosis
- Development of models for extending the lifespan of infrastructure through collaboration among business science, science and engineering, and economics
- R&D on special GPR devices such as chirp radar in cavity and backfill subsidence surveying
- Development of devices to determine rebar corrosion inside concrete
- R&D on product development for precast members using ultra-durable concrete
- Various inspection technologies to compensate for the many problems that exist in ongoing surveys based on close-up visual inspection due to differences among individual engineers
- Maintenance of structures using drones and AI technologies
- Technical development on inspection, diagnosis, and performance evaluation for more sophisticated life cycle management of harbor structures
- Curing methods and methods to eliminate fogging error
- If any technologies exist that make it easy to check for buried objects and the like, I would be interested in seeing them.
- Use of fly ash concrete
- Technologies to supplement maintenance based on ICT technologies (because it should be possible to prioritize maintenance tasks through visualization of floor slab soundness on urban expressways)

[October 16, 2017 survey results:]

- I learned about new endeavors based on the remarkable progress that has taken place in drone technology in recent years. I hope to make use of drone technology in the future.
- Technology for checking deterioration in gaps between the ends of girders and abutment parapets
- Development of devices to determine corrosion of rebar inside of concrete
- It would be useful to be able to discover corrosion of internal rebar by nondestructive means at an early stage.
- Promoting the use of fly ash and using it in operations
- Drone inspection technologies
- Development of back scattering X-ray devices for visualizing the interior of concrete
- I hope to be able to perform inspections using new technologies.
- Deterioration, maintenance, etc. of river structures
- Diagnostic technologies for inspection and monitoring
- Exploratory methods for buried objects (water pipes, sewer pipes, etc.)
- It’s good to learn about the use of drones for detecting flaws at minimal cost.
- I would like to make use of fly ash concrete technology in certain cases.
- Bridge maintenance
- Bridge inspection technologies
- Regional implementation of FA concrete
- Ways to utilize ETC 2.0 in the future (“soft” aspects)
- Technologies for the reuse of industrial waste

**Table 2** Obstacles to use of new technologies

| [February 21, 2017 survey results:] | [June 16, 2017 survey results:] |
|---|---|
| • Costs<br>• Lack of public awareness; description in standards and guidelines, etc.<br>• Based on the need for productivity measures, higher-level institutions should take the lead in using new technologies and establishing qualifications.<br>• It seems to be difficult to construct a business model related to maintenance.<br>• Administrators need to have better awareness. There is resistance to adopting new technologies with no track record. Okinawa Prefecture has announced key achievements of senior officials in the Department of Civil Engineering and Construction.<br>• The cost is high.<br>• High costs, guarantees (including the number of years of usability), and inadequate examination by planning agencies<br>• Research findings and expense budgets<br>• Costs and volume of construction<br>• When the party ordering a project has a low level of awareness, it is difficult for me to propose the use of new technologies. I need more actual examples showing how much more accuracy can be achieved, compared to conventional methods and technologies.<br>• Costs and lack of technical guidelines. I would like to be able to use new technologies without hesitation.<br>• Use of new technologies in fields where relevant standards and guidelines, etc. have not yet been developed<br>• As far as bridge inspection is concerned, close-up visual inspection is mandatory. As this kind of technology advances in the future, I expect that it will also be necessary to relax the guidelines so that close-up visual inspection can be omitted.<br>• It is costly. I am not familiar with how to use it.<br>• The cost is high.<br>• Lack of familiarity on the government side, and lack of a proven track record (SIP technologies)<br>• The periodic inspection guidelines are based on visual inspection. Mechanical means are merely supplementary. I don't know whether the mechanical means are truly trustworthy.<br>• It is not easy to obtain the necessary budget and engineers.<br>• Ordering parties tend to depend on established precedents in their attitudes toward technology, and it is hard for them to accept new technologies. They do not study these matters adequately.<br>• More clarity is needed concerning the costs and the level of accuracy.<br>• Even if a technology is excellent, it's difficult to use it at a work site if it has not been fully anticipated, or if there are issues in terms of cost or safety.<br>• Not many people are able to use these kinds of new technologies.<br>• There are not many opportunities to experience the latest technologies.<br>• There needs to be a proven track record, a budget for purchasing, and institutional changes. | • Getting funds budgeted for infrastructure maintenance<br>• Constraints based on the existing systems; budgetary constraints<br>• Financial aspects such as cost, education, and human resources in relation to the introduction of new technologies, and the lack of human resources who can handle such technologies<br>• Whether the technologies are registered in NETIS<br>• Local governments cannot easily introduce new technologies without precedent cases and a track record.<br>• Expensive<br>• Not enough information is available on new technologies.<br>• The prefectural government has not established relevant specifications.<br>• The track record of new technologies does not have enough credibility. The explanatory materials are not adequate to overcome doubts.<br>• There is a lack of familiarity with new technologies.<br>• Complicated regulations<br>• In the design process, one is always asked for references and examples of previous use.<br>• Not yet widely known<br>• No clear advantages to be seen; costly<br>• Lack of skills, lack of human resources, aging workforce, etc.<br>• It will not be easy to use high-priced technologies until the prices come down.<br>• Even if a technology is effective, the fact is that it cannot be adopted easily unless it has a proven track record.<br>• From my perspective as a consultant, I believe that registration in NETIS is indispensable.<br><br>[October 16, 2017 survey results:]<br><br>• Reliability and price of technology<br>• Ordinary, commercially available drones cannot be used (for surveying) in drone inspection on the underside of a floor slab.<br>• Providing information about future development, dissemination, etc.<br>• There are problems of economical costs.<br>• In some cases, it is difficult to demonstrate whether a technology meets the standards set by the national government.<br>• Can you give an explanation concerning proof that it can be reliably used in business, confirming that it is acceptable for use at each respective worksite? (Questions are raised about its track record, etc.)<br>• Response of administrators<br>• In public works projects, a proven track record is emphasized.<br>• I think the rules about close-up visual inspection and hammering in the periodic inspection guidelines pose an obstacle to the introduction of new technologies.<br>• It is difficult to use new software programs and equipment because both are expensive.<br>• Many of them are still under development (technologies using GPS, radar, soundwaves, etc.).<br>• Lack of flexibility in the existing standards; versatility of new technologies |

# Inspection system using flying robots with close-up visual inspection and hammering test functions

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## Background and summary

The local government level that manages the close-up visual inspection of a large number of diverse bridges to be performed once every five years suffers due to limited budget and lack of technicians. Therefore, there is a dire need for a cost-effective and efficient inspection system. The SIP group's "Development of Framework and New Technologies for Infrastructure Maintenance Management in Kansai-Hiroshima Region," which was supervised by Hitoshi FURUTA, Kansai University, conducted an experiment with an inspection system that used flying robots equipped with close-up visual inspection and hammering test devices in the Nara Prefecture.

## Outline of the technology demonstrated

In this experiment, a drone was used to conduct surface observations of areas under girders, deck surfaces, and the sides of piers of bridges using a camera, conduct the proximity confirmation of bearing, and perform hammering tests. This process was proposed by a group led by Shin-Nippon Nondestructive Inspection Co., Ltd.

Demonstration date: February 20, 2018, Tuesday

Weather: Sunny with a wind speed of 1–2 m/s

Location: Sakurai City, Nara Prefecture, Miwa viaduct (multi-span post-tensioned composite bridge, three-span continuous non-composite plate girders, bridge length: 784 m, bridge width: 16.10 m, 24-spans, construction date: December 2008, height from the ground to the under surface of girder: approximately 5 m)

Equipment: A flying robot for horizontal surface, i.e., under the surface of girder and deck, as shown in Fig. 1, and a flying robot for a vertical surface, as shown in Fig. 2, were used.

The flying robot for a horizontal surface, as shown in Fig. 1, comprises a movement mechanism for flying and traveling with the attached inspection device. The combination of the components constitutes an inspection system with a visualized inspection signal and an analytical system that supports evaluation. The decks

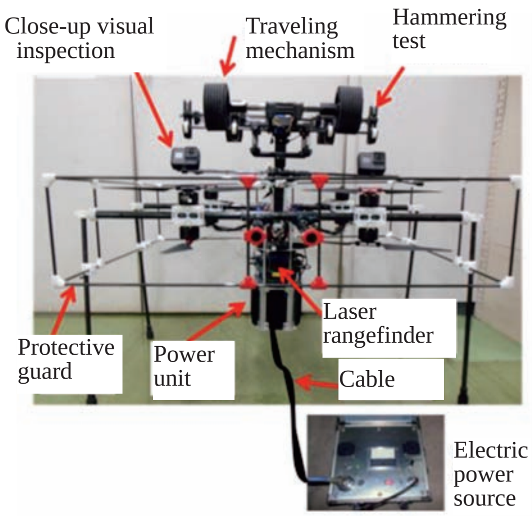


**Fig. 1** Flying robot for horizontal surface.

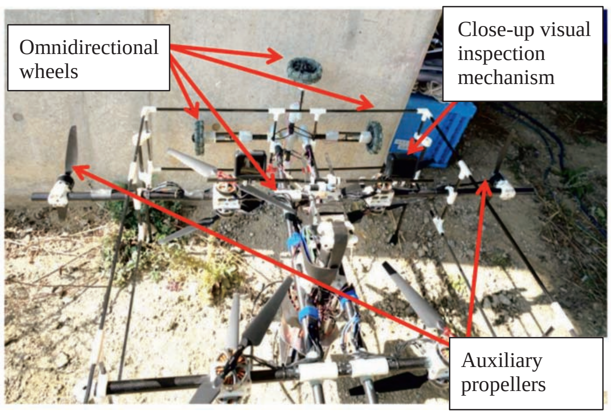


**Fig. 2** Flying robot for vertical surface.

and beams on the backside of a bridge can be examined using a multicopter. Wheels are pressed against the surfaces that are to be inspected using a lift, and then the robot travels along the surface using wheels. The direction in which the robot travels can be controlled by changing the rotational speed of the left and right wheels. The inspection device operates based on the hammering test mechanism comprising four percussion instruments placed at equal intervals and a microphone, as shown in Fig. 3, and an observational mechanism that obtains images with proximity data using two cameras, as shown in Fig. 4. The robot performs efficient inspections by linking the inspection mechanism with the movement mechanism. Power is supplied to the robot using a cable and hammering signals are transmitted to the computer for data analysis using a designated cable. Positional data and images captured by the camera for close-up visual inspection are transmitted using a LAN cable. The robot employed for vertical surfaces has the same flight mechanism as that of the horizontal robot, though it is equipped with omnidirectional wheels for traveling. Auxiliary propellers arranged in the right and left sides are used to exert a horizontal pressure force against the vertical surfaces. The close-up visual inspection mechanism is installed in the upper part of the flight mechanism.

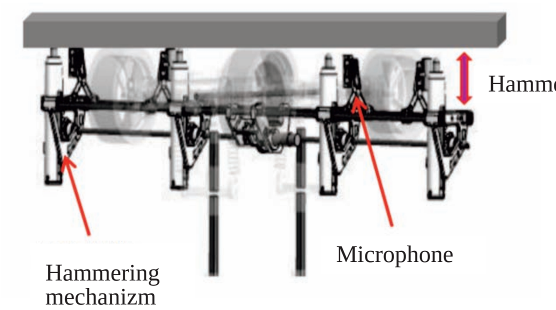


**Fig. 3** Hammering test mechanism.

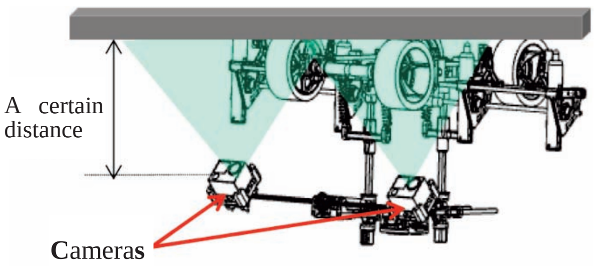


**Fig. 4** Observation mechanism.

## Demonstration experiment

In the demonstration experiment, the horizontal robot was used and the area under girder was covered twice, whereas that under the deck was covered thrice. We considered the entire surface as the target area to ensure that no part of the surface was overlooked during the inspection. The vertical robot was used to inspect the side of the piers and observe bearings. Inspection performance and functionality were verified in the following manner. For inspection performance, verification items included the following: (1) close-up visual inspection and hammering testing of the areas under the post-tensioned composite plate girder (horizontal robot), (2) close-up visual inspection and hammering testing of the decks (horizontal robot), and (3) close visual inspection of the sides of piers and bearings. For functionality, verification items included the following: (1) close-up visual inspection (under girders, decks, side of piers, and bearings), (2) hammer testing (under girder and decks), (3) inspection sites (beam and decks) and shape measurements of inspection sites, and (4) vertical surface inspection (sides of piers).

## Results of the demonstration experiment

Inspection performance, such as conducting a close-up visual inspection and the hammering test of post-tensioned composite girder surfaces and deck, was sufficiently performed through image observation and evaluation of hammering test results (Figs. 5-7). There were no limitations associated with functionality, such as close-up visual inspection, hammer testing, inspection positions, and the measurement of shapes of inspection sites. However, since no abnormalities were found in the inspected bridge, we were unable to confirm whether this inspection method can detect abnormalities.

Next, we used the vertical flying robot, as shown in Fig. 8. Initially, it took time for the robot to climb the side of a pier, but upon starting, it traveled smoothly. There were no problems with close-up visual inspection of the bearing.

The results of our demonstration experiment are summarized in Tables 1–4, including the advantages and challenges faced.

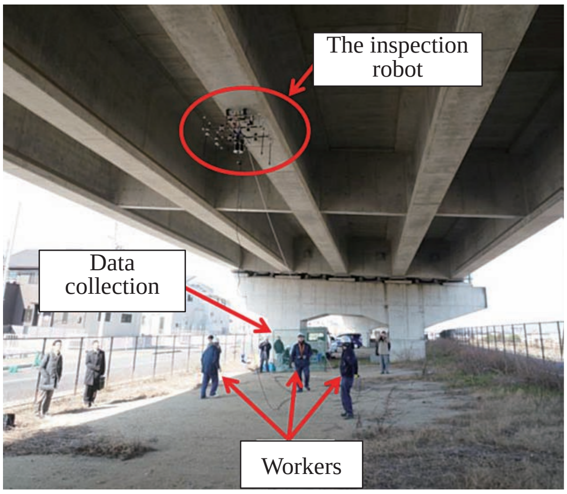


**Fig. 5** The demonstration experiment.

**Fig. 6** Inspection of the area under girder.

**Fig. 7** Inspection of the deck.

**Fig. 8** Inspection of the side of a pier.

**Table 1** Advantages of the inspection performance

- Arriving and traveling on the girder surface and deck surface using the flying robot was smooth.
- The robot was able to record a video of the inspection site, from which still images could be captured. It was easy to confirm the surface condition of members, and it was particularly useful when the inspection area was wide.
- Analysis of the audio signals from the hammering tests allowed the evaluation of the bridge.

**Table 2** Advantages of the functionality

- From the video of the inspection sites, images of the hammering test sites can be confirmed, and cracks can be delineated by an automatic detection process.
- Areas that cannot be easily accessed by human workers can be safely and economically inspected.
- There was a minor difficulty when climbing the side of a pier was initiated, but it traveled smoothly thereafter, and bearing could be examined without building a scaffold for human workers.
- It is more efficient for performing the hammering test in comparison with human workers.
- With the laser rangefinder installed on the robot, the position of the robot can be calculated and the traveling path can be confirmed. Since the current position of the robot can be confirmed, inspection oversight can be reduced or prevented entirely.
- By providing electricity using a cable, inspection can be performed continuously, making the task efficient. In comparison with the wireless flying robots, it is more stable and reliable in performing tasks.

**Table 3** Challenges (part 1)

- It requires training to operate the robot.
- An expert team must be formed, which includes an operator, guide, data analyst, data evaluator, and supervisor, among others.
- There is a protective guard around the flying robots, which makes it impossible to inspect the edge of beams, and at some instances, there is a limited space between beams; thus, a smaller model may be necessary to properly inspect certain areas.
- Protection protocol for falling concrete pieces from the hammering test must be developed.

**Table 4** Challenges (part 2)

| |
|---|
| • When the surface of the concrete member has a particularly smooth finish, an improvement is necessary to prevent wheels slipping on the side of piers.<br>• Measurements done using a simple noise meter showed that the maximum sound was approximately 85 dB around the robots (similar to a subway train), which is similar to the sound of an engine generator. The noise level of about 65 dB was measured in the adjacent residential area (about 10 m from the site). To reduce the noise level, the wings or blades of flying robots should be improved.<br>• It is advantageous that the robot with a cable can conduct the inspection for a longer time period as compared to a wireless type robot, but long continuous inspection with a robot is exhausting for the operator, and 30–40 min is the reasonable limit. In the future, development of automatic operation with programming, among others, will be necessary to reduce the burden on the operator.<br>• It must be confirmed whether a stable inspection is possible if the operator cannot enter the area under girder (over the sea or in a deep canyon).<br>• In the present demonstration experiment, the inspected structure did not appear to have any signs of problems, and thus, its performance could not be absolutely confirmed. However, during the detection or screening of areas with abnormalities, its utility should be carefully and closely compared with an inspection conducted by a human worker.<br>• For its practical use, a business model needs to be examined, including rental of equipment, operation, and training. |

As shown, these robots are useful and advantageous, but there are still some challenges that restrict their use in the inspection of various types of bridges (depending on the topographic condition of the bridges). This technology has been tested with bridges over a river by other teams (a team from Gifu University), where an operator could not enter the area under the flying robots; thus, these studies reported that improvements are necessary for the practical applications of this technology.

However, technologists in the Nara Prefecture, who attended the demonstration experiment, stated that “It is a better option for inspecting locations where a scaffold cannot be constructed. By appropriately classifying the locations suited for this technology, for human workers and for other inspection methods, I hope more areas that are difficult to inspect will be inspected in the future.” Therefore, this technology would be superior for inspecting certain locations as long as the conditions are stipulated. Though it may not be applied to practical use immediately, the existing limitations should be solved and improvements should be made so that it can be applied to practical use in the near future. To that end, a significant amount of work is required, but it is difficult to use one technology to inspect all bridges, and it is important to integrate conventional methods with new technologies to optimize the inspection process. We hope to see this strategy realized, along with continuous improvement in the future so that bridges can be inspected efficiently, safely, and reliably.

B-5

# Application of new technologies to damaged reinforced concrete T-beam bridges and cut girder loading tests

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## Cut girder loading tests

Two of the main activity areas of the Nagasaki University team, which is one of the regional implementation teams, are technology information sessions and field demonstration testing. In technology information sessions, explanations on development endeavors are provided by multiple developers to local government officials, inspection personnel, and others. In demonstration testing, the development endeavors of developers who participated in technology information sessions are applied to actual bridges in public tests. The Nagasaki University team holds both types of activity several times per year. Following the removal of a reinforced concrete T-beam bridge (RCT bridge) in Nagasaki Prefecture in December 2017, demonstration tests for inspection and investigation were conducted, and loading tests were performed on two main girders which were cut after removal and used to study the applicability of new technologies.

## Description of bridge

The RCT bridge in question (Fig. 1) is a reinforced concrete T-beam bridge in one direction, and a single span bridge of approximately 8 m consisting of a reinforced concrete (RC) deck slab in the other direction. The RCT bridge is about 60 years old. Its current girders G2 to G6 were built in 1954, and girders G1 and G7 were added five years later in 1959, for a total of seven main girders.

According to the most recent periodic inspection records, the bridge's health index was II, but the main girders showed peeling and rebar exposure with a great deal of leakage and free lime, and peeling and rebar exposure (countermeasure classification C2) and lifting (C1) were especially serious in the outside girders G1 and G7, which were added later (Fig. 2). Outside girders tend to be more affected by rain, and this is a possible factor in the damage, but the concrete in the added girders showed significantly more deterioration than girders G2 to G6, implying that their materials and construction were inferior.

## Verification items

For verification of SIP development technologies, etc. with regard to inspection and diagnosis, a comparison was conducted concerning the extent of damage and diagnostic results of bridges inspected and diagnosed according to the bridge periodic inspection guidelines.

(a) From the side

(b) From under the girder

**Fig. 1** The inspected bridge

(a) G7 (b) G1 (c) G1

**Fig. 2** Damage seen under the main girder

For optical measurement, another SIP development technology, we verified measurement accuracy and the potential for structure identification. The verification items were displacement measurements using a conventional contact type displacement gauge and a sampling moire camera, which is a new technology, and vibration measurements using a conventional contact type accelerometer and a laser Doppler accelerometer, which is a new technology. Another was the possibility of application in CAD drawing of general bridge drawings and automated finite element method (FEM) modeling and analysis based on three-dimensional data obtained through Structure from Motion (SfM) and laser scanning.

## SIP development technologies, etc. used in actual bridge inspection

Here, we will summarize the results of demonstration of a flying robot based inspection system that performs close-up visual inspection and sounding tests (No. 51, R&D led by Hideki WADA of Shin-Nippon Nondestructive Inspection Co.).

In this technology, a sounding test mechanism is mounted on a flying robot; however, the space under the girder was about 1.5 m, large enough to allow manual access. Therefore, this mechanism was removed from the robot and moved by a person while pressing it against the underside of the girder, as shown in Fig. 3. The sounding test mechanism was used to strike the concrete surface, and these hammering sounds were picked up by a microphone for detailed acoustic analysis. Based on the results of analysis, several signals were detected that appeared to show a variation. One example is described below.

In the analytical results shown in Fig. 4, the X-axis shows the position of hammering of lower flange from A2 to A1, and the Y-axis shows frequency. In this graph, point [1] indicates a place where there is a large change in signal strength, and point [2] indicates a place where a strong signal of 1.5 kHz is generated, clearly differing from the frequency distribution of the spectrum up to that time. Figure 5 shows an image from the camera mounted on the mechanism at the place where a spectrum change occurred, as well as an image taken by another camera to show a wider view. Images from the mounted camera and inspection records confirm that there is lifting in the area around point [2], and the possibility of spalling can be inferred. Point [1] is close to a portion where spalling has already occurred and rebar is exposed, and although the images do not confirm lifting, the presence of an internal cavity can be inferred.

Based on this demonstration test and results with a simulated test specimen, it was confirmed that there is a tendency for broad spectrum distribution in sound portions, while portions with cavities show a tendency for a specific frequency to be dominant. Therefore, a new analytical method has been found in which an indicator for determination of soundness is obtained by normalization processing of spectrum distribution, root-mean-square processing, and so on.

Variations such as lifting and spalling are present in portions where changes in the hammering sound spectrum are clearly observed in the results of sounding

**Fig. 3** Conducting inspection

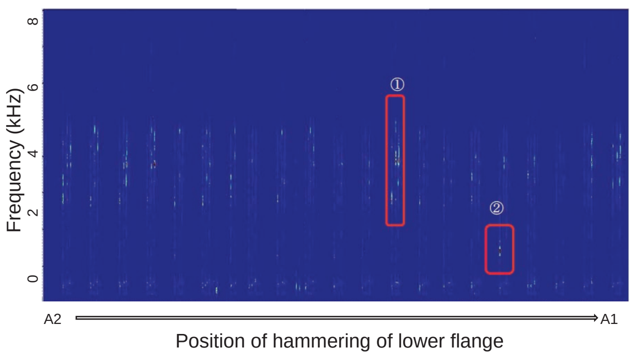
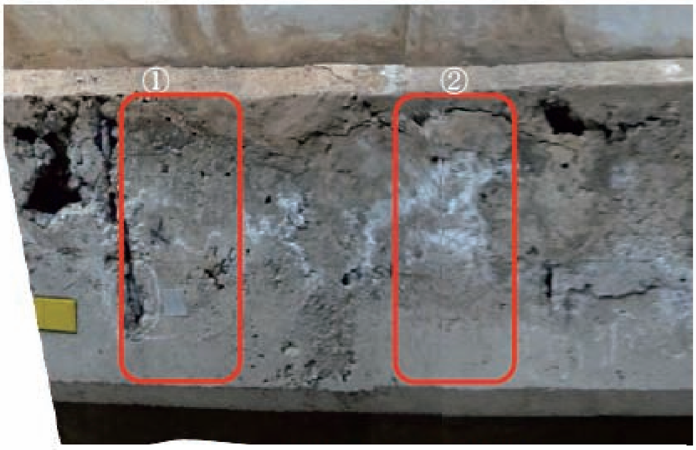


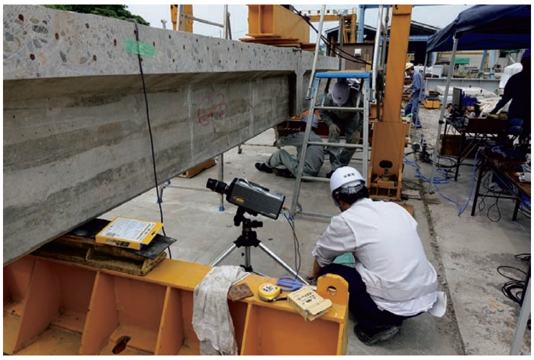

**Fig. 4** Analytical results


(a) Taken by the mounted camera



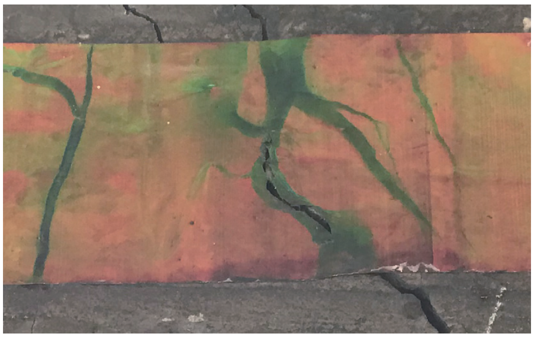

(b) Taken by another camera at a distance

**Fig. 5** Images of areas of lifting



(a) Conducting a loading test

(b) Installation of the measurement device



(c) Color change

**Fig. 6** Loading test of cut girder

test analysis, and this system is considered to provide a means of detecting variations such as lifting and peeling.

## SIP development technologies, etc. used in cut girder loading tests

Here, we will summarize the results of demonstration of a project to construct a research base on the structural materials of infrastructure for structural deterioration mechanism elucidation and efficient maintenance technology (No. 35, R&D by Koichi TSUCHIYA of the National Institute for Materials Science).

Fig. 6 shows a view of loading test implementation, strain visualization sheet installation, occurrence of color changes, and measurement results. There are two types of cut girders: G1, showing significant deterioration, and G3, showing almost no deterioration although it was constructed earlier. The loading test was two-point bending, and strain on the underside of the girder was measured by a strain visualization sheet of the present technology and a strain gauge. Here, the results of demonstration of the strain visualization sheet are summarized below.

As the figure shows, a color change occurs in the strain visualization sheet at locations having wider crack widths. Increasing crack width was associated with larger areas of color change. Although this system was not capable of detecting strain regions of several dozen µm, we determined that it is capable of detection above approximately 100 µm, which is the level of strain that produces cracks in general concrete.

## Having completed demonstration testing

We performed verification with regard to lifting and strain detection. For periodic inspection, the new technology is required to be completely consistent with close-up visual inspection; however, with regard to lifting, we have determined that it may provide results of even greater accuracy than close-up visual inspection in some situations. With regard to strain, we have expectations for future implementation because this technology does not require a power supply and is capable of detecting the maximum strain history experienced in the past.

# Nondestructive high-sensitivity magnetic detection of corrosion in light pole bases

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## Case of light pole collapse in Osaka Prefecture

On February 14, 2016, a light pole collapsed on the Suita elevated bridge on Route 479, a general national highway, in Osaka Prefecture. The reason is believed to be that the base of the light pole, which was embedded in concrete, had been exposed to wet conditions for a long period of time, and the plate thickness of the pole was reduced by macrocell corrosion to the point that it collapsed. In response to this incident, emergency inspections based on visual inspection and plate thickness investigation were performed on the light poles and signposts (approximately 36,000 units) managed by the Osaka Prefectural Government, and those light poles and signposts classified as decision class IV (emergency measures stage) have been removed or renovated.

As shown in Fig. 1, many light poles and signposts are embedded in asphalt or concrete, and because the bases of poles set in asphalt or concrete are susceptible to corrosion below ground level, there is a need for inspection techniques to evaluate corrosion in the underground portions of pole bases.

## Matching with SIP technologies

A nondestructive high-sensitivity magnetic measurement technology under a SIP project of “nondestructive high-sensitivity magnetic inspection for assessment of infrastructure deterioration and maintenance planning” (Prof. Keiji Tsukada, research and development officer, Okayama University) was a matching technology for nondestructive measurement of the amount of corrosion in a steel plate. Matching was performed with regard to corrosion inspection of underground portions of the bases of signposts and light poles using this device. The conventional probes for nondestructive high-sensitivity magnetic measurement is structured so as to contact the structure to be measured in a perpendicular orientation, as shown in Fig. 2(a). However, Tsukada et al.[1)] developed a probe device equipped with two probes set at a downward angle of 30° in order to evaluate corrosion below ground level, and we decided to conduct assessment using this device. (Fig. 2(b)) The two probes are provided to estimate the amount of reduction in plate thickness due to corrosion and the location of such corrosion.

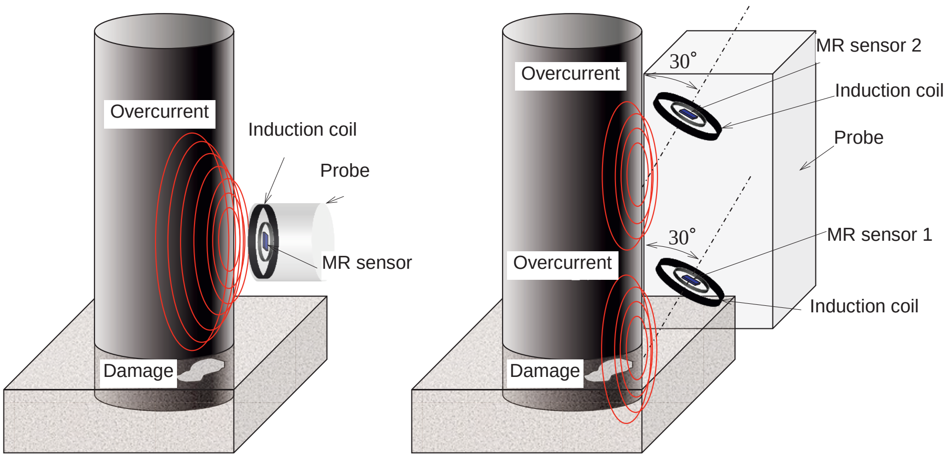
**Fig. 1** Embedded portions of the bases of light poles and signposts

A preliminary survey was performed using the downward-angled probes on an already-removed light pole base that showed pitting, and it was capable of measuring the reduction in plate thickness due to corrosion from a position about 40 mm above the corroded section, as shown in Table 1.

## Survey for corrosion in actual light pole bases

Using the probe developed for use at ground level, we investigated the base of a light pole (decision class II) embedded in asphalt on a sidewalk by Suita City Hall, Osaka Prefecture.

Fig. 3 shows photos and measurement results from this investigation. When performing measurement above ground level with a perpendicular magnetic probe, the reduction in plate thickness was

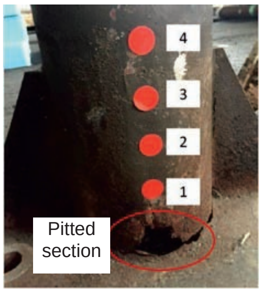



(a) Perpendicular magnetic probe

(b) Magnetic probe developed for ground-contacting portions

**Fig. 2** Magnetic probe for nondestructive high-sensitivity magnetic inspection

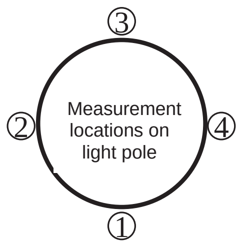
**Table 1** Preliminary evaluation of corrosion in a downward angled direction

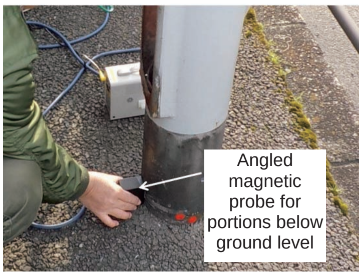



| Measurement location | Perpendicular direction (%) | Downward angled direction (%) |
|---|---|---|
| 4 (standard) | 100 | 100 |
| 3 | 103 | 111 |
| 2 | 99 | 99 |
| 1 | 95 | 40 (60% loss of thickness) |


(a) Vertical magnetic probe

| Measurement location | Plate thickness (mm) | Ratio (%) | Thickness reduction (%) |
|---|---|---|---|
| Undamaged portion | 4.2 | 100 | 0 |
| #1 | 3.5 | 83.3 | 17 |
| #2 | 3.7 | 88.1 | 12 |
| #3 | 3.6 | 85.7 | 14 |
| #4 | 3.3 | 78.6 | 21 |




(b) Angled magnetic probe for underground portions

| Measurement location | Magnetic sensor 1 (ground-contacting portion) | | | Magnetic sensor 2(4 cm above sensor 1) | | |
|---|---|---|---|---|---|---|
| | Plate thickness (mm) | Ratio (%) | Thickness reduction (%) | Plate thickness (mm) | Ratio (%) | Thickness reduction (%) |
| Undamaged portion | 4.2 | 100 | 0 | 4.2 | 100 | 0 |
| #1 | 2.7 | 63.2 | 37 | 3.4 | 79.9 | 20 |
| #2 | 2.8 | 67.2 | 33 | 4.9 | 117.2 | -17 |
| #3 | 3.2 | 76.4 | 24 | 5 | 119.2 | -19 |
| #4 | 3.1 | 73.9 | 26 | 4.5 | 105.8 | -6 |

**Fig. 3** Nondestructive high-sensitivity magnetic inspection of light poles: Photos and measurement results

quantitatively shown to be approximately 10-20%. Furthermore, performing measurement with an angled magnetic probe for portions below ground level, the extent of corrosion was judged to be approximately 20-30%.

Nondestructive high-sensitivity magnetic inspection is capable of performing measurement in just a few seconds per point, and this investigation has demonstrated that it can be used in screening for corrosion in portions of steel members that are embedded in concrete.

[Reference]
1) Tsukada, K., Tomioka, T., Wakabayashi, S., Sakai, K. and Kiwa, T.: Magnetic Detection of Steel Corrosion at a Buried Position Near the Ground Level Using a Magnetic Resistance Sensor, *IEEE Transactions on Magnetics*, pp.1-4, 2018.5

# Observations and thickness measurements to develop repair proposals for low-water bridge collapse: Iwama Ohashi bridge

**Pang-jo CHUN**

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## Iwama Ohashi bridge

This research examines the accidental collapse of the Iwama Ohashi bridge over Shimanto River in Japan. Iwama Ohashi bridge was designed to be underwater during a flood. The low-water bridge can be built cheaply and quickly because it is constructed without raised piers and the bridge can be shorter than that of an elevated design.

Here, we aim to investigate the collapse of one such low-water bridge across the Simanto River: the Iwama Ohashi bridge. Fig. 1 shows the bridge before the incident; it does not have parapets, as is the characteristic of low-water bridges. On November 11, 2017, the steel bridge pier near the center of the Iwama Ohashi bridge buckled, and its central span collapsed, as shown in Fig. 2. Owing to its importance, the bridge must be repaired promptly. In addition to replacing the buckled pier, it must be decided whether countermeasures should be taken on the other piers. Herein, we evaluate the cause of the damage and present a potential repair strategy by measuring the thickness.

**Fig. 1** Iwama Ohashi bridge before collapse

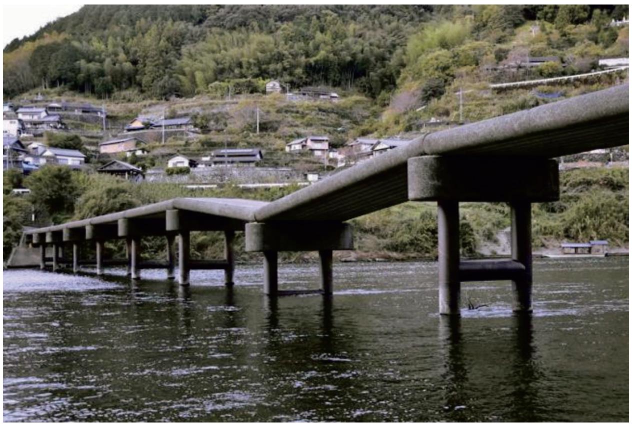


**Fig. 2** Collapse of the Iwama Ohashi bridge at its center

An ultrasonic device is generally used for such measurement. To use this device, the surface of the target material must be smooth. However, the piers of the Iwama Ohashi bridge were corroded with rust. Therefore, surface preparation (i.e., scraping the submerged surface) would be necessary. Unfortunately, this process is highly complex, presents a risk of the corrosion products removed from the surface contaminating the river environment, and can only be done on one side of the target material because it is impossible to access inside the steel piers. Thus, ultrasonic measurements are not suitable for this application.

## Matching between seeds developed in SIP and needs of a local government

As conventional means such as using an ultrasonic device are not suitable to accurately measure the steel thickness in this case, we propose to use technique called extremely low-frequency eddy current testing (ELECT) developed by Prof. Tsukada in Okayama University in SIP project. ELECT can be used to measure plate thickness on the basis of magnetism and can determine the thickness of the undamaged portion buried inside the corroded portion of a material.

ELECT addresses the limitations of the conventional instruments: this approach does not require surface preparation or scraping on both sides of the material as the surface need not be smooth. In addition, magnetism does not require a medium as an ultrasonic wave does; thus, non-contact and underwater measurements are possible. Moreover, the measurement time is short (about 10 s per point), which enables thorough measurements of the target material.

We conducted measurements as in Fig.3 on June 1, 2018, and results are shown in Fig. 4. Pier P6 was more damaged than pier P1, implying that the damage was more severe near the center of the river, where the current was stronger than near the riverside.


**Fig. 3** Measurement performed using the ELECT system

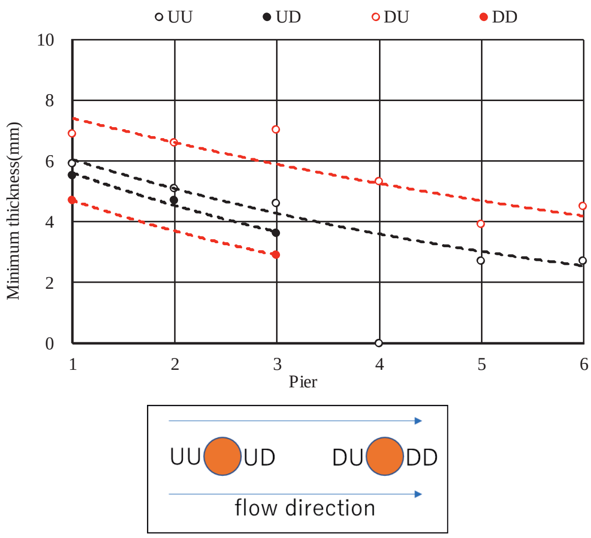
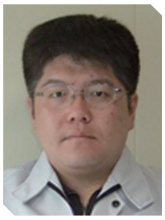



**Fig. 4** Measurement results and naming convention of the piers

## Recommended repair plan

On the basis of the findings, we propose a plan to repair the damage and counter future incidents. In addition to replacing the buckled pier, P7, the other severely damaged piers P4–P6 require reinforcement work. First, create dead-water regions around each pier by placing large sandbags. Next, fill the inside space of each pier with the underwater inseparable mortar to prevent them from buckling. Finally, fix the reinforcing pipes to the outer surfaces of the existing piers by underwater welding. By this approach, the strength of the pier can be restored without spoiling the surrounding scenery, and similar buckling incidents can be prevented in the future.

# Slope monitoring using a wireless sensor network: An example of collaboration between SIP technologies and university-developed technologies



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In slope disaster prevention, there is an increasing need for constant wide-area monitoring of remote locations in outdoor environments, and there are expectations for multi-point monitoring through the installation of multiple terminals, combining measurement sensors and wireless modules. This will require reduced power consumption, independent power supply based on solar energy and the like, and stable wireless communications.

In this paper, with regard to a former stabilization waste disposal site in Sasebo City where mechanical stability has been a concern, we will discuss research and development for a slope failure early warning system based on constant monitoring of multi-point inclination change and soil moisture (Chuo Kaihatsu Corp.), a SIP technology, combined with a monitoring system for groundwater level and soil moisture which is under development by a group led by Nagasaki University.

## SIP technology used in this case

The SIP technology proposed by Chuo Kaihatsu Corp. (research representative: Lin WANG) is a multi-point measurement system that uses inexpensive inclination sensors for efficient and accurate determination of predictive phenomena prior to slope collapse (Fig. 1). The purpose of this technology is to realize inexpensive multi-point measurement using inclination sensors, which can be easily installed at a lower cost, and to develop a stable, highly accurate slope failure early warning system by using multi-point measurement to determine the planar deformation distribution of a slope. The sensor modules installed in the surface of the slope are equipped with a biaxial inclinometer (X-Y), and wireless modules installed above ground are equipped with a triaxial inclinometer, enabling immediate detection of a fall. The former is a module that constantly measures the angle of inclination in a biaxial orientation, while the latter is a module that is only activated for immediate detection when a large change in inclination occurs suddenly. This can be connected with an alarm device to provide early warnings for evacuation. The system was constructed on this slope in June 2017 (Figs. 2, 3) as described below, and monitoring has continued for one year and three months as of September 2018, with no particular problems encountered so far.

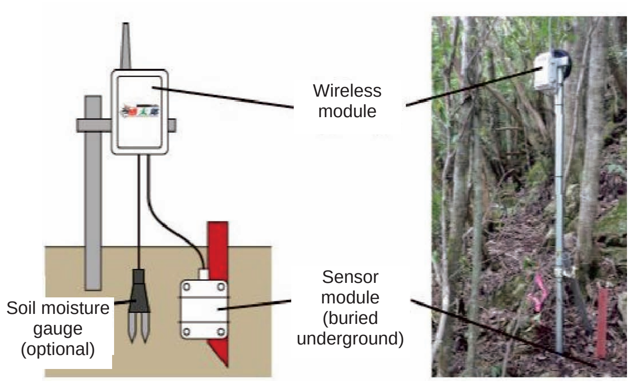


**Fig. 1** System installation diagram

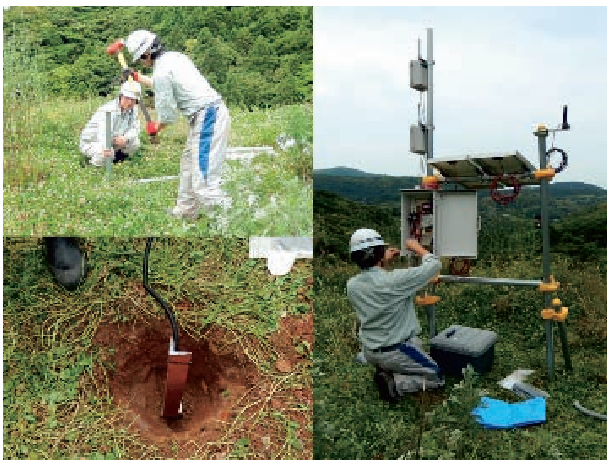

**Fig. 2** Installation at the site

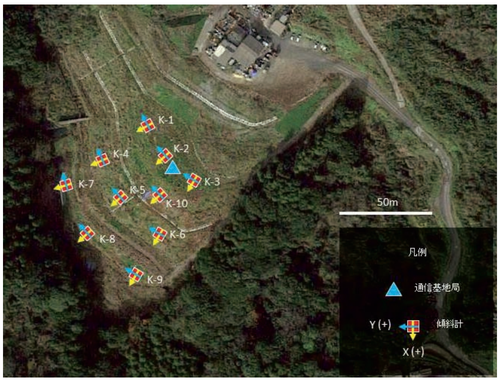


**Fig. 3** Sensor locations and inclinometer orientations

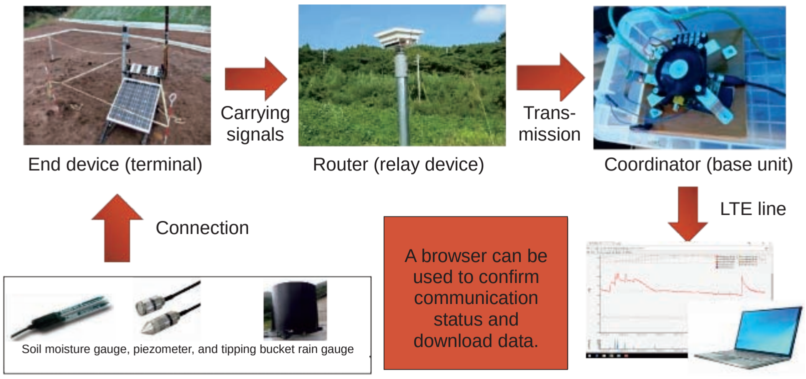


**Fig. 4** Components of the system developed by Nagasaki University

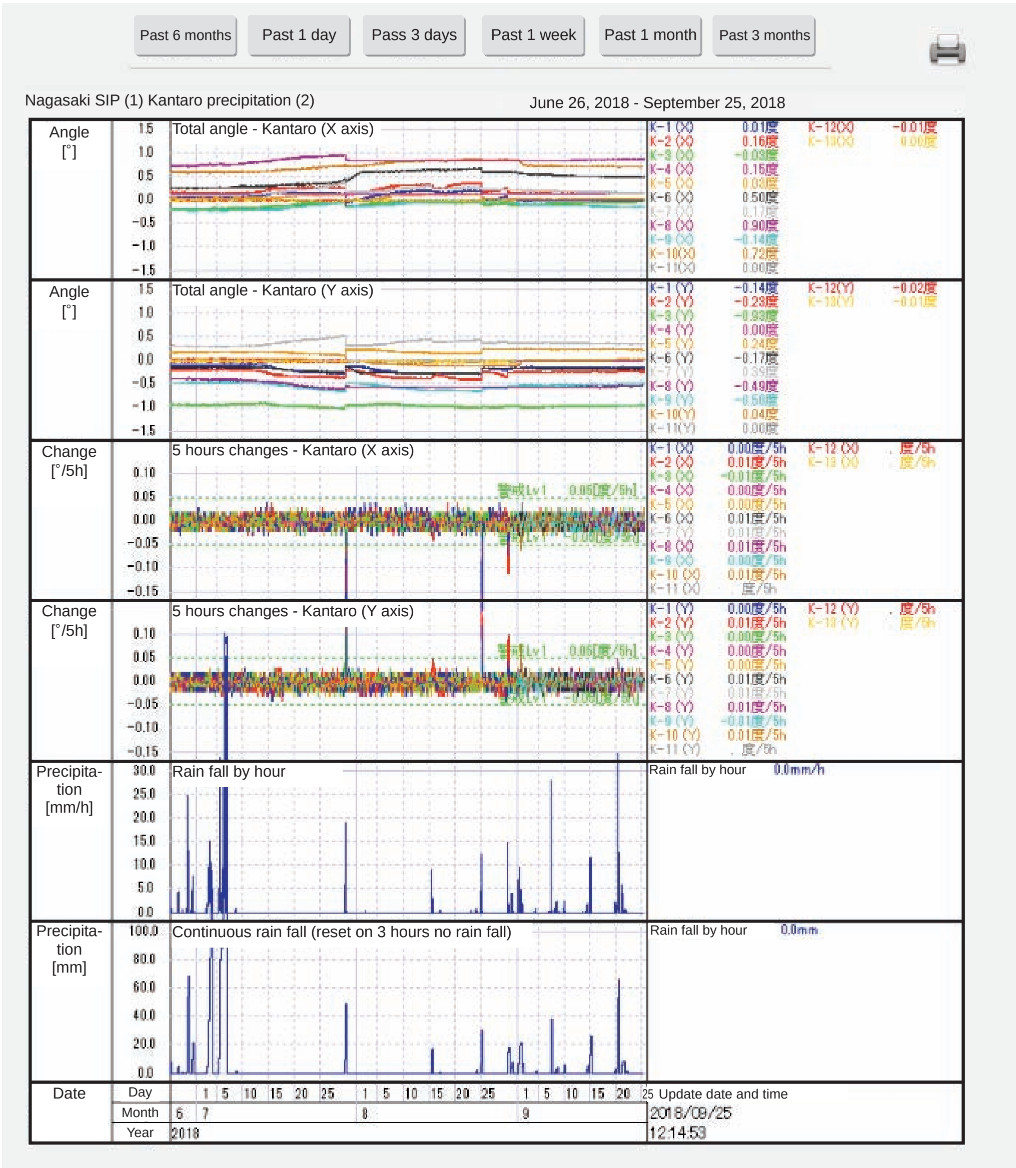


**Fig. 5** Example of data displayed by the automatic remote monitoring system

## Technology developed by Nagasaki University

For about two years, Nagasaki University has been monitoring groundwater levels and changes in soil moisture content on a slope that is a former stabilization waste disposal site. This slope is composed of industrial waste consisting mainly of soil and sand near the surface, with talus deposits and bedrock underneath. The slope was deformed about three years ago due to heavy rains. Therefore, the slope was made more gradual by ground crosscutting, and water permeability was reduced by soil covering; however, there were concerns about further deformation.

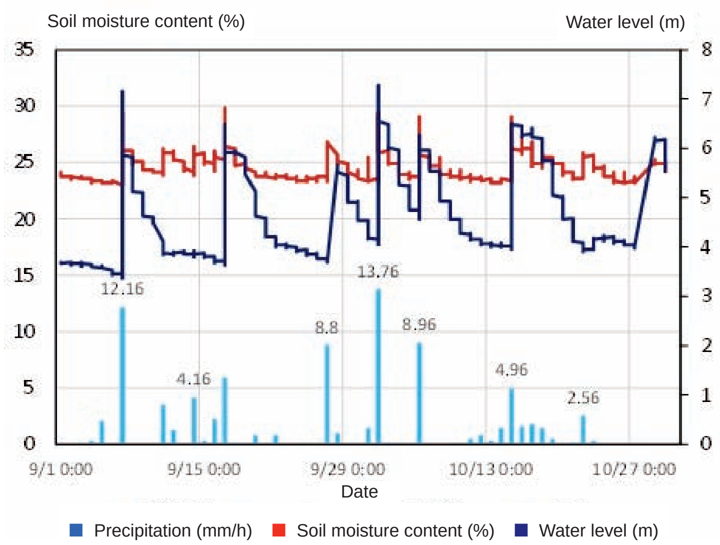


**Fig. 6** Example of rainfall, soil moisture, and groundwater level measurements

The monitoring system developed by the group consists of three devices, as shown in Fig. 4: an end device, router, and coordinator. A soil moisture gauge, piezometer, and tipping bucket rain gauge are connected to the end device, and this system measures changes in the soil moisture content of the slope surface, changes in groundwater level in the monitoring hole, and rainfall at the site. These output values are sent to the coordinator by way of a wireless network via the router. The collected data is stored in the coordinator, and a browser can be used by way of the LTE line to confirm communication status and download the data. This makes it possible to perform remote monitoring and evaluate the mechanical stability of the slope based on the sensing data. Each terminal is connected to a solar panel and rechargeable batteries for autonomous operation.

## Monitoring records

In monitoring by the SIP technology since 2018, slight deformation of the slope surface has been confirmed at the time of rainfall, on the level of about 30 to 50 mm. The monitoring data is stored by a two-way automatic remote monitoring system that was developed separately, and this is always available for online viewing, as shown in Fig. 5. It displays the cumulative inclination angle in a biaxial orientation obtained from acceleration sensors, the angle of inclination per 1 to 5 hours, and the amount of rainfall observed at the site; and warning levels concerning angles of inclination can be determined using three stages of the respective threshold values.

In monitoring using the technology developed by Nagasaki University, data was collected and analyzed from September to October 2017, when total rainfall was relatively high. Fig. 6 shows the relationship between the amount of rainfall and the groundwater level and soil moisture content at the lower part of the slope. The soil moisture content was 23% or 24% in sunny weather, but was found to rise by approximately 5% with rainfall. The groundwater level rose by 3m or more with rainfall of more than 10 mm/h, and similar rises in the groundwater level were observed even with low-intensity rainfall when the rain continued for a long period of time.

Stability evaluation for individual slopes is expected to become more sophisticated in the future, as monitoring data is collected on changes in water levels as a contributing factor to slope inclination, in addition to the physical quantities of ground as a predisposing factor in the modeling of ground for the evaluation of slope stability, with the performance of numerical simulation in which this is incorporated as feedback. We believe that this will also be useful in a SIP technology for the determination of deformation threshold values.

B-9

# Regional implementation of a mobile profilometer for road surface inspection of next generation

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## Demand for Pavement Roughness Inspection

In today's socio-economic situations, as road infrastructures have aged, the demand to implement effective pavement maintenance and rehabilitation rises in consideration of the welfare of road users. Surface roughness is one of the most important indicators associated with the functional performance of a pavement. Smooth paved surface provides positive ride experience for road users travelling on the road.

The Road Bureau of Ministry of Land, Infrastructure, Transport and Tourism (MLIT) issued a pavement inspection guide in 2016. The guide provides the standard procedures for inspection, diagnosis, treatment, and data recording during the service period of a pavement. In the procedure, the International Roughness Index (IRI) has been introduced as the index of surface roughness instead of the traditional index which is a standard deviation of profile elevation obtained with a 3 m-profilometer.

Although a lot of devices measuring the IRI has so far been developed in response to the inspection purposes, these technologies have mainly focused on comparatively major roads such as expressways and national highways. In local governments administering over 90% roads in Japan, the surface inspection has so far relied on visual and/or subjective ride quality evaluation rather than objective measurements.

In particular, since a major transportation of passengers and freight in Hokkaido depends on road traffic with the severe snow and cold climatic environment, development of an easy and efficient method of a surface inspection are strongly required in this region.

Against this background, Kitami Institute of Technology as a part of the Hokkaido regional implementation group which consists of Hokkaido University, Muroran Institute of Technology, and Kitami Institute of Technology introduces a Mobile Profilometer (MPM) to overcome the difficulties of surface inspection on local roads.

This report includes the following contents:
- overview of the MPM,
- summary of hearing surveys regarding pavement management situations for municipalities on Okhotsk area in Hokkaido,
- regional implementation and trial runs of the MPM on local roads, and
- reports of the regional seminar of surface inspection using the MPM.

## Overview of the MPM

The MPM consists of two small accelerometers, which can be simply attached to a suspension system for any passenger and commercial vehicles. Two accelerometers achieves the measurement principle which is faithful to the standard quarter-car (QC) model used for the IRI calculation. It enables us to measure IRI data on a wheel-path by the sensors right above a tire for arbitrary intervals with survey locations measured by a global positioning system (GPS). Fig. 1 shows the overview of the MPM. The following ten features are intended to develop the MPM:
- Collecting IRI faithfully
- Real-time measurement
- Compact component
- At cruising speed
- Unaffected by weather condition
- Simple
- For any vehicles
- Light memory
- Economical
- Mount easily

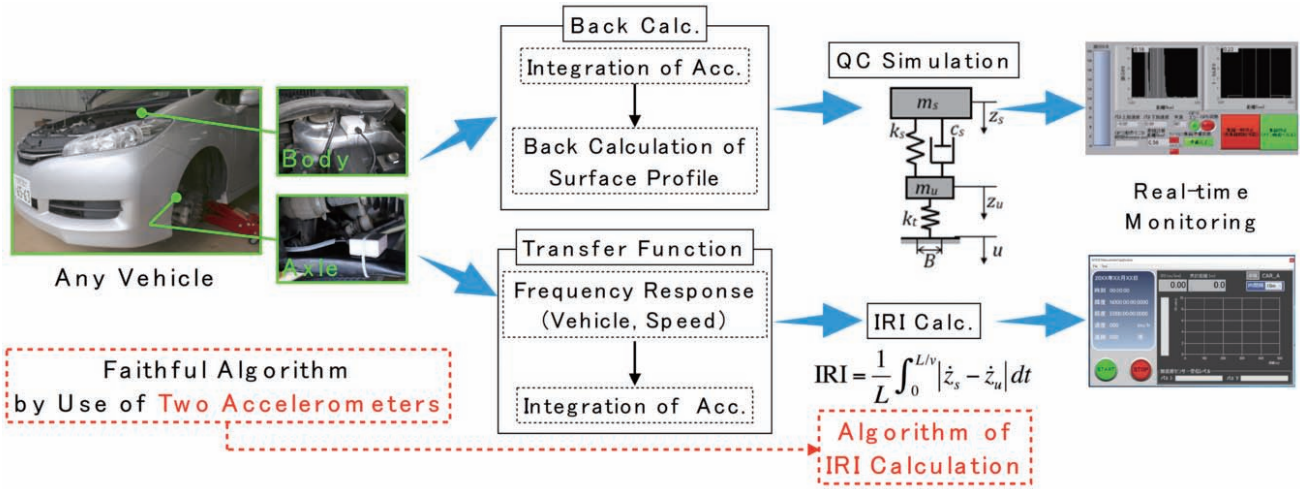

**Fig. 1** Overview of the MPM

**Table 1** Contents for hearing survey

| Content | Aim |
|---|---|
| General issue | Current situation and concerns of pavement management |
| Serious distress type | Serious distress type(s) and the reason from the standpoint of pavement management |
| Inspection activity | Inspection system of pavement surfaces and its operation including road patrol |
| Motive | Plans and issues for managing pavement |

## Hearing Surveys for Municipalities

We conducted hearing survey regarding pavement management situations listed in Table 1 for two municipalities in April, 2017. As a result, high motives toward pavement management were confirmed for both cities from the fact that they frequently inspect their pavements as a part of road patrol. However, the pavement surface evaluation relies on the qualitative visual inspection. A city claimed that “inconsistency of the inspection results due to individuals and the lack of expert engineers have become critical matters for managing pavement”. Under these situations, the both cities desires to measure surface properties easily and economically for the evidence of maintenance and rehabilitation activities. In particular, they regard not only cracks and potholes, but also surface roughness with respect to ride quality and ground vibration as serious distress types. The results of the hearing survey has proved the technical contribution of the MPM for the pavement management of local roads. In contrast, renovation of an administrative framework has potentially been required to introduce new technologies.

## Regional Implementation and Trial Runs

During the project period (FY 2017-2018), surface inspection activities using the MPM were implemented in cooperation with road administrators and a civil engineering consultant as shown in Fig. 2 and Fig. 3.

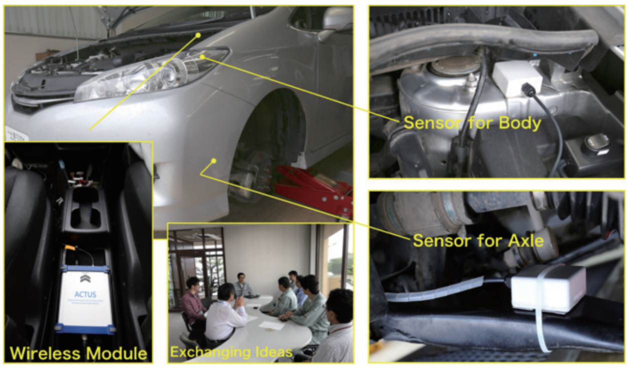

**Fig. 2** Trial in Kitami

**Fig. 3** Trial in Chitose

Fig. 4 shows a visualization example of inspection result aided with GIS (Geographic Information System) in a city. The data indicated were obtained with just one day surveying. The markers are colored in accordance with the diagnostic categories of the pavement inspection guide.

The MPM is available not only on dry surfaces but also on wet and snow-covered surfaces unlike laser-based measurement devices. This functional feature contributes to the local needs for road control such as snow removal operation. Fig. 5 shows an example of the MPM implementation on a snow-covered road.

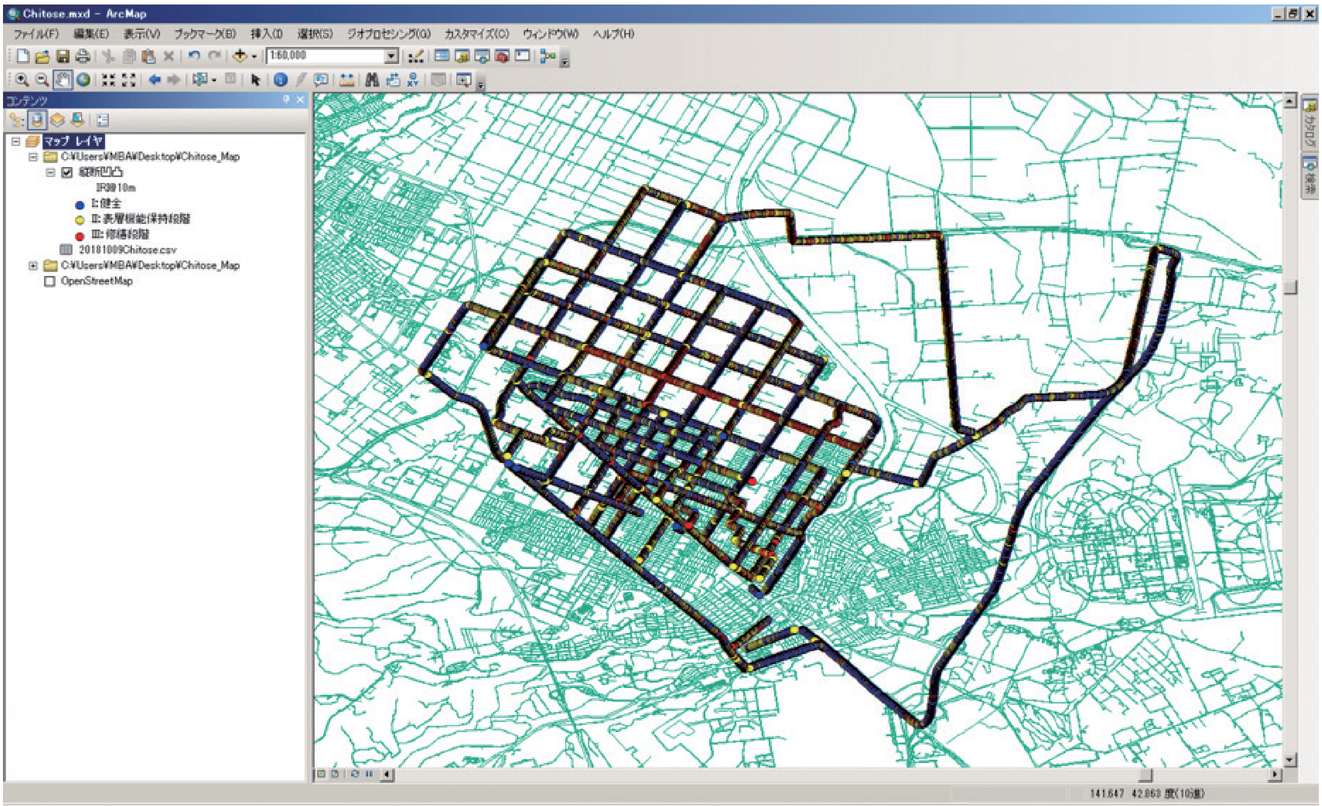


**Fig. 4** Inspection result of GIS

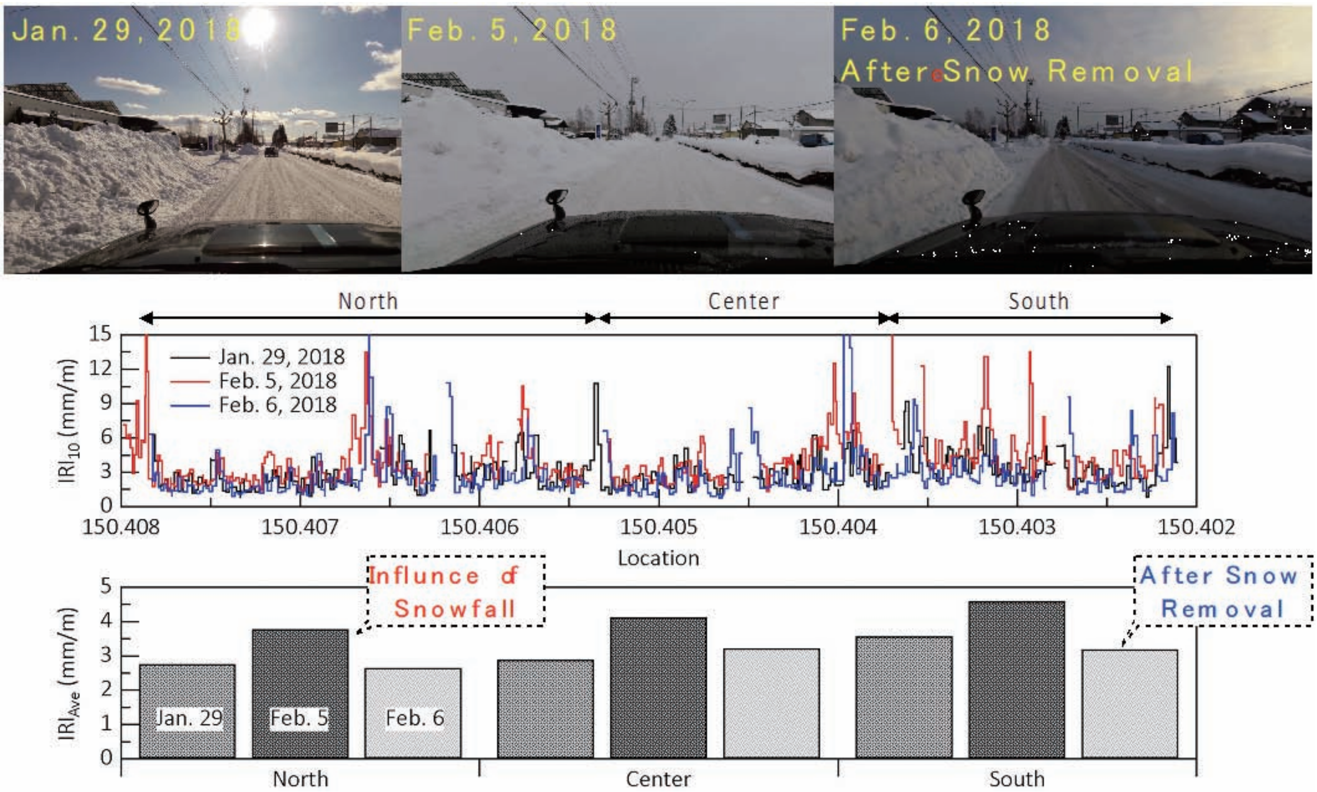


**Fig. 5** Implementation on snow-covered road

(a) Seminar in Kitami

(b) Demonstration in Kitami

(c) Seminar in Chitose

(d) Demonstration in Chitose

**Fig. 6** Regional seminars

## Regional Seminar of Surface Inspection

In order to spread the technical knowledge of reasonable surface inspection, we held regional seminars regarding the MPM technology in Sapporo, Kitami, and Chitose in Hokkaido (Fig. 6). In the seminars, opportunities of the demonstration of MPM and the exchange of ideas were provided as well as lectures about pavement inspection. In the seminars, we had a lot of feedback from the participants as an example as follows:

- There are difficulties on visual inspection for huge amount of road stocks in respect of the limitation of human resources and the judgement consistency.
- The MPM is useful to carry out the accountability of road control on road users.
- The ability to store the data for comprehending the progress of deterioration will be appreciated as an advantage. It would be better if the MPM could distinguish the measured location with lane by lane.
- The seminar was helpful for gathering new measuring technologies.
- The MPM will be effective to collect the surface conditions in daily road patrol.
- Municipalities could easily introduce such a new technologies, if the ministry and/or prefectures would implement ahead.

B-10

# Using CalSok to monitor river embankment slopes: Inspection technology improved by regional implementation support


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## Situation Surrounding Infrastructure Maintenance

In maintenance methods for dealing with aging infrastructure, it is expected that new technologies will be introduced and used, including robots and sensors. In 2014, MLIT, the Ministry of Land, Infrastructure, Transport and Tourism publicly sought applications on technical R&D to promote the use of infrastructure monitoring technologies, calling for development of monitoring techniques in combined processes from measurement to analysis.

A technology for efficient riverbank monitoring was selected in the area of river embankments, one of the fields covered; and in response, a system for area mole hole detection by a large weeding machine (referred to below as “CalSok”) was developed from 2014 to 2016, with funding from the Strategic Innovation Promotion Program (SIP) of the Cabinet Office.

Meanwhile, a regional implementation support team was formed for the sake of regional implementation of the developed technologies, and institutes were selected from eight blocks nationwide to serve as bases.

Aero Asahi, in collaboration with Gifu University, which is one of those bases (Gifu University’s SIP project), and the Kisogawa Joryu River Office of MLIT, has evaluated the effectiveness of CalSok in Ibigawa River for the purpose of implementation in Gifu Prefecture. The results are reported below.

## About CalSok

CalSok, a measuring system that can be easily attached to the back of a large weeding machine, was developed for the purpose of collecting ground data measurements on sloped surface at the same time as weed cutting and collection. The measurement system consists of a power supply unit, data collection unit, laser scanners (two scanners), digital camera, and GNSS/IMU unit. An important feature is its ability to collect high density point cloud data by laser-scanning embankment slopes at very close range immediately after weed cutting and collection. This system is designed to detect a wide variety of deformations, from micro-level deformations such as holes made by moles (or other small animals) and erosion (gullies), to macro-level deformities such as slope convexities and concavities.* Fig. 1 shows a photo of CalSok mounted on the back of a large weeding machine. Table 1 shows sensor performance, and Table 2 shows overall performance.

* Slope convexity and concavity: This refers to slope deformation due to consolidation settlement of an embankment under its own weight or deformation due to high levels of saturation in the embankment. A concave area forms above a bulging area, or convexity.

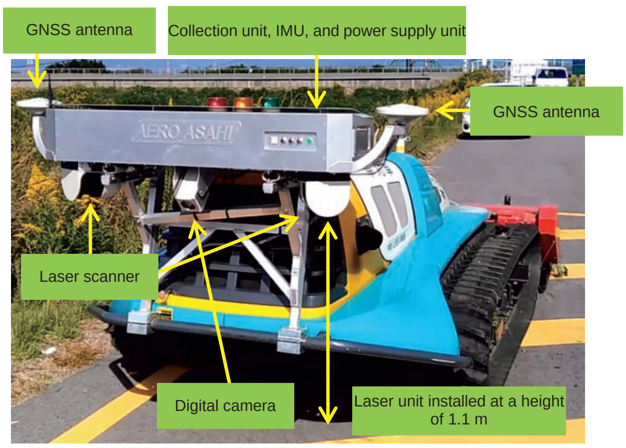


**Fig. 1** CalSok

**Table 1** Sensor Performance

| Sensor | Item | Specifications |
|---|---|---|
| Laser scanners | Number of irradiation points * 2 units | 57,000 points per second total |
| | Measurable distance | 0.7 to 80 m |
| | Irradiation angle | 190° |
| | Reflection intensity data | Can be acquired |
| | Number of units | 2 units |
| Digital camera | Number of pixels | 1.9MP x 1 camera |
| GNSS / IMU | Position accuracy | 2 to 5 cm |
| | Roll and pitch accuracy | 0.025° |
| | Heading accuracy | 0.08° |

**Table 2** Overall Performance

| Item | Specifications |
|---|---|
| Total weight | 45 kg (measurement equipment: 35 kg, mount: 10 kg) |
| Power consumption | 120 W |
| Point density | Approximately 10,000 points per $m^2$ |
| Ortho resolution | 1 mm |
| Position accuracy | Horizontal: 8 cm, Height: 15 cm |
| Data capacity | Approximately 15 GB/hour |

## Past Timeline of CalSok

Table 3 shows the points of the past timeline of CalSok, from R&D to trial utilization and contracting of services.

At Ibigawa River, the area from 43.4 to 43.6 KP (right bank, land side only; referred to below as the "monitored area") was selected for June and November 2017 as an area having a large amount of deformation. Again in October 2018, measurement was performed in the same area as 2017 for the sake of comparison and evaluation at two times; and measurement was performed in a total of two areas for the purpose of evaluating effectiveness at flood warning area (from 42.2 to 42.6 KP, right bank, land side only). The measurement locations are indicated in Fig. 2.

**Table 3** Past timeline

| Fiscal year | Event |
|---|---|
| 2014 - 2016 | R&D (Agagawa River) with funding from SIP of the Cabinet Office |
| 2017 | Trial introduction at two times (June and October) at Ibigawa River in collaboration with SIP regional implementation team |
| | Trial introduction at two times (June and November) at Maruyamagawa River |
| | Service contracted by the National Institute for Land and Infrastructure Management, MLIT |
| 2018 | NETIS registration (July; NETIS No. KT-180041-A) |
| | Trial introduction at Ibigawa River for a second year (October) in collaboration with SIP regional implementation team |
| | Trial introduction at Maruyamagawa River for a second year (June and November) |

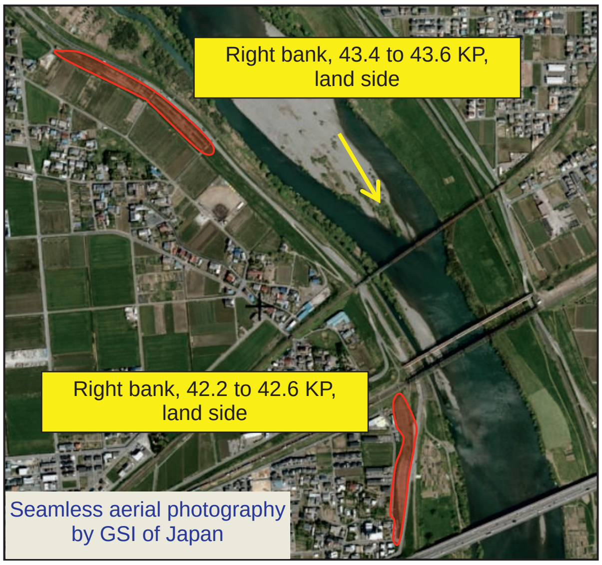


**Fig. 2** Areas measured in trial introduction

## Measurements at Ibigawa River

The first step toward implementation of CalSok was measurement at Ibigawa River in 2017. However, there was unanticipated failure of measuring instruments. Measurement was performed in conjunction with daily weed cutting and collection, unlike the usage environment in the evaluation field; and this failure was clearly caused by effects on the measuring instruments due to vibration in the weeding machine itself, which could not be determined in advance. To solve this problem, measures were implemented to reduce vibration in the frame and the measurement system.

As a result, stable measurement was achieved at Maruyamagawa River in June 2018 as well as Ibigawa River in October 2018, with practically no malfunctions.

In 2018, when measurement was only performed at a time subsequent to water effluence, measurement was performed during weed cutting and collection for the sake of comparison and evaluation of ground data by

**Fig. 3** Measurement during weed cutting

**Fig. 4** Measurement during weed collection

measurements at the time of weed cutting and collection, in addition to the above purpose (Figs. 3 and 4).

During weed cutting, measurement is performed while the just-mowed weed clippings remain on the slope surface (Fig. 3); and during weed collection, measurement is performed while clippings are removed on both sides using a front attachment (Fig. 4). This makes it possible to minimize the effects of weed clippings on measurements.

## Filtering Process

After measurement, data analysis is performed according to the sequence shown in Fig. 5. Specifically, after creating 3-D data from the measurement data, we eliminate the effects of points having much lower elevation than their surroundings and the effects of surrounding vegetation, etc., and the original data is prepared. Next, automatic filtering of the original data is performed at a fixed mesh interval, the effects of weed clippings are minimized, and the ground data is prepared.

The width of measurement data in a single run (referred to below as "cut width") and the mesh interval are important parameters in automatic filtering. With regard to the optimal parameter values at present, we have learned from the results of trial measurement data processing thus far that the effects of weed clippings are best minimized when the cut width is 5 m (the weeding machine passing through a range of approximately 1.85 m) and the mesh interval is 5 cm. Therefore, the data collected after weed cutting and after weed collection were respectively filtered with these parameters.

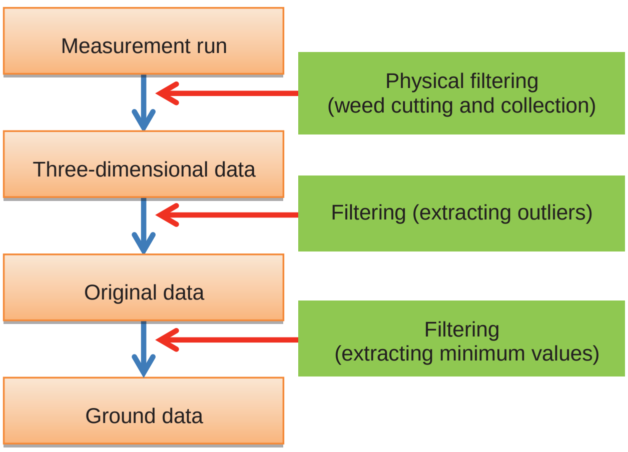


**Fig. 5** Sequence of filtering process

## Comparison with Shaded Relief Map

To compare the data collected after weed cutting and after weed collection, shaded relief maps were prepared to clearly indicate unevenness in the data. Figs. 6 and 7 are shaded relief maps after weed cutting and after weed collection, respectively.

The effects of weed clippings are still present in the measurement data from the time of weed cutting (Fig. 6), but these effects are minimized in the measurement data from the time of weed collection (Fig. 7).

Fig. 8 is a comparison of the cross sectional data prepared along the transverse lines of Figs. 6 and 7. The data after weed cutting clearly shows unevenness due to the weed clippings, and this also affects the final data quality.

Shaded relief map is widely used, and because shading provides an easily understandable visual representation of the results of measurement by CalSok, Shaded relief map is to be included as a standard type of image data.

As an example of the detailed depiction of deformation provided by Shaded relief map, Fig. 9 shows a

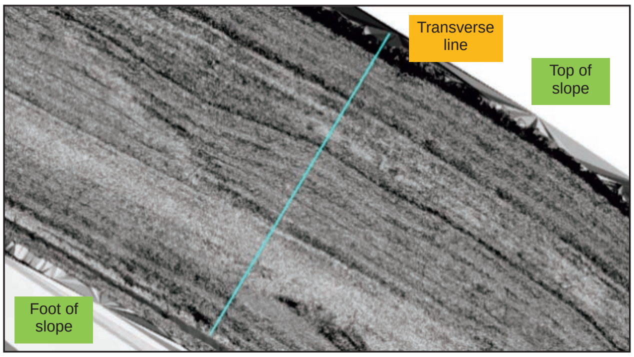


**Fig. 6** Shaded relief map based on measurement data after weed cutting

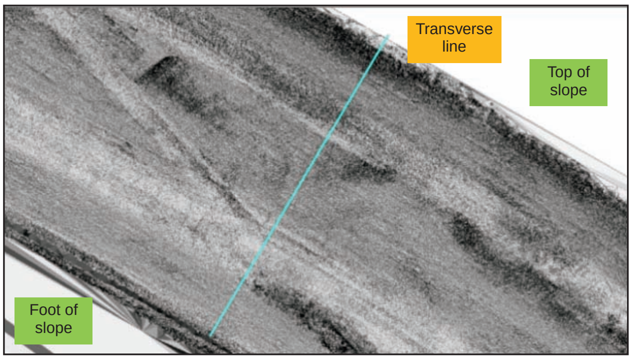


**Fig. 7** Shaded relief map based on measurement data after weed collection

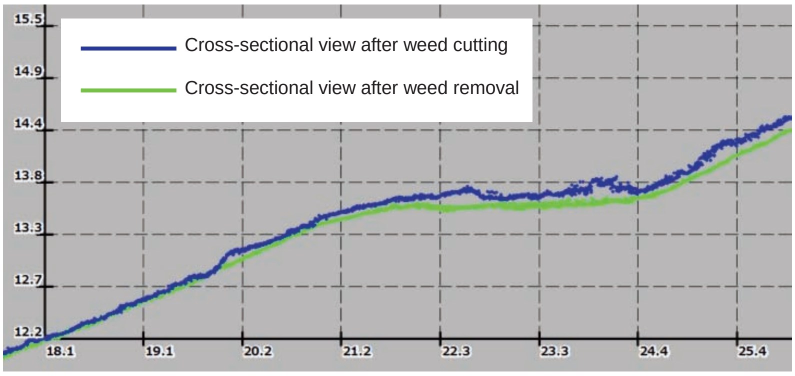


**Fig. 8** Comparison of cross-sectional data after weed cutting and after weed collection

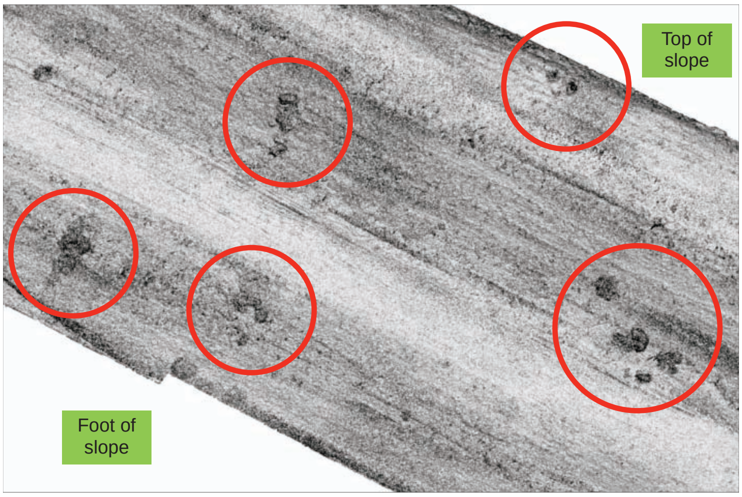


**Fig. 9** Mole hills clearly visualized in a Shaded relief map

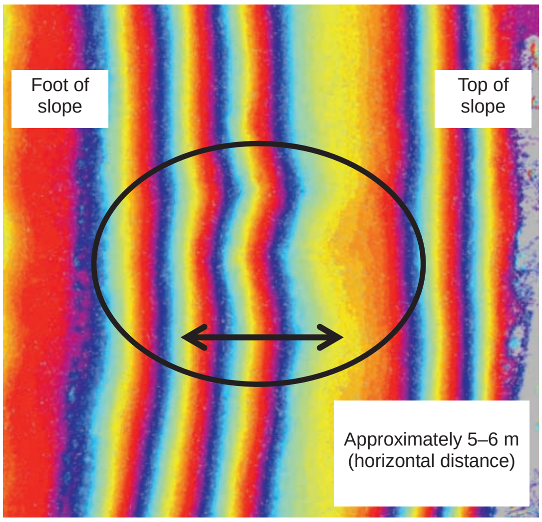


**Fig. 10** Iterative color contour map for determining embankment deformation

Shaded relief map based on the June 2017 measurement data. As Fig. 9 illustrates, the mole hills confirmed during measurement can be clearly observed. Shaded relief map is a suitable type of image data to depict micro-level deformations such as slope erosion (gullies) and holes made by small animals.

## Use of Iterative Color Contour Map to Determine Deformation Locations

Iterative color contour map is another form of representation that can be effectively used to determine the locations of deformation. Fig. 10 is part of an iterative color contour map prepared from data at flood warning area, from measurements taken after weed collection in October 2018.

Fig. 10 shows a deformation that appears to be an area of convexity. Although this kind of deformity may not necessarily need to be recorded in a river chart, it does seem to be necessary to monitor the progress of deformation through periodic measurements in future. This makes it easy to use data to determine macro-level changes (such as convexities and concavities) that are not easily confirmed even by on-site visual observation.

## Future Outlook

We have heard many comments at times such as the public test field testing of CalSok at Ibigawa River where concerning of future directions, including recommendations to conduct measurements at flood warning area, retain the data as an archive, and conduct analyses as needed, especially in view of data that could contribute to future disaster prevention and mitigation. We will continue to promote wide usage of this technology so that it can be used by many people.

[References]
1) River Engineering Education Council: Textbook for river maintenance technical training course (basic), p. 50, June 2018 [in Japanese]

# Regions

C-1

# Problems and needs of municipality for maintenance of road bridges in four prefectures in Hokuriku region


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## Procedure of Investigation

Table 1 lists the results of an investigation of the municipalities visited thus far, while Table 2 lists the contents of the interview. Issues concerning the maintenance of road bridges were recorded for 32 cities and towns in four prefectures (Niigata, Toyama, Ishikawa, and Fukui) in Hokuriku. In this study, the inspection situation and repair were considered based on a "life-extending plan for road bridge". Here, the plan is that each manager relies on all road bridges in a bid to attempt a systematic repair. Moreover, since FY2014, a visual and feel inspection of all road bridges with a length of 2 m or greater has been made mandatory every five years.

The procedure of the interview is explained as follows. First, authors sent a letter and E-mail to the person-in-charge of the Control Division of each municipality, and an appointment for a meeting was scheduled. Then, several faculties of the university and technical colleges visited the municipality. The outline of this activity was explained, and the first interview was conducted for 1 h 30 min. The questions asked during the interview are listed in Table 3. After an interview at a public office building, the bridge abutment that held uncertainty due to the effect of repairing the Alkali Silica Reaction (ASR) was partly discussed in the field. Moreover, the rope access was inspected on a separate day.

In the second visit, discussions were held on the problems from each municipality. In addition, discussions were held on the system that the specialists used to support the municipality and the standard maintenance procedure draft (inspection, judgement, repair, and update) during the third visit.

## Arrangement of problems and countermeasure plans

The results of the investigation revealed a number of overlapping problems, regardless of the municipality. Moreover, to solve the problems, we designed a suitable system and procedure for the rationalization of the inspection and repair. Table 4 lists the consolidated results. Herein, preventive maintenance implies an action after which the deterioration rate decreased before it can be visually confirmed.

Herein, the general order for an inspection is shown in Figure 1. A way to improve this system was noted through the interview. For instance, the consignment of the inspection to the consultant was controlled to reduce spending and the municipality staff was inspected by oneself without using the scaffold. There was a case where the staff who had been moved to another section through job rotation assisted too. To improve upon this, we proposed using a tablet developed by Prof Ibayashi of the National Institute of Technology, Nagaoka College, who is one of our team members, to conduct the inspection. Figure 2 shows the inspection undertaken using the tablet. Such an inspection form utilized not only in Japan but also in Cambodia and Kirgiz (http://www.globalnewsasia.com/article.php?id=4897&country= 6&p=2; https://www.facebook.com/jicap r/posts/1420460767990066). The municipality staff noted the following merits of using the tablet. (1) As the inspection can be conducted in the field while comparing the results with those obtained previously, this decreased uncertainty. (2) As the inspection results could be easily converted to a report by connecting the tablet to a PC in the public office, the time taken to achieve the same task if done in the office reduced. In addition, during the demonstration, we installed at some municipalities.

**Table 1** Results of the interview (classified as per municipality)

| Prefecture | Municipality | Population | Area ($km^2$) | Number of bridges |
|---|---|---|---|---|
| Niigata | Jyoetsu city | 193,939 | 973.8 | 1,146 |
| | Itoigawa city | 43,897 | 746.2 | 525 |
| Toyama | Toyama city | 417,760 | 1,241.7 | 2,222 |
| | Himi city | 48,671 | 230.6 | 360 |
| | Asahi town | 11,936 | 227.4 | 122 |
| | Takaoka city | 172,535 | 209.6 | 1,200 |
| | Imizu city | 93,289 | 109.4 | 492 |
| | Oyabe city | 30,162 | 134.1 | 449 |
| | Nanto city | 51,171 | 668.6 | 923 |
| | Nyuzen town | 24,894 | 71.6 | 450 |
| Ishikawa | Kanazawa city | 466,183 | 468.6 | 1,388 |
| | Kahoku city | 34,293 | 64.4 | 90 |
| | Wajima city | 26,312 | 426.3 | 446 |
| | Nomi city | 48,934 | 84.1 | 252 |
| | Hakusan city | 109,581 | 754.9 | 369 |
| | Uchinada town | 26,943 | 20.3 | 7 |
| | Houdatsushimizu town | 12,805 | 111.5 | 132 |
| | Nonoichi city | 55,297 | 13.5 | 220 |
| | Komatsu city | 106,905 | 371.0 | 473 |
| | Tsubata town | 37,618 | 110.6 | 174 |
| | Suzu city | 14,573 | 246.9 | 171 |
| | Kaga city | 67,357 | 305.9 | 356 |
| | Nakanoto town | 18,102 | 89.5 | 257 |
| Fukui | Fukui city | 264,344 | 536.4 | 1,771 |
| | Echizen town | 21,021 | 153.2 | 225 |
| | Sabae city | 68,397 | 84.6 | 399 |
| | Obama city | 29,534 | 233.1 | 402 |
| | Katsuyama city | 23,392 | 253.9 | 349 |
| | Tsuruga city | 66,060 | 251.4 | 307 |
| | Ikeda town | 2,604 | 194.7 | 99 |
| | Mihama town | 9,609 | 152.4 | 130 |
| | Echizen city | 83,184 | 230.7 | 675 |

**Table 2** Contents of interview investigation

| | Content |
|---|---|
| 1st | Explanation of activity aim and interview regarding problems at each municipality |
| 2nd | Inquiry about the result of arranging problems at each municipality |
| 3rd | Proposal of standard procedure and system to maintain road bridges for affected municipalities in Hokuriku region |

**Table 3** Questions in the first interview

| No | Question |
|---|---|
| 1 | Feature and problems of inspection and judgment for bridge by municipality staff |
| 2 | Feature and problems of inspection and judgment for bridge by consultant (for example, difference etc.) |
| 3 | Influence on finance of visual and feel inspection every five years |
| 4 | About visual and feel inspection at second cycle for monitoring the health of bridges whose length is less than 5 m and traffic is little |
| 5 | Feature and problem concerning repair |
| 6 | Is “life-extending plan for road bridge” effectively promoted and improved if necessary? |
| 7 | For shift from corrective maintenance to preventive maintenance (When do you think shifts? What is problem?) |
| 8 | Worry about maintenance for road bridge in the future |

**Table 4** Municipality problems and proposed countermeasures

| Reason | No. | Problem (Needs) | Countermeasure plan |
|---|---|---|---|
| Support system | [1] | Technical findings cannot be obtained easily. | A center that can confer is established. |
| | [2] | Contributing feedback to the rationalization of maintenance is inexpensive, though the registry fee required to update the road bridge database by a prefecture is high. | An effective database is designed and operated. |
| Plan | [3] | When the repair plan to prolong bridge life is revised, the model is not find. | Ideas are introduced. |
| | [4] | Asset management is optimized based on the life cycle cost, including the cost of renewal. | |
| | [5] | It is not possible to plan though the shift to preventive maintenance is hoped. | |
| | [6] | The necessity of preventive maintenance could not be understood because bridges are safe even though no countermeasures were taken until now. | A fact embarrassed due to the early deterioration in the adjoining municipality is explained. |
| Inspection | [7] | The inspection process was similar for all bridges. | Factors such as importance and type of bridge change the inspection process. The inspection of a short bridge is made simple. |
| Repair | [8] | As it is necessary to keep the inspection cost, the budget for the repair does not have to be executed. | When it is judged that repair is necessary as a result of the inspection, a simple repair method is designed and executed simultaneously. |
| | [9] | Appropriate repairing methods are not understood. | An effective repair method corresponding to the management level is introduced. |

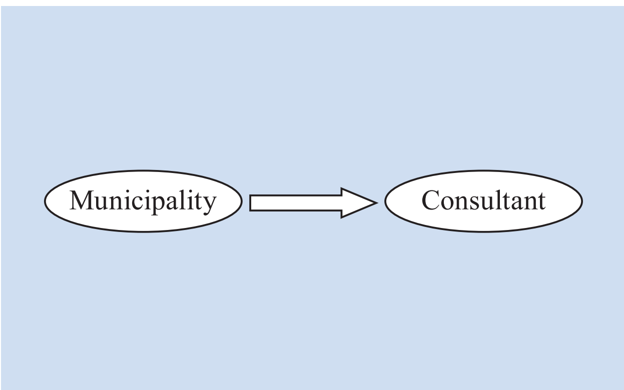


**Fig. 1** System of general order for inspection

**Fig. 2** Inspection using tablet

# Visualization of needs of a local community and interaction of engineers with local needs

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## Interaction between local needs and technology

This paper intends to clarify the way infrastructural engineers should interact with the problems of a local community and local infrastructure.

Infrastructure is constructed for the sake of the local community. From this perspective, it is necessary to appropriately ascertain and meet the local needs. Figure 1 shows a conceptual drawing of the process of analyzing local needs into technology. It is convenient to conceive three levels of needs and two phases connecting these needs.

At the level of ascertaining what the community desires (the needs of the community), the wish of a community is generally characterized by its vagueness. Even when asked, they usually cannot express their needs in concrete terms. At the very least it is comprehended as their needs that they want engineers to provide comfortable and useful social infrastructure.

The level of the needs for the right infrastructure to be built is a level to express the vague wish of the community, such as safety/security and comfort, in the form of performance requirements for the infrastructure.

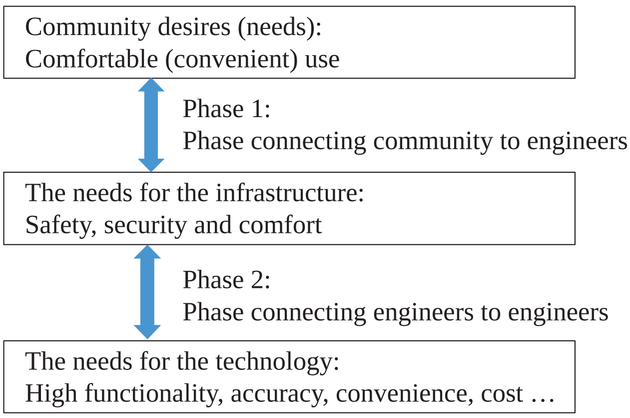


**Fig. 1** Phases connecting community needs to technology

The level of the needs for the right technology to be used is a level where the above-mentioned needs are analyzed to select infrastructural technology, dealing with specific techniques and systems.

## Human resources to connect the needs of each level and proneness to self-satisfied technology

What is important in this process is that technical development that is satisfactory for both the community and civil engineers involved is possible when all these needs are organically connected, instead of being isolated from one another.

Figure 2 shows a case where the community wants a number of overpasses while the desired number is questioned from the aspect of the right infrastructure, causing conflict. This is an example in which the needs of the community are not connected well with the infrastructure.

Communication between the community and engineers is essential when matching the needs of the community and the needs for the infrastructure. As stated above, however, the community can only express their needs vaguely. For this reason, the needs of the community are generally embodied by engineers (the owner, supervisor, etc.).

Communication between engineers concerned is essential in Phase 2, where the needs for the right infrastructure are connected with the needs for the right technology. At this phase, the performance requirements of the structures are considered, and the way technology should be to meet the requirements is presented. Engineers may often consider technology within the limitations of their thinking, without

**Fig. 2** Example of a number of overpasses built on community needs

providing the exactly required technical development. In other words, technical development is prone to be based on the engineers' self-satisfaction.

Back when new construction prevailed, the technology to build structures was materialized in the form of structures in most cases. It was therefore easy for users to realize the benefit of technology, encouraging technical development. However, in the current environment where maintenance prevails over new construction, users are less likely to directly receive (recognize) the benefit of new technology. This may have led to the current tendency toward technical development in the infrastructural field often seen to be based on engineers' self-satisfaction.

With devastating natural disasters occurring in recent years, aerial photography using drones to ascertain the state of damage has been spreading at a remarkable pace. This is a result of technology being connected to the desire of the community to know the current state. Drainage pavement is another example of accelerated dissemination due to the fact that users can directly experience the effect of new technology.

## Importance of human resource development of engineers

Accordingly, technical development useful for the world can be achieved by appropriately connecting the desire of a community, the right infrastructure to be built, and the right technology to be used. In view of the fact that it is engineers who make this connection as stated above, it is understood that fostering the growth of engineers is crucial. Not only professional skills in a specific field but also knowledge of surrounding fields and communication skills are particularly required. The Maintenance Expert (ME) Training Courses of Gifu University are therefore considered to play a significant role in this regard.

# Developing an integrated bridge maintenance database through collaboration among industry, academia, and government, with support for introduction by local governments

**Makoto HISADA**

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## Background of database introduction

After the Sasago Tunnel collapse of December 2012, aging infrastructure has been recognized as an urgent challenge. Local governments have an enormous stock of infrastructure to manage, and inevitably, they have been fallen behind with the necessary measures.

Taking the example of Yamagata Prefecture, about 8,200 bridges are managed by local public organizations, namely the prefectural government and 35 municipalities in Yamagata Prefecture. The prefectural government and these 35 municipalities have already recorded 10,000 instances of bridge inspection data, and this data is expected to continue to increase by about 1,600 instances per year. Although this past management data is in electronic form, it is not uniform due to differences in the file formats, levels of resolution, and other aspects. No information platform had been established to enable the effective use of this data for purposes such as lifespan prediction and repair decisions, and there was no system in place to utilize existing data for more efficient infrastructure maintenance.

Faced with the need to respond to frequent natural disasters in various locations in recent years, local governments have had a tendency to postpone countermeasures for existing infrastructure, and at present, local governments face many challenges in terms of time, funding, staffing, and technical capabilities.

## Involvement of Tohoku University

In December 2013, Tohoku University signed an agreement on cooperation regarding infrastructure maintenance with the Tohoku Regional Development Bureau of the Ministry of Land, Infrastructure, Transport and Tourism, as a way to support local governments facing various challenges related to infrastructure maintenance. Based on that agreement, the university established the Center for Infrastructure Management Research (referred to below as “Tohoku University IMC”) in January 2014, and has been engaged in technical support in infrastructure maintenance for local governments, human resource development for infrastructure maintenance, and research on subjects such as elucidating the mechanisms of deterioration.

Tohoku University IMC has also concluded cooperative agreements with NEXCO EAST, the Yamagata Prefecture Land Development Department, the Miyagi Prefecture Construction Center, the city of Sendai, and other local government organizations, and is strengthening and advancing activities related to infrastructure maintenance in the region.

## Infrastructure maintenance database system for local governments

Tohoku University IMC used the results of a SIP project on technical development for processing, storage, analysis, and application of various types of data for advanced infrastructure management (representative: Isao UEDA, NEXCO EAST), and customized this to the specifications of Yamagata Prefecture, along with the Yamagata Prefecture Land Development Department and the Yamagata Construction Engineering Center, as a collaborative project involving industry, academia, and government for the construction, introduction, and operation of a bridge maintenance database system (Fig. 1). This has resulted in the development of a database for maintenance cycle information and unified management of inspection, assessment, and repair records for road bridges of Yamagata Prefecture and 35 municipalities in the prefecture. The introduction of this database has made it possible to improve the efficiency of evaluation and assessment concerning aging countermeasures that will be needed in the future, and to optimize the planning of repairs and budgeting. This has become an

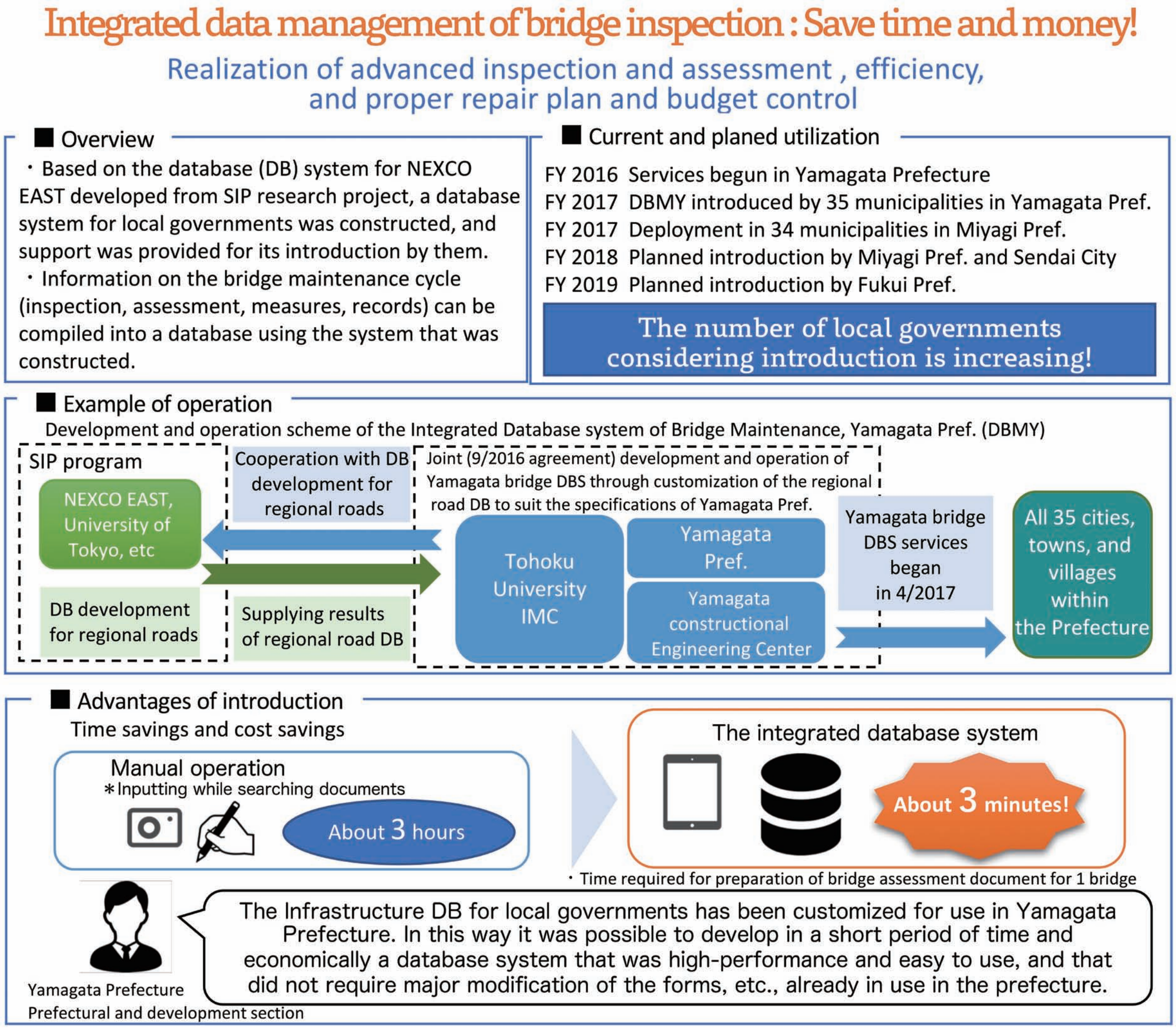


**Fig. 1** Integrated database system of bridge maintenance

effective database system for local governments which are responsible for management of many bridges.

## Development of infrastructure maintenance database system for local governments

The database system in Yamagata Prefecture was taken as a model case, using knowledge concerning the information platform database and operation methods in order to introduce and begin database operation in the Miyagi Prefecture Construction Center, and also to introduce the database in Sendai City. Database deployment has also begun in regions outside the Tohoku region (Fig. 1). We hope to continue the development and operation of applications that are suited to the situations of local governments to meet high levels of local needs.

## Comments from participating organizations

### Yamagata Prefecture Land Development Department

● Development objectives of DBMY

A repair plan to extend the lifespan of bridges in Yamagata Prefecture was developed in FY 2007, and the prefecture is promoting countermeasures for aging bridges based on preventive maintenance. In the promotion of countermeasures, it is particularly important to carefully compile maintenance cycle data, including challenges and results in past cases of damage and repair, to ensure greater accuracy and lower costs in future measures. Meanwhile, municipalities in Yamagata Prefecture are responsible for the management of enormous numbers of bridges, although they face more challenging circumstances than the prefectural government in terms of inadequate budgets, lack of personnel, and lack of technical staff. Therefore, some kind of support seemed necessary in order to establish an appropriate bridge maintenance system. The Integrated Database System of Bridge Maintenance, Yamagata Prefecture (abbreviated as Database of Bridge Maintenance of Yamagata, DBMY) was developed jointly with Tohoku University IMC and the Yamagata Construction Engineering Center (YCC), and operation of DBMY commenced in FY 2016.

● Functions and benefits of DBMY

DBMY displays the specifications of bridges such as bridge type, bridge length, and design standards, along with maintenance data such as inspection, assessment, and repair records, and links this

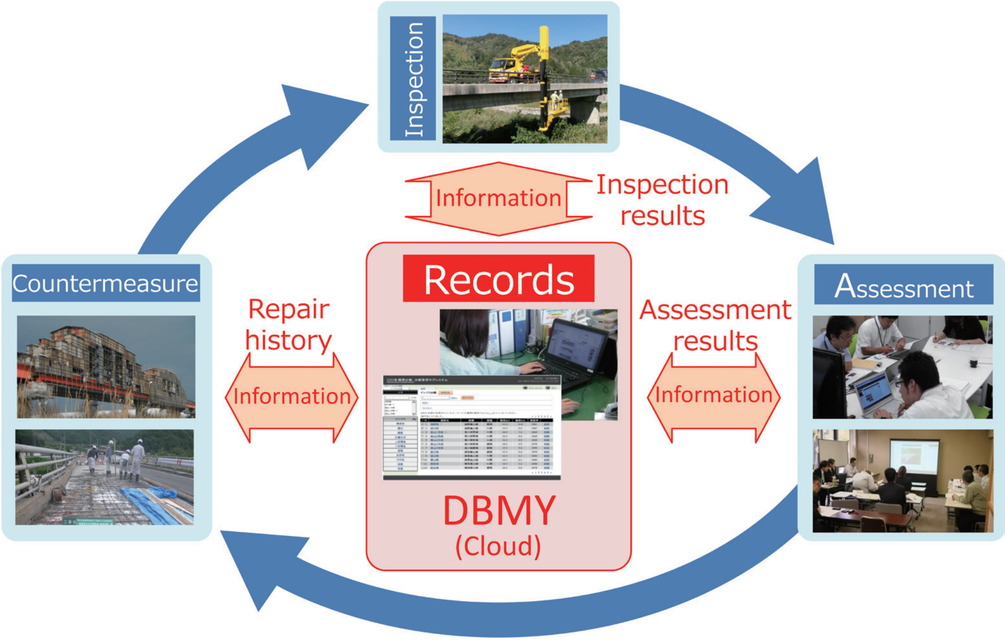


**Fig. 2** Maintenance cycle

information to each individual bridge (Fig. 2). It may be possible to discover characteristics and trends in damage to bridges in Yamagata Prefecture by using functions of the database system to search, extract, and compile this data according to the types and grades of damage along with various conditions that are thought to be factors in damage. Furthermore, by reviewing and compiling data such as the situation of past repairs and subsequent deterioration for each instance of damage addressed so far, it should be possible to create an environment whereby bridge maintenance can be made more effective and efficient, in line with actual conditions in Yamagata Prefecture. In the future, when integrated database operation records are in place for areas with cold, snowy winters where roads are sprayed with anti-icing brine, such as the Tohoku and Hokuriku regions, it will be possible to propose rational, unified bridge maintenance systems by linking with other areas that share the same deterioration problems.

● Joint research with the university

Yamagata Prefecture is conducting joint research with Tohoku University IMC in FY 2018 (Fig. 3). We are receiving guidance on matters such as using DBMY to review damage trends, while providing information on matters such as ICT technologies, AI, and instances of advanced practices in road maintenance.

● Future steps

DBMY is not only a system to manage information assets. It combines previously disconnected information for unified management, and connects Tohoku University IMC, the prefectural government, YCC, and municipalities with each other through data sharing. The municipalities took a serious look at the future of infrastructure maintenance, and all 35 municipalities decided to participate in DBMY, with not even one municipality rejecting the proposal put forward by the prefectural government. Our hope is that the combined strengths of industry, academia, and government will provide a strong driving force for infrastructure maintenance in Yamagata Prefecture through the use of DBMY.

**Fig. 3** Research meeting between Yamagata Prefecture and Tohoku University IMC

## Miyagi Prefecture Construction Center

● Joint research with the university

The population is declining in Miyagi Prefecture, while infrastructure built during the period of rapid economic growth is deteriorating due to age. The population in the coastal region has declined especially sharply due to the effects of the 2011 Tohoku earthquake and tsunami. Many problems must be addressed, including the need to obtain personnel and funding under difficult financial conditions. The following is a summary of the results of a study to

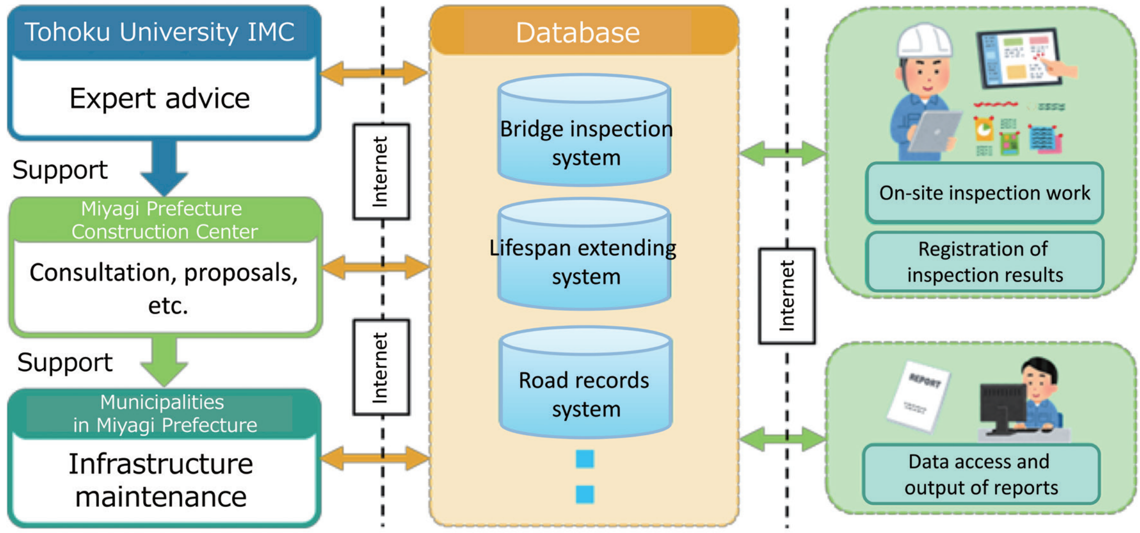


**Fig. 4** Conceptual diagram of inspection system operation by the Miyagi Prefecture Construction Center

improve the efficiency of infrastructure maintenance using information technology, which was conducted along with Tohoku University IMC with the goal of achieving greater efficiency in the infrastructure maintenance cycle, in view of this situation.

● Use of information technology

The Miyagi Prefecture Construction Center has contracted to perform bridge inspection work as a part of infrastructure maintenance. Previously in bridge inspection, the results were recorded on paper at the site and later typed into an internal database, but this was time-consuming and introduced typographical errors.

Therefore, we constructed a bridge maintenance database based on intellectual property of SIP (referred to below as the “bridge MD”) and developed a new system in which data is entered into tablet terminals at the site (Fig. 4). This system allows users to capture photographs at the same angle while referring to previous inspection photographs on the screen, making it easier to determine changes over time and damage conditions (Fig. 5). Information is transferred immediately from the tablet terminals, making it possible to study the level of deterioration from a remote location and provide advice while looking at the same screen. This is expected to increase the efficiency of work and lead to improved results. It is also expected to produce benefits such as cost savings because even inexperienced staff members can easily perform inspections with shorter working time.

**Fig. 5** Bridge inspection using a tablet terminal

● Utilization in Miyagi Prefecture

The system will be used for bridge inspection work performed by the Miyagi Prefecture Construction Center, and it will also be used as a basis for incorporating new technologies and expert advice, etc. from Tohoku University IMC in the future.

[References]
Tohoku University IMC: http://imc-tohoku.org/

# Developing asset management systems to suit local government needs


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## Obstacles to development of asset management systems

Today, the importance of infrastructure maintenance is understood by all of the different types of engineers who are involved in civil engineering. Every engineer who is responsible for infrastructure management surely desires to leave infrastructure in a healthy condition for the next generation.

However, in actual practice, maintenance tends to fall short of the ideals of engineers because of obstacles such as insufficient funds, lack of technology or information, and inadequate implementation systems. Some local governments and infrastructure administrators have succeeded in developing maintenance implementation systems by analyzing the problems and taking appropriate measures. Unfortunately, these kinds of success stories are not directly transferable to the situations of infrastructure maintenance in other local governments. The optimal strategy will vary according to the circumstances of each local government because a variety of factors are involved in infrastructure maintenance, including the types and quantities of infrastructure, the usage environment, the technical level of management engineers, the structures of organizations that implement maintenance, the availability of funding, and issues of responsibility.

In subprocess 3 of the SIP program of the University of Tokyo, a comprehensive study aimed at road infrastructure management cycle development and deployment in Japan and overseas, we are analyzing the root causes of maintenance problems faced by municipalities, proposing solutions to those problems, and endeavoring to support the construction of systems for the implementation of maintenance work (here, this is called development of asset management systems). We will describe the content of this study in this paper.

## Model project implementation and nationwide deployment

In this program, we have publicly recruited and selected local governments to implement model projects, while also publicly recruiting supporters for the model projects (private businesses) to promote these projects. The project implementation system is shown in Fig. 1.

Each of the selected local governments concludes an agreement with the Japan Society of Civil Engineers (JSCE), and the respective model projects are implemented on the basis of these agreements. A practical research committee for asset management system implementation has been established at the JSCE Organization for Promotion of Civil Engineering Technology, and this committee is in charge of analyzing the current situation of each local government, providing support for asset management system development, and collecting and storing case information. Private businesses that have concluded agreements with JSCE as project supporters are to provide support for model project promotion under the direction of this committee.

Based on survey reports and proposals by project supporters, the committee discusses specific support measures and proposes them to local governments, and after receiving such a proposal, a local government works on constructing an asset management system within its own organization. Various obstacles are encountered in the process of system construction, and the experience of overcoming these difficulties becomes helpful in the construction of asset management systems for other local governments.

To construct an asset management system, a local government needs to develop an accurate understanding of its own situation and make up for the places where it is lacking, with help from the private sector.

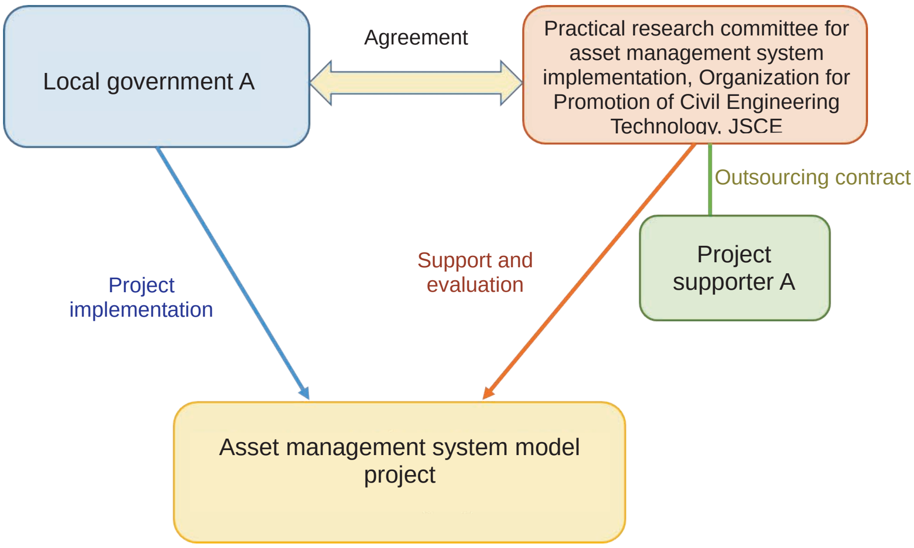



**Fig. 1** Model project implementation system

This analysis and the development of an agreement model to derive incentives to the private sector were formed with reference to "Maintenance and renovation bidding and contract guidelines: Approach to comprehensive contracts" [in Japanese], compiled by the Construction Management Committee of JSCE.

## Model project in Niigata City: How to maintain an enormous number of bridges

Niigata City is responsible for the management of 4,073 bridges. About 84% of these are small bridges less than 5m in length, but 90 of them are long truss bridges over 100 m in length whose management was transferred from Niigata Prefecture to Niigata City. The proportion of bridges with age-related deterioration is expected to climb sharply in the future.

The city is taking steps to disperse and mitigate the effects of aging by shifting to a maintenance system based on urgent preventive maintenance while accelerating bridge renovation. The city has been making steady progress in countermeasures for bridges with severe deterioration, but the progress of its plan for shifting to preventive maintenance was encountering delays. In addition to budgetary problems, the reasons included the diversity of bridge types, efficiency in repair work, the bridge management system, and problems in recruitment.

Niigata City organized a bridge asset management review committee, consisting of interested parties and experts, to study ways to solve the problems. As a result, a decision was made to attempt to solve the problems by classifying the bridges into three categories according to their characteristics and using comprehensive contract methods suited to each category (Table 1). The first is a small-scale bridge inspection model designed for smaller bridges, and its goal is to secure bridge inspectors while reducing costs by placing combined orders for inspection of multiple bridges, each less than 15 m in length. The second is a corrective maintenance outsourcing model designed for larger bridges at least 15 m in length, and its goal is to even out the workload and achieve greater efficiency by signing comprehensive contracts that cover inspection and corrective work on multiple bridges for multiple years. The third, a lifespan-extending model designed for priority bridges, is based on comprehensive contracts that combine inspection, corrective work, and maintenance work in combination, covering multiple bridges for multiple years.

Actual orders based on these three models were placed in FY 2017 for trial implementation. As a result, verification work showed divergence between the data and the situations of bridges, demonstrating the need to review the database for the sake of appropriate maintenance. In addition, combined ordering did not work well as a means of distributing the time periods of work, and it became clear that improvement is needed. We are currently considering how to revise the plan based on these realizations.

## Model project in Kuwana City: Improving street tree maintenance efficiency and harmonizing residents' future image of the community

In Kuwana City, the project covered street tree maintenance in Oyamada New Town, which was developed on the concepts of symbiosis with the natural environment and green city planning. Over time, the maintenance of street trees became a large drain on the city's finances. The city wanted to find ways to reduce administrative costs while upholding the emphasis on greenery, which was emphasized in marketing.

In this endeavor, street trees in each area were positioned according to the characteristics of the respective streets. On that basis, through interviews with residents and persons in the landscaping industry related to street tree maintenance, a plan for the placement and maintenance of street trees was proposed,

**Table 1** Bridge management model of Niigata City

| | Corrective maintenance outsourcing model | Lifespan-extending model | Small-scale bridge inspection model |
|---|---|---|---|
| Purpose and anticipated benefits | ① To accelerate repairs for bridges in need of countermeasures<br>② To prevent wintertime repair work and improve construction quality<br>③ To minimize reworking between design and implementation<br>④ To reduce costs through combined ordering | ① To complete small repairs in order to maintain bridges for the next generation<br>② To gather and store detailed information on bridges for the next generation<br>③ To verify new technologies and new countermeasure methods to help extend bridge life spans<br>④ To promote safety through early detection of hazards and immediate repairs<br>⑤ To reduce life cycle costs with an eye to the next 10 or 20 years | ① To reduce future inspection costs<br>② To even out the annual workload to help compensate for lack of personnel<br>③ To obtain and develop human resources through outsourcing to local companies<br>④ To improve disaster countermeasures through familiarity with topography and natural features |
| Summary | ○ For bridges in need of immediate countermeasures<br>○ Multiple bridges are combined in contracts covering the repair work design and implementation processes<br>○ Times of work implementation are optimized by signing multiple-year contracts | ○ For long bridges of historic value on the Agano River<br>○ Comprehensive contracts for annual inspections, small-scale repairs, maintenance work, etc.<br>○ Demonstration fields are provided for new technologies, new countermeasure methods, etc. | ○ For bridges in management zone 4<br>○ Groups of bridges with low bridge tolls<br>○ Comprehensive contracts for annual inspections suited to Niigata City on a per-area basis |
| Model projects (proposals) | ○ Multiple bridges (about 3 to 5)<br>○ Design and implementation (end reinforcement, painting, etc.)<br>○ Multiple years (implementation from late 2016 to first half of 2018; verification in second half of 2018) | ○ Multiple bridges (about 2)<br>○ Annual inspections<br>○ Cleaning such as power washing<br>○ Small-scale repairs (partial painting, etc.)<br>○ Multiple years (late 2016 – verification in first half of 2017) | ○ Multiple bridges (selected from bridges that underwent legally mandated inspection in 2015)<br>○ Inspection methods (introducing the technique of inspection using tablets)<br>○ Multiple years (implementation from late 2016 to first half of 2017; verification in second half of 2019) |

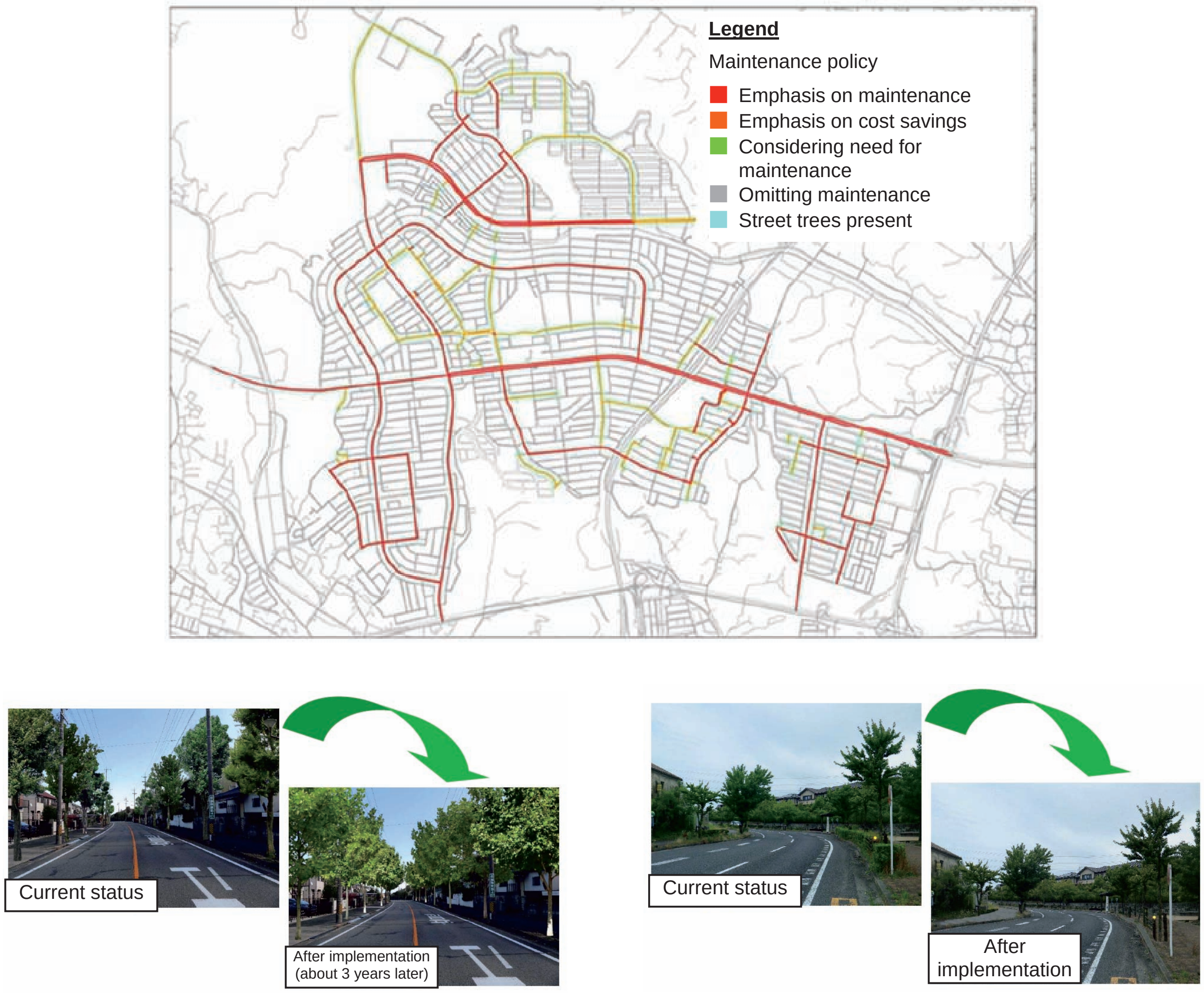
Souce: Practical research committee for asset management system implementation, FY 2016 report

including street tree thinning, changes in tree species, and maintenance by residents (Fig. 2). In FY 2017, on the basis of that proposal, discussions were held with residents with regard to the future image of the neighborhood and the street trees that it should have. At present, adjustments are being made to obtain the understanding of residents concerning street tree maintenance for practical implementation of the plan, and expansion to other areas is also being considered.

## Model project in Machida City: Developing an infrastructure maintenance system that can be managed and modified by local government personnel

Machida City has 239 bridges and 138 km of arterial and sub-arterial roads. This infrastructure has been maintained according to a lifespan-extending repair plan, but in the course of implementing the plan, the actual situation has increasingly diverged from the plan. According to interviews with personnel, the current system makes it difficult for personnel to modify the plan in light of factors such as inspection results, and the actual situation has diverged more and more from the plan due to the accumulated results of factors such as predictions of deterioration progress that did not match up with reality and postponement of work due to budget reductions. Some expressed concern about declines in technical skills among local government personnel, indicating the need to maintain and improve their skills.

It was decided that new tools would be developed as a way to address these problems, and an attempt was made to develop a system in which the overall road maintenance plan can be modified appropriately by local government personnel themselves in light of the latest information, while confirming the results of past maintenance and checking for consistency with deterioration predictions. In 2018, a prototype was completed for a management system that allows for plan modification by personnel, and trial implementation by the relevant staff members has begun. Hands-on learning and other training is also being planned in response to the need to maintain and improve the technical skills of local government personnel. Consideration is being given to more general application of the tools developed in this project.




a) Less frequent maintenance

b) Removal of low shrubs

**Fig. 2** Example of determining sections for infrastructure savings through functional assessment with resulting landscape changes (Source: Interim report of the practical research committee for asset management system implementation)

## Model project in Fuji City: Awareness raising and cooperation among relevant divisions

Fuji City had a basic policy on public facility management in place to define the city's basic approach to maintenance and management, and measures were being taken with regard to public buildings, but the city government overall had a low awareness of risks and problems related to the management of civil engineering infrastructure, lacking the necessary attitudes and systems for a unified response by the relevant offices.

In the model project, opportunities were provided for the relevant offices to come together to discuss a future vision and approach for asset management in Fuji City, and in addition to developing a framework to advance unified efforts, the problems faced by each office were analyzed and solutions were proposed. As a result, efforts to improve the efficiency of overall infrastructure maintenance have begun. A roadmap has been drafted for the promotion of asset management, and steps to improve awareness among personnel have begun, including study sessions for a comprehensive agreement and meetings to exchange information across different divisions.

## Development of asset management systems

Different local governments face different problems related to maintenance, as discussed in this paper, and there is no one-size-fits-all solution. The first step in organizational change is to share information and raise awareness among related persons, and this is expected to lead to the development of systems for asset management.

# Community-based management of local water supply system: A new technology and style of collaboration among local government and community

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Hokkaido Research Organization
Chief for resource oriented system

## Promising model of future water infrastructure management for shrinking society

Population decrease in rural area of Japan is proceeding severely. As one of serious results, water supply systems, those generally managed by local government and have to employ corporate accounting, are facing heavy deficit situation due to decrease of customers. Furthermore, local government itself has already shrunken in terms of both budget and human resources, and therefore it seems difficult for local government to continue sufficient management of water infrastructure.

To challenge above mentioned situation, this project focused on local small water supply systems those supply potable water for about 10 to 100 households and are managed not by local government but by users (here after we call them Community based managed water supply system: CBMW). We regarded them as one of promising model of sustainable water infrastructure management in shrinking society, however very few information of CBMW are available because those water system have been managed mostly independent from local government.

This paper reports overview of CBMW based on field research in Hokkaido and discuss on (a) how to support sustainable management of CBMW, and (b) how we should consider new technology application for shrinking society, especially where we cannot expect sufficient management by local government.

## Lesson and learnt from present Community Based Managed Water Management System

It is estimated that there exist more than 500 CBMWs in Hokkaido, however exact number is unknown[1].

**Table 1** Tasks for community based managed water system and players taking the role, by counting from interview results of 11 CBMW cases.

| | | community | Water related constructor | Ex-constructor of water facilities | Local municipality | Heavy machine lease agency | Water quality test agency | Local electronics shop |
|---|---|---|---|---|---|---|---|---|
| Tasks to manage water supply system | Bill collection | 10 | | | | | | |
| | Detection of leakage point | 4 | | | | | | |
| | Manager of construction | 2 | 7 | 1 | | | | |
| | Supply of heavy machine | 2 | 6 | | | 1 | | |
| | Operation of heavy machine | 3 | 6 | | | | | |
| | Keep the drawing | 4 | | | 2 | | | |
| | Disaster response | 1 | | | 2 | | | |
| | Water quality check | | | | | | 5 | |
| | Clean up water source area | 10 | | | | | | |
| | Maintenance of filter | 1 | 1 | | | | | |
| | Snow removal | | | | 1 | | | |
| | Material stock | 2 | | | | | | |
| | Paperwork for construction | 1 | | | | | | |
| | Fixing pump | | | | | | | 1 |

This project conducted interview survey on total 39 CBMWs those we could contact. According to the results[2], we found that CBMWs have been succeeded to manage their system on the bases of their agriculture related skills, machines, community bound and network (Table 1), however their weak points seemed to be (a) large dependency to good quality of water source and lack of barrier to reduce health risk (Fig.1), (b) lack of sufficient asset information such as pipe network map, in many cases detail of pipe network information are only in CBMW manager's brain.

In order to overcome those weak points, this project designed supporting network for CBMWs, which consists of CBMW managers, local high school, central and local government, local shops and wide variety of specialists (Fig.2). In this supporting network, high school students contribute to monitor their water quality and to provide GIS asset data for CBMWs. This network can provide good education topic and field for high school. Furthermore, high school students get a chance to learn technique of water analysis and GIS software operation. Data created by high school students are stored in database and shared with local water managers, local government and related specialists. Limited budget of CBMWs should be used to sustain local shops and local technicians. If those shops and technicians were disappear, CBMWs have to use shops and technicians outside of the region, and it costs and time consuming.

## Field trial with high school students

This project partially tested the supporting system, on the basis of collaboration with CBMWs in Furano City in Hokkaido, local government of Furano City, and Furano high school science club. In this trial, high school students visited CBMWs to take water sample and to make interview about pipe network (Fig.3).

Sampled water was analyzed onsite and in the high school laboratory. Water quality analysis items and methods were selected in light of easy and low cost but worth for CBMWs. In total, while fiscal year of 2018, they have checked water quality of 6 CBMWs, including supplied water, source water, and surrounding surface water.

Regarding pipe network, this project employed easy GIS system developed by SIP project No.60; R & D of

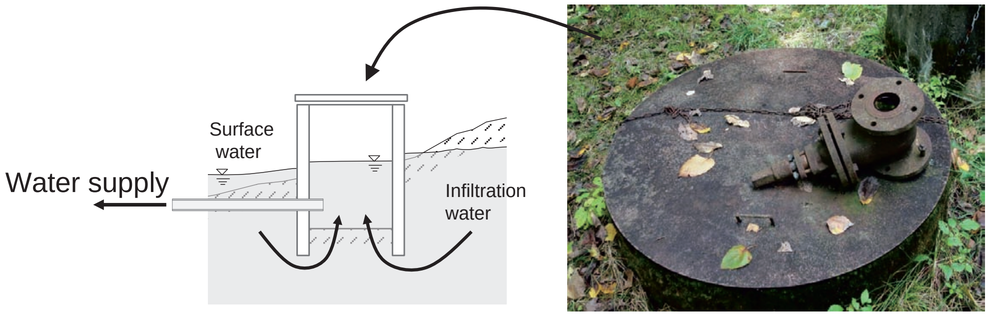


**Fig. 1** Typical example of water source which employ artificial infiltration; vertical image (left) and picture (right); valve on the cover is old broken one and now it is used as weight to fix the cover

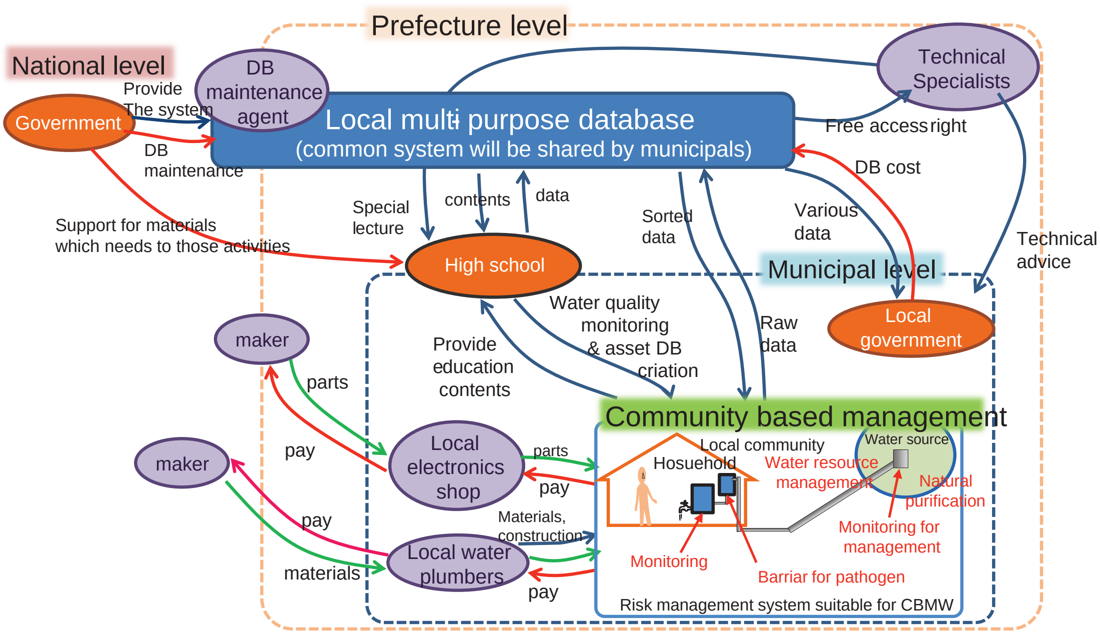


**Fig. 2** Supporting network for CBMW, which consists of CBMW management group, local high school, local government, and variety of specialists

Development of Strategic Asset Management Technologies for Trunk Agricultural Water Facilities (National Agriculture and Food Research Organization). Using this GIS system, high school students inputted the information on the digital map directly via tablet device on site, and they converted those field data into GIS data set after go back to high school. In total, while fiscal year of 2017 to 2018, high school students have created GIS data set of 5 CBMWs (Fig.4).

Summarized results were fed back to CBMW managers, local government, and specialists (Fig.5 & 6). As a specialist, Hokkaido Research Organization and Hokkaido University provided special lecture for related topics and training of water analysis for students.

## What we found through field test of CBMW supporting system

As a technology, employed GIS software which uses tablet onsite were easily accepted not only by high school students but also CBMW managers though they are mostly aged person (Fig.3). Through the trial, we also found some points to be improved as GIS software. Those points were fed back to version up of add-on software of the GIS.

As a supporting system, we could validate that high school students can work well and contribute much in this system. As unexpected advantageous effect, we found that high school students can withdraw more collaborative attitude from local actors, probably because local people expect those students to become local leaders of next generation. In fact, many of present local leaders were alumnae and alumni of this high school. Those local network based on high school alumnae and alumni will not appear officially, but it will be important network for driving future CBMWs and supporting system.

## Recognition shift for new style of collaboration

This study proposed community based water management and supporting system for them, as one of countermeasure model for shrinking society, especially in rural community. The results of survey on present CBWMs and field trial of supporting system suggest us that people in community have higher skills and potential as water infrastructure managers or supporters, than generally considered. They, especially farmers, also have higher potential to understand and accept new technology, than people living in urban area, because present farmers are using wide variety of technologies via agricultural machine, chemical products, and so on, in their daily work. Thus, we should shift our recognition about local actors, and should consider new technology application and design of infrastructure management system in rural area, based on new style of collaboration among local government, local community and related actors in and around the region.

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**Fig. 3** GIS mapping of water pipe network by high school student; CBMW manager starts operating by himself.

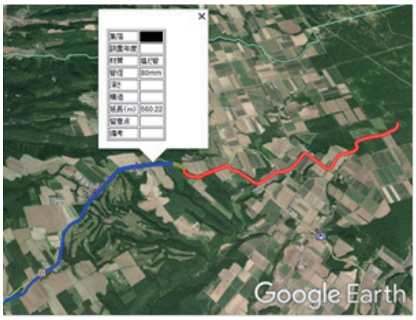


**Fig. 4** Results of GIS mapping by high school students; exported to Google Earth format in order to share with CBMW members.

**Fig. 5** Reporting workshop by high school student

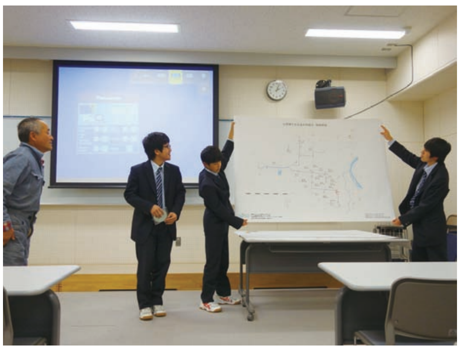

**Fig. 6** Asset data in GIS were fed back to CBMW managers by high school student

C-6

# Efficiency promotion and sophistication of periodic bridge inspection by robotic technology with drastically reduced time of traffic restriction

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## Adoption of RT for periodic bridge inspection

Periodic inspection of bridges by visual observation from a close distance once every five years has been mandated since July 2014. Introduction of robotic technology (RT), including drones, for periodic inspection is expected to bring about the effects given below but has yet to be fully implemented.

- Shorten the time of traffic restriction for inspection
- Enhance safety of inspection work
- Accumulate detailed inspection data
- Reduce the cost

The Gifu University Project for Regional Implementation of SIP (Gifu Univ. SIP)[1)] has been undertaking activities focusing on the adoption of RT, including drones, for periodic inspection of Kakamigahara Bridge managed by Kakamigahara City, which is scheduled for fiscal 2018. This article is an excerpt from Reference[2)].

## Difficulty in periodic inspection of Kakamigahara Bridge

Kakamigahara Bridge with a bridge area of 11,200 $m^2$ shown in Fig. 1 is a prestressed concrete continuous 10-span fin-back bridge 594 m in length over Kiso River. The superstructure of this bridge completed in 2013 is of a semicylindrical box girder structure, with a height of approximately 10 m from the water surface. The elliptical piers have no hammerhead. The standard vehicle lane width is 7.5 m, with 3-m wide lanes for cyclists and pedestrians on both the upstream and downstream sides, which are locally widened to 5 m near Piers P5 and P7.

Inspection of the undersurface of Kakamigahara Bridge is impossible even with a large bridge inspection vehicle widely used for general bridges, as shown in Fig. 2, due to the wide sidewalk and the fin-back members constructed between each sidewalk and vehicle lane. The P2-P9 spans 420 m in length above the river are particularly difficult to inspect from the underside, as they require inspection with an ultralarge bridge inspection vehicle with a sidewalk-overbridging capacity of around 5 m, suspended scaffolding, or ropework, which would incur heavy costs.

## Problems and efforts for solutions

Table 1 shows problems arising when RT is employed, regarding standards, RT, and cost. This table also includes the key points of the efforts by the Gifu Univ. SIP.

**Fig. 1** Kakamigahara Bridge

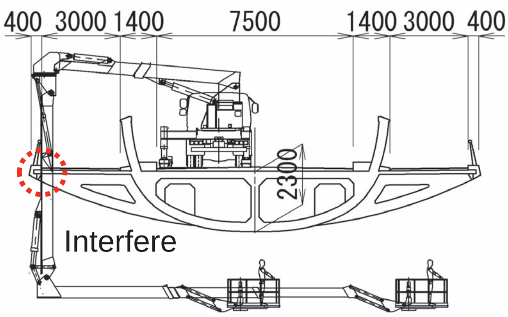


**Fig. 2** Inspection with a general large bridge inspection vehicle

## Conformity to standards

When introducing RT into periodic inspection of bridges under the management of municipalities, it is important that the technology conform to the Guideline for Periodic Road Bridge Inspection[3]. Also, technical specifications are necessary to serve as a basis for placing an order for bridge inspection involving RT.

Gifu Univ. SIP organized the Assessment Committee for Applicability of New Bridge Inspection Techniques (July 2017 – March 2018), which formulated and published Recommendations for Bridge Inspection Incorporating Robotic technology (draft) – for Local Municipalities (hereafter the Draft Recommendations)[1,4].

Gifu Univ. SIP also proposed a two-step method for periodic inspection of Kakamigahara Bridge. This method consists of RT-supported preliminary research in accordance with the Draft Recommendations and visual inspection of the entire bridge from a close distance using an ultralarge bridge inspection vehicle (Fig. 3).

Since Kakamigahara Bridge is a special bridge (finback bridge) with wide sidewalks, it requires 10 days to inspect the bridge using an ultralarge bridge inspection vehicle, of which only one of its kind is available in Japan. However, by conducting RT-supported preliminary research, the time requiring the large vehicle can be reduced to 4 days. This reduces the congestion due to the closing of one lane by 6 days. This can be

**Table 1** Problems associated with introduction of RT into periodic inspection of bridges and Gifu Univ. SIP's efforts

| | Problem | Key points of Gifu Univ. SIP's efforts |
|---|---|---|
| Standards | No standard is available to serve as a basis for introducing RT | Formulated the Recommendations for Bridge Inspection Incorporating RT (Draft) – for Local Municipalities[1, 4] |
| | Inspection methods should conform to Guideline for Periodic Road Bridge Inspection | Proposed preliminary research by RT prior to visual inspection from a close distance based on the inspection guideline |
| RT | Performance requirements for RT is unclear | Required that the technology is capable of providing information for judging if the soundness grade of each member is Grade II or higher with respect to Guideline for Periodic Road Bridge Inspection (Table 2) |
| | Assessment of technology is insufficient | Assessed the performance of RT by field testing at Kakamigahara Bridge (Table 3) |
| | No single RT can inspect all segments | Proposed combinations of multiple robotic techniques (Figs. 3 and 4) |
| Cost | The possibility of inspection cost reduction is not obvious | Proposed to change RT-supported preliminary research to screening survey and utilize AI |

**Table 2** Requirements for information obtained through RT

| | | Requirements | Verification |
|---|---|---|---|
| Detection of damage | Presence and type | Damage can be detected and classified. | Pictures and sketches of damage are provided to confirm the requirements in the left column. The locations, ranges and directions of damage shown in the provided pictures and sketches are roughly in agreement with those in the damage chart prepared by visual inspection from a short distance. |
| | Location | Damage can be detected in a manner to allow sketching of damaged portions in relation to other members. | |
| | Size | The overall image can be obtained to judge whether the damage is localized or extensive. | |
| | Direction and pattern | The direction (horizontal, vertical, diagonal, longitudinal or transverse to reinforcement, etc.) and pattern (map cracking, etc.) of damage can be detected. | |
| | Water penetration paths | The source and path of water ingress can be detected regarding damage involving water, such as water leakage and free lime. | |
| Measurement of damage | Size | Crack width:<br>The crack width of 0.2 mm or more can be measured with an error margin of 0.0 to + 0.1 mm. | The measurement results of damage described in the damage chart prepared by visual inspection from a short distance or artificially created accuracy verification marks are roughly within the tolerances shown in the left column. |
| | | Crack length, peeling, rebar exposure, leakage, etc.:<br>The size can be measured with an error margin of 5 cm.<br>(Length: L = XX cm, Area: A = XX cm × XX cm) | |
| | Displacement | The displacements of expansion gaps and bearings can be measured with an error margin of 10 mm. | |

※ The following performance is required so that there can be no omission of cracks with a width of 0.3 mm or more.
For a crack width of 0.2 mm, it is acceptable to output a measurement result of 0.3 mm (0.2 mm + error 0.1 mm) to be on the safe side.
For a crack width of 0.3 mm, it is not acceptable to output a measurement result of 0.2 mm (0.3 mm – error 0.1 mm) on the dangerous side.

Introducing technologies

Technologies

Regions

Deployment

done without incurring additional cost, if the cost of RT can be covered by the reduced cost for the inspection vehicle.

## Performance and operation method of RT

It is difficult to clearly define the performance required of RT for bridge inspection, since RT has scarcely been introduced to periodic inspection of bridges so far. The above-mentioned Draft Recommendations require that the technology be capable of providing information for judging if the soundness grade of each member is Grade II or higher with respect to the Guideline for Periodic Road Bridge Inspection. Gifu Univ. SIP specified the performance requirements for the information to be acquired as Table 2 by inventorying the data necessary for inspection engineers to judge the soundness of each member of the bridge and data that the RT should provide. Table 3 gives the key results of the performance of RT confirmed by field testing. Note that the measurement performance was selected referring to Gifu Prefecture's Bridge Inspection Manual[5] and tolerances were specified also taking account of the results of field tests.

Table 3 reveals that it is currently difficult to inspect all segments by one single robotic technique within the range of the techniques considered. As shown in Figs. 3 and 4, Gifu Univ. SIP intends to combine multiple techniques making the most of their features.

## Future development

Gifu Univ. SIP is undertaking the projects given below with the aim of introducing RT in periodic inspection of Kakamigahara Bridge (first inspection in fiscal 2018).
- Formulate Recommendations for Bridge Inspection Incorporating RT (Draft) - for Local Municipalities
- Present performance requirements for, and assess the performance of, RT
- Provide examples of optimum combinations of robotic techniques

Utilizing RT for bridge inspection will bring about the following advantages:
- Facilitate inspection of bridges with a large cross section such as Kakamigahara Bridge
- Significantly shorten the period of traffic restriction on bridges with a large inspection vehicle (in the case of Kakamigahara, the period of 10 days was reduced to 4 days)

**Table 3** Assessment of RT performance

| Inspection segments of Kakamigahara Bridge | Assessment of applicability to Kakamigahara bridge | Operation by drone engineer | | | Operation by inspection engineer | |
|---|---|---|---|---|---|---|
| | | Drone with wheels for visual observation and hammering tests | Two-wheeled drone with a camera for bridge inspection | Drone with controllable pitch propellers | Robotic camera indicating crack scale for bridge inspection | Camera system for bridge inspection |
| Bridge members above water | A: Applicable<br>B: Conditionally applicable<br>C: Inapplicable | B (Using boat) | B (Using boat) | B (Using boat) | A | A |
| Bottom surface of deck | | A (+) (hammering test) | A (-) (Revaluation) | A | A | A |
| Girder (Side surface ) | | B (Only upper part) | C (Except for curved surface) | A | A | A |
| Girder (Bottom surface) | | A | A (-) (Revaluation) | A | A | B (Except for center part) |
| Beam on bearings | | C (Unavailable) | C (Unavailable) | A | B (Only side surface) | A |
| Bracket | | B (Only lower surface) | A | A | A | A |
| Bearing | | C (Unavailable) | A | A (-) (Revaluation) | B (Except for space between bearings) | B (Except for space between bearings) |
| Drainage pipe and metal fitting | | A | A | A | A | A |
| Substructure (Top surface) | | C (Unavailable) | A | A (-) (Revaluation) | C (Unavailable) | C (Unavailable) |
| Substructure (Side surface above water) | | C (Unavailable) | A | A | C (Unavailable) | C (Unavailable) |

| | | A2 | P9 | P8 | P7 | P6 | P5 | P4 | P3 | P2 | P1 | A1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | W.Z. | | W.Z. | | | | | |
| Preliminary survey with RTs | Wide view | Drone | | | | | | | | | | |
| | Narrow view | Drone/Robotic camera | | | | | | | | | | |
| | Hammer | Drone with hammer | | | | | | | | | | |
| Human Visual inspection | | Inspection vehicle | | | Rope access | Inspection vehicle | Rope access | Inspection vehicle | | | | |

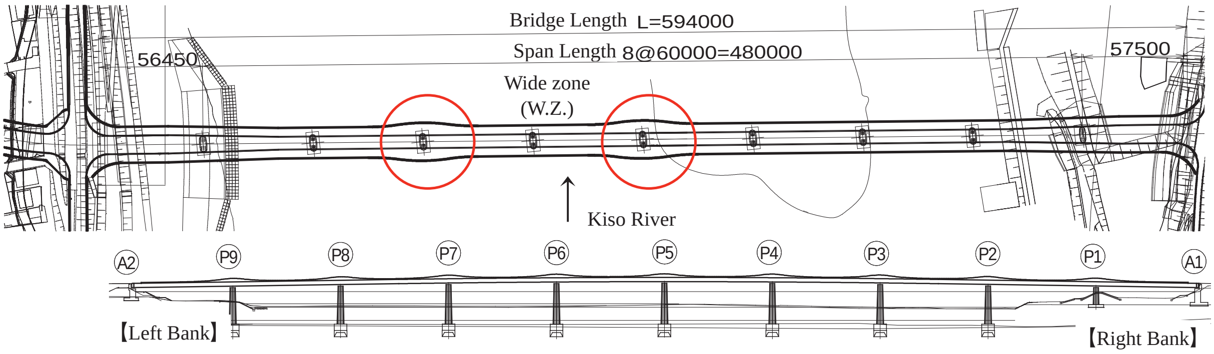


**Fig. 3** Combination of robotic techniques

(a) Drone with wheels for visual observation and hammering tests

(b) Two-wheeled drone with camera for bridge inspection

(c) Drone with controllable pitch propellers

(d) Robotic camera indicating crack scale for bridge inspection

(e) Camera system for bridge inspection

(f) Drone with hammering test equipment for bridge inspection

**Fig. 4** Robotic techniques for inspection of Kakamigahara Bridge

When revising technical standards, it is hoped that the inspection items and performance requirements will be reviewed from the aspects of evolving technology and adopting new technology, including the improvement of measurement technology using robots, enhancement of the accuracy of acquired data, and sophistication of data processing technology.

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# Approach to use of robotic technologies in periodic inspection of steel bridges


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## Anticipation for robotic technologies in steel bridge inspection

Gifu University's SIP implementation project includes activities aimed at incorporating robotic technologies in periodic inspection of the Kakamigahara Bridge, which has a length of 594m and is managed by the city of Kakamigahara. As part of these activities, operational proposals have been made for the introduction of new technologies such as inspection robots for use in inspection of concrete bridges, including the development of related standards,[1] clarification of performance requirements,[2] evaluation of technologies,[2] and combinations of technologies.

Meanwhile, steel bridges have a more complex cross-sectional shape than concrete bridges because they use many truss structures and arch structures, and this means that inspection work using bridge inspection vehicles and the like is less efficient. Therefore, it is necessary to promote bridge inspection using robotic technologies for steel bridges as well, and standards must be developed on the basis of challenges encountered in steel bridge inspection.

We will discuss the approach for expanding the scope of application of the standards and requirements that have been proposed for concrete bridges in activities thus far to include steel bridges.

## Challenges in periodic inspection of steel bridges

In steel bridges, the members of thin-walled structures have a large surface area requiring inspection, and there are also many complex frame structures. In the inspection of truss bridges and arch bridges, the bucket of an inspection vehicle needs to be inserted between complicated frame structures in a careful operation, as shown in Fig. 1 and Fig. 2. This significantly lowers the efficiency of inspection work, and restrictions due to the shape of the bucket make it impossible to bring it up close to some portions. Therefore, although there is widespread interest in using bridge inspection robots to conduct inspection for the sake of efficient and accurate implementation of bridge inspection work, broader application of bridge inspection robots is considered to involve a great deal of difficulty at the present time.

**Fig. 1** Inspection of a trussed Langer bottom-road bridge[4)]

**Fig. 2** Inspection of an arch deck bridge[4)]

We will describe the required performance of robotic technologies for use in periodic inspection of steel bridges managed by local governments, based on findings from application of the proposed guidelines for concrete bridges[1] to the Kakamigahara Bridge.

## Inspection functions at wide and narrow fields of view

Degradation of anticorrosive function, a change that is typically seen in steel bridges, requires information gathering over a relatively wide range. Meanwhile, local corrosion, which has a major impact on integrity evaluation, requires information gathering in a relatively narrow field of view; that is, information must be gathered at a level where it is possible to judge whether to perform measurement for reductions in plate thickness.

## Inspection in places with inadequate brightness

Many coatings, which come in a variety of colors, are used on steel bridges, and a great deal of inspection work is performed in situations with inadequate brightness in the case of steel bridges with dark coatings, compared to concrete bridges.

## Crack detection accuracy

Cracks in steel materials originate at welds, and when a crack involves cracking of a coating at an early stage, it is sometimes detected as a change involving rust staining. The standard of concrete cracks about 0.2 mm in width could be introduced as an accuracy requirement for detection of cracked coatings during periodic inspection of bridges, although further discussion is necessary.

## Detection of loosened and missing bolts

In steel bridges, it is necessary to detect when bolts that connect members are loose or missing. An inspection engineer can detect loosened bolts by hammer sounding, but accurate hammer sounding of bolt heads and nuts by robotic means is difficult based on the current state of the technology, and it is considered more realistic to use alternate means, such as detecting gaps due to loosening of bolts or cracked coatings where a bolt head or nut contacts the steel plate.

## Crack detection accuracy in reinforced concrete floor slabs of steel bridges

The accuracy of crack detection in concrete floor slabs of steel bridges is an issue. As long as the condition of the bridge is equivalent to at least soundness category II, it is sufficient to be able to detect wide-ranging unidirectional or bidirectional cracks without free lime (cracks up to about 0.2 mm in width).

## Close-up access in narrow spaces

Many types of structures in steel bridges involve constraints on the directions in which they can be accessed by inspection robots from the horizontal or vertical direction, etc., and this means that accurate operation within a narrow range is necessary. An inspection robot equipped with a rotating spherical shell,[5] like the one shown in Fig. 3, performed very well in providing close-up access to narrow spaces during a field test performed by the authors on a steel bridge (Chidori Bridge in Gifu-shi). Other types of robots also perform very well in providing close-up access to narrow spaces by making use of the characteristics of steel bridges, including an inspection robot that moves omnidirectionally under a girder under control by the length of a hanging wire,[5] an inspection robot equipped with a mechanism that moves it while adhering to steel by magnetic attraction,[6] and an inspection robot that moves while suspended from the lower flange of a steel plate girder bridge.[6] It is anticipated that these types of robots will be utilized in steel bridge inspection.

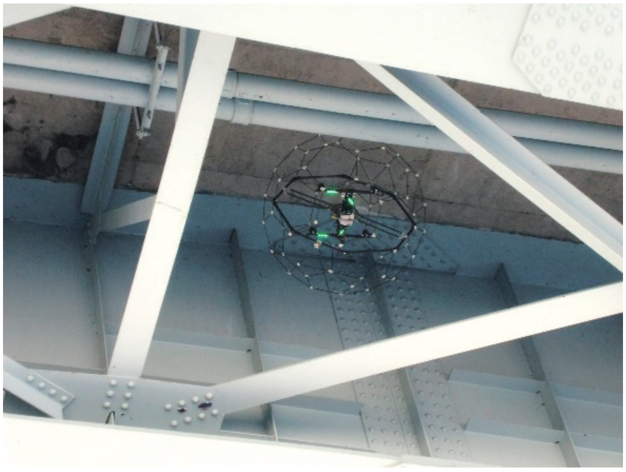

**Fig. 3** Inspection robot equipped with a rotating spherical shell

## Efficient imaging of deterioration in narrow spaces

In steel bridges having many narrow spaces, it is necessary to capture images in multiple directions while positioned close-up to a narrow space, and to reduce the amount of time needed to get in and out of such spaces. For example, images could be captured using a high-resolution 360° camera. Fig. 4 shows an example of a robot operating in a narrow space on a concrete bridge; this is a bridge inspection robot equipped with a 360° camera that we tried out on the Kakamigahara Bridge. An image captured by this robot is shown in Fig. 5. This camera-based method was fully capable of detecting cracks about 0.2 mm in thickness on the web surface on the left side.

**Fig. 4** Drone equipped with a 360° camera

**Fig. 5** Image obtained by a 360° camera

## More efficient inspection work on members above the road

When using a drone robot to inspect a bottom-road bridge, as shown in Fig. 1, it is possible to inspect the underside of the bridge without any traffic restrictions; however, the bridge needs to be closed to traffic when inspecting the members above the road. There is presently a need to devise ways to avoid lengthy closure to traffic. To reduce the amount of time that a bridge is closed to traffic, it is necessary to take steps to accomplish inspection work more efficiently, such as operating multiple robots simultaneously.

## Example of performance requirements for inspection of steel bridges (draft)

Based on the matters discussed above, the performance requirements according to the bridge inspection manual of Gifu Prefecture[3)] are as shown in Table 1. Steel bridges involve very different performance requirements from concrete bridges with regard to close-up access to narrow spaces, depending on bridge type; so these requirements are classified by the type of bridge concerned. This table is presented as a set of initial values for future use when considering standards, based on the authors' activities with the use of bridge inspection robotic technologies on concrete bridges.

**Table 1** Example of performance requirements for information obtained by robotic technologies (steel bridges)

| Content requirements | | | Verification method |
|---|---|---|---|
| Bridge types | Steel girder and box girder (deck bridges) | The inspection mechanism can freely pass through spaces of about 1m × 2m in a vertical direction. | Verified by field testing on actual bridges or model bridge facilities, organized by committees, etc. including persons having relevant knowledge and experience. |
| | Deck bridges | The inspection mechanism can freely pass through spaces of about 3m × 5m in a horizontal or vertical direction in a truss bridge, etc. | |
| | Bottom-road bridges | The inspection mechanism can freely pass through spaces of about 3m × 5m in a horizontal or vertical direction in a truss bridge, etc., and the length of time of traffic closure during bridge surface inspection can be minimized. | |
| Detection of deterioration | Presence and type of deterioration | Capable of detecting and categorizing deterioration (corrosion, cracked coating, loosened or missing bolts and rivets, fracture, degraded anti-corrosive function, deformed or damaged steel plates). | Comparison with deterioration diagrams prepared on the basis of close-up visual inspection, confirming that it shows generally the same location, scope, etc. of deterioration. |
| | Location | Capable of detecting deteriorated spots and relative positions with other members. | |
| | Extent | Capable of determining whether deterioration is localized or widespread. | |
| | Direction, etc. | Capable of detecting the directions of cracks, fractures, deformation, etc. | |
| | Route of moisture intrusion | Capable of detecting the route of moisture intrusion and the origin with regard to corrosion and degradation of anticorrosive function. | |
| Measurement of deterioration | Dimensions | Capable of detecting steel plate deformation and damage with an error of less than 1 cm. | The measurement results of deterioration and accuracy verification indicators are generally within the permissible error limits shown at left. |
| | | Capable of measuring the dimensions of deterioration with an error of less than 5 cm. | |
| | Displacement | Capable of measuring girder expansion gaps and displacement of supports with an error of less than 10 mm. | |

## Combinations of robotic technologies

Based on utilization in field testing at Kakamigahara Bridge and in actual bridge inspection work, it is essential to select and combine robotic technologies according to the portions to be inspected and the types of inspection work. It is desirable to compile field test results performed throughout Japan and prepare documentation including the correspondence of robotic technologies to different portions for inspection.

## Formats for use of robotic technologies to support inspection

The following are conceivable formats for the use of robotic technologies in support of bridge inspection.

(1) Using robotic technologies for preliminary surveys to improve the efficiency of overall close-up visual inspection work (the current proposed guidelines[1]).

(2) Using robotic technologies for screening to select those portions where close-up visual inspection work will be performed.

(3) Using robotic technologies in place of close-up visual inspection on bridges classified as soundness category I based on close-up visual inspection in the previous fiscal year.

Formats (2) and (3) are thought to be desirable future steps in terms of improving efficiency and reducing costs in bridge inspection work.


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# Infrastructure maintenance system development for local governments and use of robotic technology in bridge inspection

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Tottori University

## Need for greater efficiency in infrastructure maintenance as construction industry staff become fewer and older

As the number of personnel involved in the construction industry continues to fall nationwide, the rate of decline has been especially sharp in Tottori Prefecture (Fig. 1). Fewer young people are taking jobs in the construction industry, and the average age of workers in this industry is increasing (Fig. 1). Tottori Prefecture has a great deal of infrastructure, and its local governments have a pressing need to find ways to manage infrastructure with greater efficiency in the future.

Therefore, we have developed an efficient infrastructure maintenance system (Fig. 2) that combines databases, GIS, sensor-based monitoring, and reporting by local residents (semi-experts), and this system has been implemented for infrastructure maintenance in Tottori Prefecture. We have also studied the use of robotic technologies in the inspection of bridges for the sake of more efficient and advanced bridge inspection.

## Greater efficiency in road patrol inspection

We developed a database and used GIS for visualization of road conditions as a means of improving the efficiency of patrol inspection of roads in Tottori Prefecture. In this system, inspection staff use tablet computers to input the results of inspections in the field, and this information is sent to a database along with images. This eliminates the need for work such as organizing inspection results and filling out forms after returning to the office. Because location information is acquired at the same time, the locations of problems are displayed on a map, making it possible to discover where problems are located at a glance. Problem repair history is also stored in this database, so data from inspection to repairs can be managed in a unified manner using this database. For the

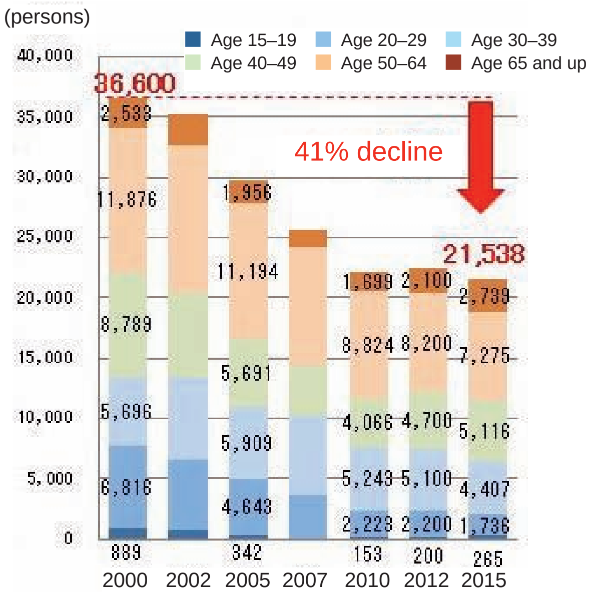



**Fig. 1** Age trends in the construction industry in Tottori Prefecture (based on data from the Department of Labor and Commerce, Tottori Prefecture)

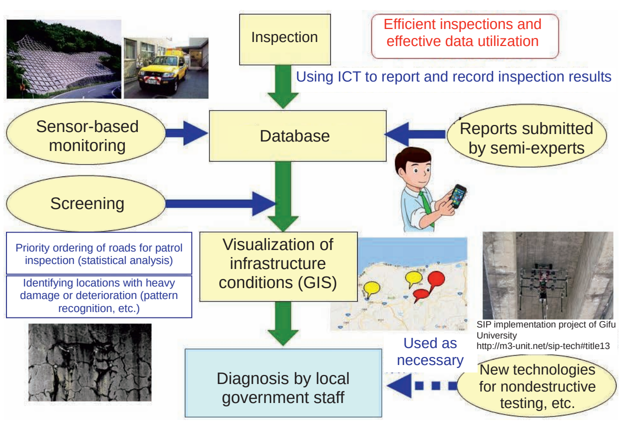



**Fig. 2** Infrastructure maintenance system

implementation of this database & GIS system in road maintenance in Tottori Prefecture, we developed an efficient, easy-to-use system through repeated improvements, incorporating feedback received from personnel of Tottori Prefecture who were using the system on a trial basis.

## Detection of road problems by onboard sensors

Sensors (acceleration sensors plus GPS) are mounted on road patrol vehicles to detect abnormal road vibrations during vehicle operation. These locations are displayed on a map using the above database and GIS. This makes it possible to efficiently detect road locations where problems exist. At present in Tottori Prefecture, this setup is only being used on road patrol vehicles; however, work is underway to develop a way to use it more frequently and over a larger area by mounting the sensors on delivery trucks of shipping companies, etc.

## Inspection support by semi-experts

After undergoing training in problems such as road damage and deterioration, local residents can become qualified as semi-experts. When these semi-experts discover a problem on the roads in areas where they live, they can use a smartphone or tablet computer to upload a description of the problem to the database, along with location information and images. The locations of problems reported by semi-experts are displayed on a map. This setup makes it possible for road administrators to determine road conditions and implement countermeasures as needed. By displaying information on the map such as whether the road administrator has decided to implement countermeasures and the results of any such countermeasures, a semi-expert can determine what actions have been taken by the road administrator in response to the problem that he or she reported. This system for semi-experts to report road problems was implemented on a trial basis with the cooperation of local residents, and the system was improved during implementation based on user feedback concerning the training and the reporting app.

## Using robotic technologies in bridge inspection

It is urgently necessary to improve the efficiency of bridge inspection in response to constraints such as declining numbers of engineers and budget limitations. In addition, close-up visual inspection is often difficult in large-scale bridges due to location conditions and structural constraints. Therefore, for the sake of more efficient and advanced bridge inspection, connecting Sakaiminato City (Tottori Prefecture) and Matsue City (Shimane Prefecture), demonstration testing was conducted to promote the use of robotic technologies in bridge inspection, using the Eshima Ohashi Bridge over Lake Nakaumi as the testing field (Fig. 3). Close-up visual inspection of this bridge is

**Fig. 3** Eshima Ohashi Bridge

difficult because of its location conditions and structural constraints, and distant visual inspection has been used to inspect this bridge during the past 14 years since it was first opened.

## Difficulty of close-up visual inspection at Eshima Ohashi Bridge

Close-up visual inspection would be difficult to achieve at the Eshima Ohashi Bridge, for the following reasons.

- Some parts cannot be accessed even by large bridge inspection vehicles, due to the large overhang and tall girder height (up to 15 m).
- Because the slope of the bridge is as steep as 6.1%, the bridge would need to be completely closed in one direction while operating a large bridge inspection vehicle, causing a significant inconvenience.
- Close-up visual inspection by rope access is problematic in terms of safety, and some portions would not be accessible even by rope access.
- It is dark inside the box girder, and a scaffold would be needed because the maximum height is nearly 15 m. It would be difficult to insert a scaffold through the narrow inspection openings.
- Installation of a hanging scaffold, etc. for close-up visual inspection would be prohibitively expensive, with inspection costs estimated at over ¥200 million.

## Collaboration between robotic technology developers and local consultants

To introduce robotic technologies for local bridge inspection, the engineers of a local construction consulting firm need to understand the robotic technologies and be able to use these technologies to perform inspections. Therefore, in the demonstration testing of these technologies, the processes of inspection planning, calculation of expenses, implementation of demonstration testing, compilation of inspection results, and report preparation were performed collaboratively by the robotic technology developers and local construction consulting firms.

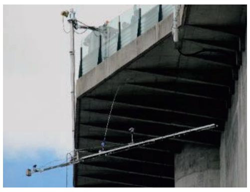
## Robotic technologies used in demonstration testing

The following four robotic technologies were used in

Shin-Nippon Nondestructive Inspection

Fujitsu

Sumitomo Mitsui Construction



Zivil Investigation Design

**Fig. 4** Robotic technologies used in demonstration testing

demonstration testing (Fig. 4).

- Monitoring system that uses robotic cameras and other devices for bridge inspection (Sumitomo Mitsui Construction)
- Flying robot based inspection system that performs close-up visual inspection and hammering tests (Shin-Nippon Nondestructive Inspection)
- Robotic system to support bridge inspection that is capable of acquiring close-up images with geo-tagging using a two-wheeled multi-copter (Fujitsu)
- Bridge inspection camera system for viewing and examination (Zivil Investigation Design)

## Participants in demonstration test implementation

Demonstration testing with an eye to the implementation of robotic technologies in the San'in region was implemented with the participation of Sakai Port Authority, which is the administrator, local governments in Tottori Prefecture and Shimane Prefecture, and engineers of construction consulting firms in both prefectures, as listed below.

[Participating organizations]
Tottori University, Tottori Prefecture, Shimane Prefecture, Sakai Port Authority, Tottori Construction Technology Center, Tottori Survey and Planning Association, Tottori Association of Concrete Consultants, Shimane Association of Planners and Surveyors, Shimane Association of Concrete Consultants, Keisoku Research Consultant Co., and Retec Engineering Corp.

## On-site demonstration testing

In demonstration testing, in addition to combined use of the four robotic technologies in inspections, we conducted accuracy confirmation testing concerning the detection performance of each of these technologies with regard to crack width, crack length, crack position, and so on (Fig. 5). The robotic technology

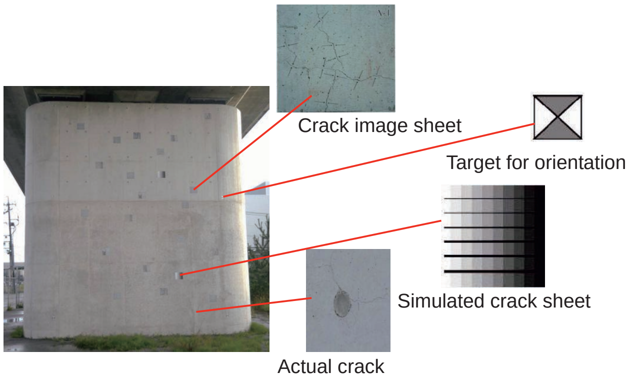



**Fig. 5** Accuracy confirmation tests

developers and engineers of local construction consulting firms collaborated in the implementation of inspections, and we obtained the comments of the construction consulting engineers concerning the use of the robotic technologies in bridge inspection.

## Benefits of robotic technologies

The benefits of using robotic technologies in bridge inspection are as follows.

- Robots can get to places that are not easily accessed by people.
- Close-up images captured by robots make it possible to detect cracks as narrow as 0.1 mm in width, which is not inferior to human eyesight.
- Images that cover the entire bridge can be recorded and retained as evidence of diagnostic results.
- The condition of the bridge can be visualized by constructing a 3-D model.
- The use of bridge inspection robots makes it possible to capture visible images even in the dark spaces inside box girders. Also, the equipment can be passed through a narrow inspection opening with relative ease.
- The efficiency of bridge inspection can be improved by using robotic technologies.

## Problems and improvement in robotic technologies

At the stage of compiling the results of demonstration testing, we discovered that it took a great deal of labor and time to identify damage such as cracks and create a damage chart based on the enormous quantities of images taken by the robots. Therefore, we synthesized the image data into developed images, displayed it at actual size using large-screen monitors and the like, measured crack width and length from the cracks displayed in this manner, and used these measurements to create a damage chart (Fig. 6). This improved the efficiency of work by reproducing the situation of close-up visual inspection next to a member of a bridge. Further improvements in work efficiency are anticipated in the future as advances in AI technology

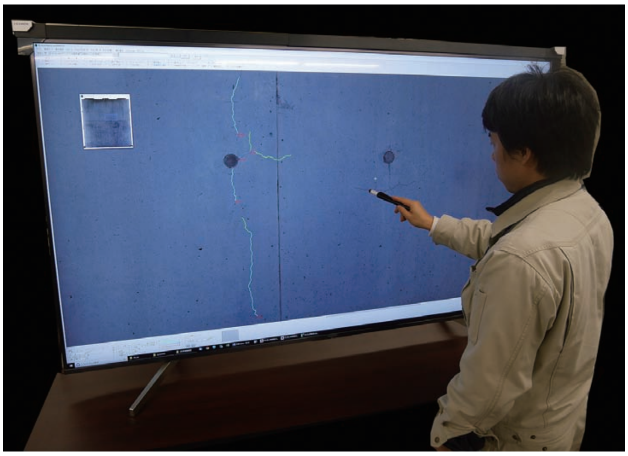


**Fig. 6** Virtual close-up visual inspection using a large touchscreen

will make it possible to automate the detection of cracks and the measurement of crack width and length.

## Comments from robotic technology users

[Administrator]

- Eshima Ohashi Bridge, which is managed by the Sakai Port Authority, is a long bridge that has high clearance because it crosses a freight shipping route, and bridge inspection by conventional methods is not feasible. We anticipate the establishment of inspection methods using robotic technologies through this project.

[Construction consulting engineers]

- Robotic cameras for bridge inspection were used in demonstration testing. The equipment was light and manually portable, and camera installation and operation using a tablet computer were also relatively easy. It was even possible to capture images inside a box girder, where hardly any light gets in, and I expect that it will become possible to use this in various places if some changes are made in the method of shooting images, the method of processing images after shooting, etc.
- More detailed inspection would be achievable by having an engineer with expertise in bridge inspection operate the robot directly.
- Based on the current situation of widespread drone utilization, I feel that this system is superior. I expect that the use of drones and the like will be indispensable in bridge inspection in the future.
- These technologies would seem to be effective in places that are dangerous to inspect (such as places that can only be inspected using rope access) and in cases where expensive equipment such as scaffolding is required for inspection.

# Efficiency improvement of crack inspection on bridges leading to remote islands using UAV digital image analysis technology

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## Needs related to bridge inspection in Okinawa Prefecture

First, we will discuss the need for structural inspection based on the geographical characteristics, natural environment, and salt damage environment of Okinawa Prefecture.

Because Okinawa Prefecture is an island region consisting of 160 islands, including uninhabited islands, many sea bridges linking remote islands with the main island or with other remote islands (remote island bridges) have been constructed. (See Fig. 1.) These remote island bridges are sea bridges, and the various types of inspections needed to confirm their soundness are subject to many constraints, making implementation difficult in some cases. Okinawa Prefecture is situated in a subtropical maritime climate, which is hot and humid throughout the year; and because it is surrounded by the sea on all sides, this region is subject to a severe salt damage environment, with rough winter seas and typhoons delivering high levels of salinity from the sea.

| No. | Name of bridge | Main type of bridge | Year completed | Bridge length (m) |
|---|---|---|---|---|
| 1 | Tobaru bridge | PC hollow girder bridge | Undergoing replacement | 17.00 |
| 2 | Ou bridge | PC hollow girder bridge | 1979 | 150.00 |
| 3 | Naneji-Ou bridge | PCT girder bridge | 1981 | 77.00 |
| 4 | Ikei bridge | Langer steel girder bottom-road bridge | 1981 | 198.35 |
| 5 | Sesoko bridge | Nielsen-Lohse steel bridge | 1984 | 762.00 |
| 6 | Yabuchi bridge | PC box girder | 1985 | 193.00 |
| 7 | Keruma bridge | PC rigid frame bridge | 1988 | 240.00 |
| 8 | Ikema bridge | PC box girder bridge | 1991 | 1,425.00 |
| 9 | Yagaji bridge | PC box girder bridge | 1992 | 300.00 |
| 10 | Kurima bridge | PC box girder bridge | 1994 | 1,690.00 |
| 11 | Miyagi bridge | Ogimi-mura | 1995 | 100.00 |
| 12 | Hamahiga bridge | PC box girder bridge | 1996 | 900.00 |
| 13 | Ou bridge | PC bridge | 1996 | 93.10 |
| 14 | Yoake bridge | PC hollow deck bridge | 1997 | 96.30 |
| 15 | Henza-Kaichu bridge | Cable stayed bridge | 1997 | 280.00 |
| 16 | Shioya bridge | PC box girder | 1998 | 360.00 |
| 17 | Aka bridge | Balanced arch bridge (PC) | 1998 | 530.00 |
| 18 | Noho bridge | PC variable cross-section box girder bridge | 2003 | 320.00 |
| 19 | Kouri bridge | PC box girder bridge | 2004 | 1,960.00 |
| 20 | Warumi bridge | RC fixed arch deck bridge | 2010 | 315.00 |
| 21 | Irabu bridge | PC box girder/steel girder (sea route portion) | 2014 | 3,540.00 |

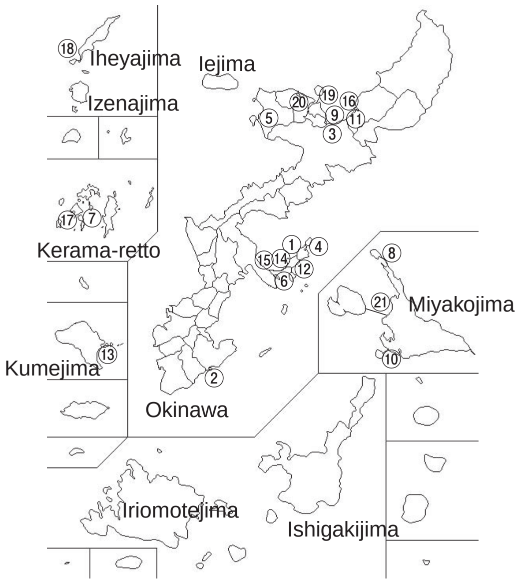



**Fig. 1** The island environment of Okinawa and list of remote island bridges (A total of 21 remote island bridges have been constructed.)

There is a high level of demand for new technologies for use in inspection of remote island bridges in Okinawa Prefecture, and this is an issue requiring urgent attention. In a survey concerning demand for new technologies that was conducted during SIP technical lectures held in Okinawa Prefecture, we found a high level of demand for remote inspection technologies.

## Summary of new technology (crack analysis technology + UAV imaging technology)

We will summarize the new technology presented in demonstration tests in Okinawa Prefecture, considering the prefecture's needs. The new technology referred to here indicates the development of a system using image analysis technology for quantitative assessment of cracks in floor slabs from a distance (Taisei Corporation's SIP technology), which is one of the technologies developed under SIP, and the use of high-precision UAV imaging technology in combination to support that technology.

Taisei Corporation's SIP technology is a technology for quantitative determination of crack width, length, and distribution (crack mapping) based on digital images of cracked concrete surfaces. This technology is a powerful tool for crack inspection, because it provides a crack width detection accuracy of 90% or higher if digital images are captured with the necessary pixel size for crack width analysis at the required level of accuracy. (See Fig. 2.) Therefore, technology for capturing high-definition digital images also plays an important role. Technical development is continuing in order to enable this technology to detect changes in concrete surfaces other than cracking, and it is currently capable of detecting free lime.

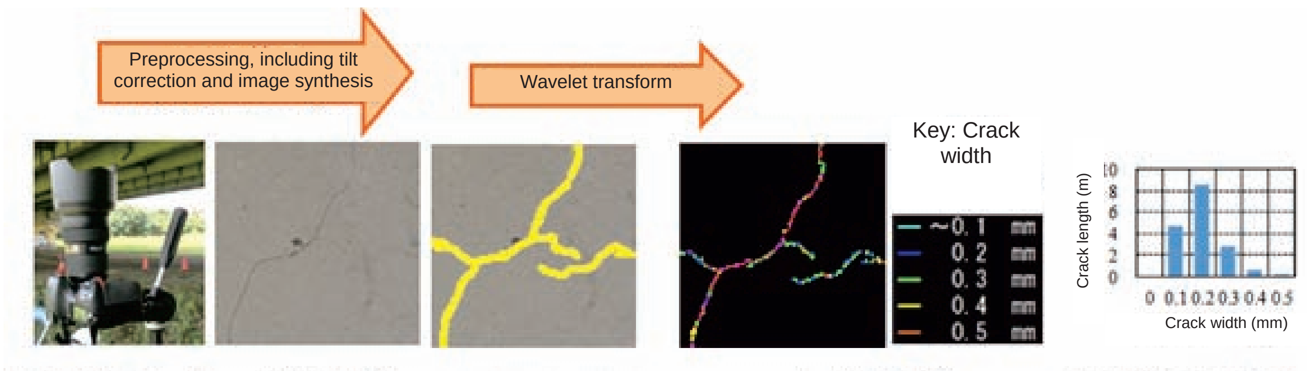
At the SIP program of the University of the Ryukyus, in order to implement and establish the use of Taisei Corporation's SIP technology in Okinawa Prefecture, a decision was made to position this technology as a technology for crack analysis using digital images, and to collaborate with local construction consultants who are actively utilizing ICT technologies for image capturing.

For the sake of UAV imaging with a high level of precision, it is necessary to address several areas, including high-performance UAV equipment, advanced UAV operation skills, photography skills and camera knowledge, and on-site surveys prior to imaging.

## Summary of successful demonstration testing proposed by an administrator

Based on a proposal from an administrator of structures (Central Okinawa Prefecture civil engineering office), it was decided that demonstration testing of the new technology would be conducted on one remote island bridge (PC box girder bridge) in Okinawa Prefecture in FY 2017. Subsequently, it was decided that demonstration testing would be conducted in FY 2017 on a total of four bridges (three remote island bridges and one river bridge), with the addition of one bridge each managed by the North Okinawa Prefecture civil engineering office and the Miyako civil engineering office of Okinawa Prefecture (two PC box girder remote island bridges) and one bridge managed by the North Okinawa national highway office of the Okinawa General Bureau (PCT girder river bridge). Contributing factors included the fact that an administrator participated in the initial demonstration test from planning to evaluation, gaining an understanding of the usefulness of the new technology, and publicity concerning the new technology (familiarization) at the SIP technical lectures conducted in the region.

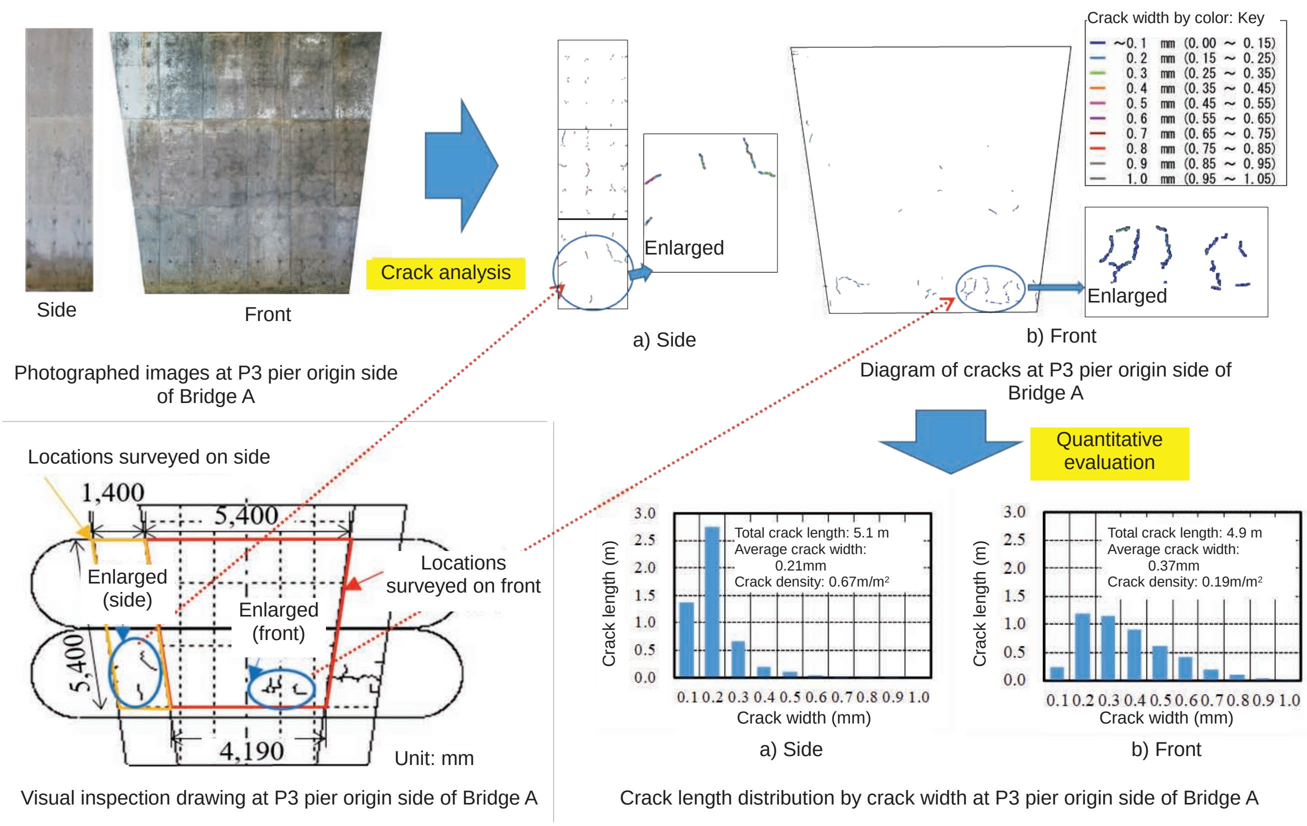
Fig. 3 shows an overview of the demonstration tests. (Demonstration testing was open to the public for the first one, Bridge A.)




1) Digital camera imaging
2) Input images (photographed images are processed)
3) Specifying scope of analysis (yellow portions)
4-1) Output images (crack images)
4-2) Crack length distribution by width

**Fig. 2** Cracking image analysis method (Taisei Corporation's SIP technology)


(a) Locations of demonstration tests and photographs




(b) Example of demonstration test results (Bridge A)

**Fig. 3** Demonstration test summary diagrams

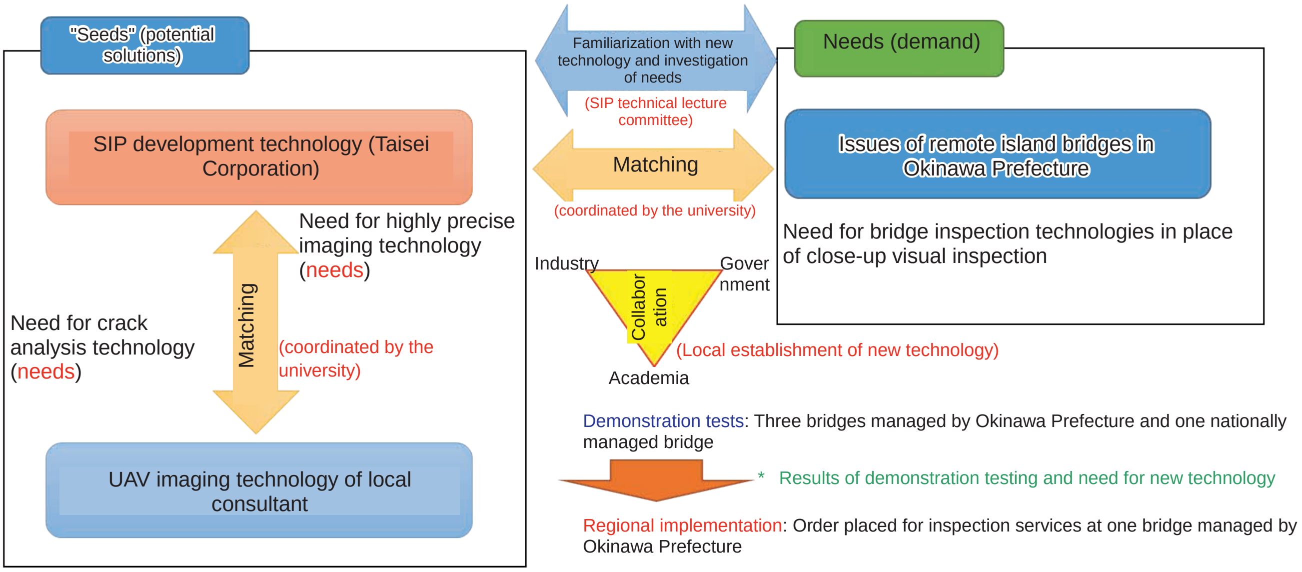



**Fig. 4** Success factors of regional implementation

## Success factors that led to regional implementation, and challenges

In this demonstration testing, the local construction consultant who was in charge of imaging signed a confidentiality agreement with Taisei Corporation concerning the use of Taisei Corporation's SIP technology, and the entire process from imaging to crack analysis was conducted in-house. As a result, the new technology was used in crack inspection as a part of inspection work on an inland elevated bridge (PCT girder + PC box girder bridge) that is subject to difficult close-up visual inspection using means such as bridge inspection vehicles, hanging scaffolds, and rope access. In other words, the SIP technology has been accepted as a technology used by local construction consultants, and is being implemented in the region.

We examined the success factors that led to regional implementation, along with the challenges, as follows, and compiled the success factors as shown in Fig. 4. One success factor was the important role played by academia in the SIP regional implementation team, including knowledge of "seeds" (potential solutions) as well as investigation of needs, along with efforts to make connections between the two (matching). In addition, the fact that demonstration testing was based on collaboration between local industry and academia is expected to contribute to better understanding of the new technology among administrators, as well as establishing it as a local technology.

Future challenges include constraints on close-up visual inspection, standards related to the new technology, and using it to detect changes other than cracking.

## Cost advantages, efficiency, and advancement of the new technology

For reference, with regard to the results of Fig. 3, we will briefly summarize the costs and work volumes in the case of crack inspection using the new technology in comparison to inspection using rope access.

We compared the cost of crack inspection using the new technology with the cost using rope access on an actual bridge (scope of survey: 12,200 $m^2$ bridge portion, 5,600 $m^2$ floor slab portion), with reference to unit prices for inspection as of 2017. As a result, we estimated that the cost when using this technology is only about 55% of the cost when using rope access. A major advantage is that on-site work is only about 10% compared to the conventional method (efficiency). In our comparison, we assumed that visual inspection by the conventional method ended with preparing a crack diagram, but we assumed that investigation using the new technology would also include quantitative evaluation of crack width and length (advancement). In this cost comparison, the calculated cost advantage is large because of the extensive scope of investigation, and a smaller cost advantage would be expected in the case of a smaller-scale bridge; therefore, it must be noted that the cost would not decline to 55% of the conventional cost in every case.

# Deployment

# Development and deployment of the Tohoku Infrastructure Management Platform (TIMP)

**Makoto HISADA**

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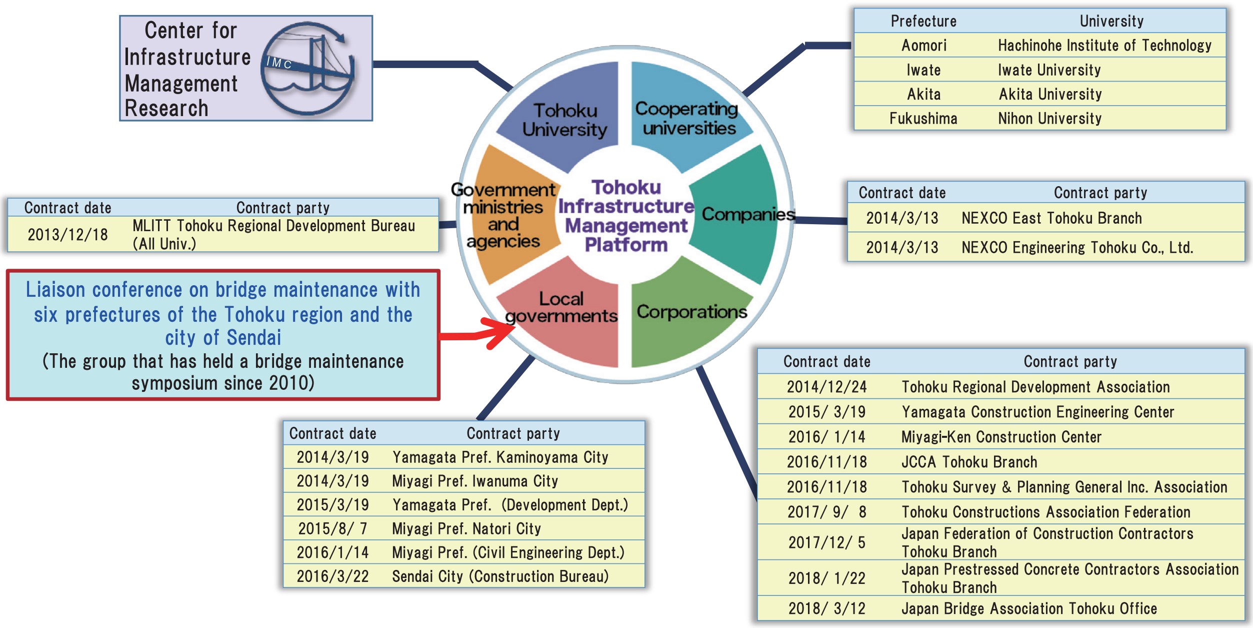
Tohoku University

## Summary of the Tohoku Infrastructure Management Platform

The Tohoku Infrastructure Management Platform (referred to below as the "TIMP") was developed as a means for universities, other research institutions, companies, government ministries and agencies, and local governments to share information with each other and cooperate together in order to make full use of the capabilities of each organization for the good of society. Its purpose is to promote implementation by creating a network that links industry, academia, and government in the Tohoku region for the sharing and improvement of knowledge and technologies related to research and development on infrastructure maintenance.

The framework for management of TIMP was developed mainly by the Center for Infrastructure Management Research (referred to below as "Tohoku University IMC" and Tohoku University, a research and development group.). The constituent members of the TIMP include Tohoku University IMC, related organizations that have concluded cooperation agreements regarding infrastructure maintenance, a government-academia liaison conference on bridge maintenance that includes six prefectures of the Tohoku region and the city of Sendai and is administered by the Tohoku Regional Development Bureau of the Ministry of Land, Infrastructure, Transport and Tourism, and four universities that are leading institutions in their respective prefectures, as well as constituent members of this project, as core members (Fig. 1).

The kickoff of this TIMP was announced at the 8th symposium on maintenance of bridges in the Tohoku




| Prefecture | University |
|---|---|
| Aomori | Hachinohe Institute of Technology |
| Iwate | Iwate University |
| Akita | Akita University |
| Fukushima | Nihon University |

| Contract date | Contract party |
|---|---|
| 2013/12/18 | MLITT Tohoku Regional Development Bureau (All Univ.) |

| Contract date | Contract party |
|---|---|
| 2014/3/13 | NEXCO East Tohoku Branch |
| 2014/3/13 | NEXCO Engineering Tohoku Co., Ltd. |

| Contract date | Contract party |
|---|---|
| 2014/3/19 | Yamagata Pref. Kaminoyama City |
| 2014/3/19 | Miyagi Pref. Iwanuma City |
| 2015/3/19 | Yamagata Pref. (Development Dept.) |
| 2015/8/ 7 | Miyagi Pref. Natori City |
| 2016/1/14 | Miyagi Pref. (Civil Engineering Dept.) |
| 2016/3/22 | Sendai City (Construction Bureau) |

| Contract date | Contract party |
|---|---|
| 2014/12/24 | Tohoku Regional Development Association |
| 2015/ 3/19 | Yamagata Construction Engineering Center |
| 2016/ 1/14 | Miyagi-Ken Construction Center |
| 2016/11/18 | JCCA Tohoku Branch |
| 2016/11/18 | Tohoku Survey & Planning General Inc. Association |
| 2017/ 9/ 8 | Tohoku Constructions Association Federation |
| 2017/12/ 5 | Japan Federation of Construction Contractors Tohoku Branch |
| 2018/ 1/22 | Japan Prestressed Concrete Contractors Association Tohoku Branch |
| 2018/ 3/12 | Japan Bridge Association Tohoku Office |

**Fig. 1** Cooperative framework of the Tohoku Infrastructure Management Platform (TIMP)

region (organized by the Tohoku Branch of JSCE, the Tohoku Regional Development Bureau of the Ministry of Land, Infrastructure, Transport and Tourism, and Tohoku University IMC), which was held on January 30, 2017. A council on the TIMP was held on May 18, 2017, and further activities are planned in the future. Even after the launch of this platform, Tohoku University IMC has concluded agreements concerning infrastructure maintenance with various organizations, and it is still adding members who will participate in the platform council.

## Comments from participating organizations

### Sendai City Construction Bureau

Many of the bridges and tunnels that were built during Japan's period of rapid economic growth are now in a state of increasing deterioration. We are working to conserve our infrastructure in an effective and efficient manner, and it is necessary to improve our capabilities, including improvement of technical capabilities and other changes in organizational systems.

This platform has been developed to cope with such challenges, and the city of Sendai has participated since the platform was first launched, using it for information sharing and improvement of technical capabilities, etc.

**Fig. 2** Demonstration testing of spherical shell drone on bridge substructure

**Fig. 3** Participating in an infrastructure maintenance study group

One of the specific endeavors in which we are participating is demonstration testing of bridge inspection using a spherical shell drone (Fig. 2), which is expected to contribute to improving the efficiency of inspection and reducing costs.[1)]

We are also participating in a study group for local government officials who are involved in infrastructure maintenance, and it has been very meaningful to be able to exchange information on new technologies, construction methods, and the like, in addition to sharing about the challenges faced by each local government.

In addition to its function of providing venues for strategy meetings so that industry, academia, and government can join forces to address infrastructure challenges that are not easily resolved by government organizations alone, we also anticipate that the TIMP will contribute to human resource development for the next generation of facility managers and engineers.

### Tohoku Branch of the East Nippon Expressway Company Ltd.

The NEXCO East Japan Group is focusing on contributing to communities through technical support for local governments, etc. as a priority plan under the basic policy of its medium-term management plan. The Tohoku Branch has concluded a mutual cooperating agreement concerning support for local governments in the area of maintenance and management, which is addressed by Tohoku University IMC. To achieve that purpose, the Tohoku Branch Group has been actively participating in the infrastructure maintenance study groups which are held for local governments by Tohoku University IMC.

At the infrastructure maintenance study group (Fig. 3), we engage directly in discussions of issues related to periodic inspection, repair plans, and repair methods, etc. for bridges and pavement managed by local governments. We have offered technical problem-solving advice and introduced maintenance methods based on the expertise developed by the Tohoku Branch Group in our work on expressways, while exchanging views with regard to realistic approaches. We appreciate the opportunity to do what we can to contribute to communities in this way, as an instance of technical support through personal networks by way of the platform with collaboration among industry, academia, and government.

[Reference]
1) Tohoku University IMC: https://www.tohoku.ac.jp/japanese/2017/05/award20170519-01.html

D-2

# Evaluation and utilization of new technologies in collaboration with the Kyushu Association for Bridge and Structural Engineering (KABSE)

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Graduate School of Engineering

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## Deployment in the Kyushu and Yamaguchi regions

Nagasaki University has continued its "Michimori" program, which trains human resources in road maintenance with close cooperation among industry, government, and academia, since FY 2008. A system is in place whereby persons who have completed the training program can serve as maintenance experts under Nagasaki Prefecture, engaging in maintenance services and projects with the latest technologies for inspection and diagnosis. Because the "Michimori" training program has earned public acclaim, we determined that it could meet a need for R&D on asset management technology under SIP.

A network has been formed to facilitate collaborative research and development in the Kyushu and Yamaguchi regions through training sessions and subcommittees of researchers and engineers working for each prefecture, with the Kyushu Association for Bridge and Structural Engineering (KABSE) playing a leading role.

## Organizational structure of the SIP Nagasaki University team

The organizational structure of the SIP Nagasaki University team is shown in Fig. 1. This figure shows the implementation support groups, in which small groups were established for each of the eight prefectures of the Kyushu and Yamaguchi regions and one person was appointed to represent each prefecture, for the sake of supporting implementation and building collaboration with the local governments of these prefectures.

As shown in Fig. 2, the participating members of KABSE include infrastructure administrators from the Ministry of Land, Infrastructure, Transport and Tourism, the seven prefectures and three designated cities of of Kyushu, and other organizations. Therefore, collaboration with KABSE is essential for smooth implementation of new technologies or procurement of demonstration fields. In fact, the SIP Nagasaki University team is planning to use bridges managed by the Kyushu Regional Development Bureau of the Ministry of Land, Infrastructure, Transport and Tourism in field demonstration tests in November of this year.

## Activities of the KABSE-SIP Subcommittee

The KABSE-SIP Subcommittee was established for the purpose of promoting the implementation of new technologies from the SIP Infrastructure Program in the periodic inspection of bridges in the Kyushu and Yamaguchi regions, especially small and medium-sized bridges. It evaluates new technologies that have been researched and developed under the development topics of the SIP Infrastructure Program, and studies issues and solutions related to implementation of these new technologies, especially with regard to maintenance of public infrastructure managed by local governments of the Kyushu and Yamaguchi regions. The activity period is FY 2017 - 2018, and three general subcommittee meetings have been held to date.

The following are the two main activity areas of the KABSE-SIP Subcommittee. WG1 works on matching between SIP topics and issues in the field. WG2 works on evaluation and analysis of demonstration test results.

In addition, at a technical exchange session of the SIP Infrastructure Program held on July 19, 2018, information was gathered concerning the following six questions as part of the activities of the KABSE-SIP Subcommittee with respect to development topics of the SIP Infrastructure Program that contribute to maintenance operations for the exhibited bridges.

(1) What is the current level of attainment with regard to the initial goals of R&D?

(2) Has field demonstration testing been requested by a regional implementation support team? Did the

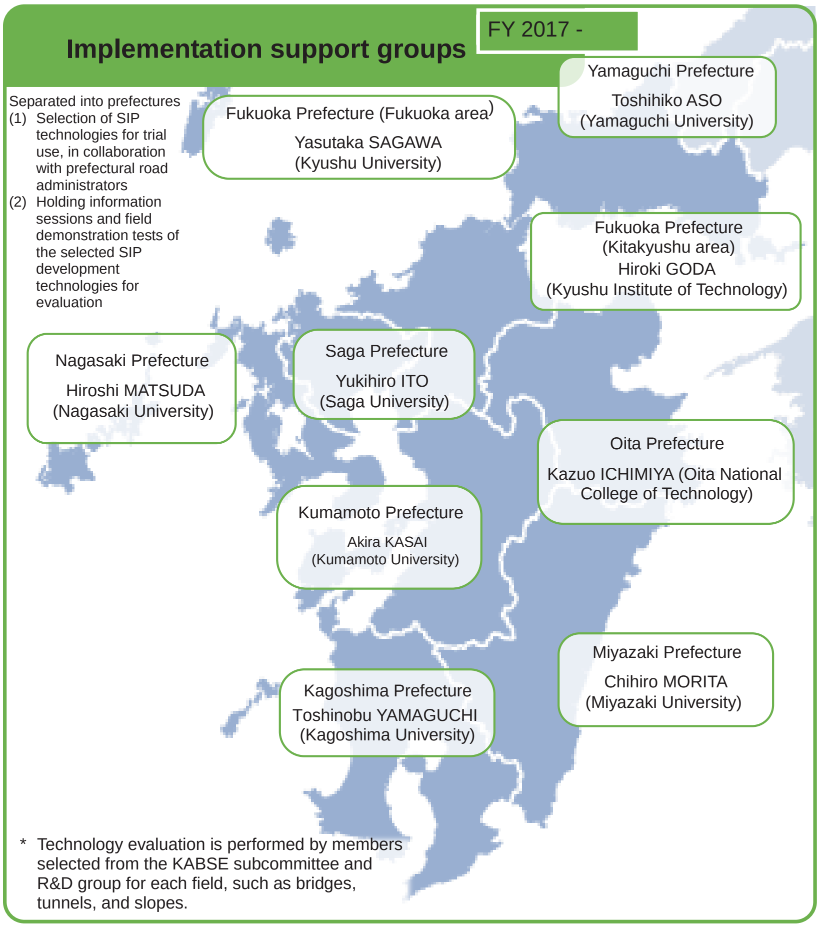


**Fig. 1** Organizational structure of the SIP Nagasaki University team

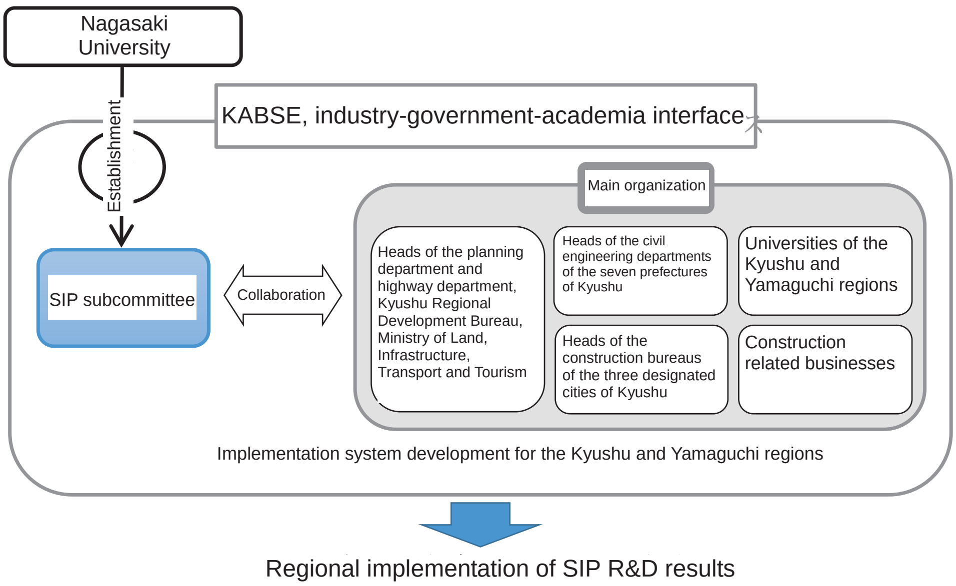


**Fig. 2** Organizational structure of the KABSE-SIP Subcommittee

measurement results adequately meet the required accuracy?

(3) Is there a track record of implementation in actual operations such as periodic inspections?

(4) Has an action plan being considered for R&D and implementation in the next fiscal year and beyond?

(5) Which area of operations is the most likely for implementation of the development topic: periodic inspection, detailed investigation, or repair design, etc.? (Is it a shortcut?)

The results of the gathered information are currently being compiled, and we would like to submit a future report including the results of the above activities by both working groups.

# Personnel training for municipality staff in Hokuriku region

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## Technological Exhibition in Countryside

The frequency of exhibitions on a new technology or item was low in the countryside, including the Hokuriku region. Moreover, time and travel expenses of the municipality staff who went to Tokyo Big Sight were insufficient. Therefore, new information was not available easily. A local technological exhibition intended for the municipality staff was held in the Hokuriku region based on such background.

Table 1 and Fig.1 show the outline of the technological exhibition. They were held at two venues separately in the morning and afternoon at the request of the municipality staff and exhibition engineers. Moreover, the schedule was decided while excluding the holding period of the Congress and the period of clearing snow.

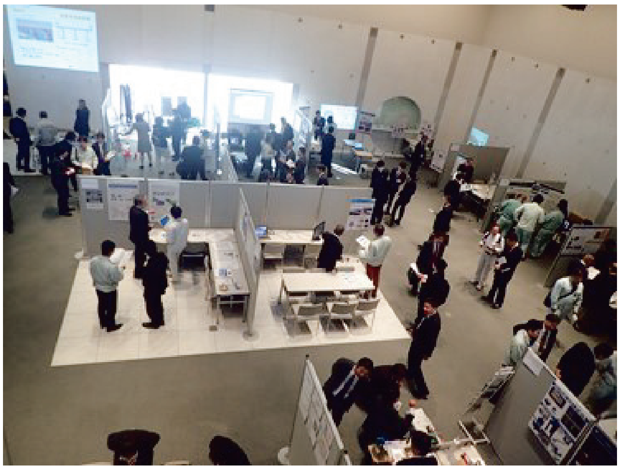
Fig.2 shows the occupational category of the participants in a technological exhibition. It can be confirmed that municipality staff accounted for approximately 30% of the participants. Therefore, it is assumed that a technological exhibition can be held for the municipality staff in the Hokuriku region as it is an original purpose.

Table 2 lists the exhibition theme. The number of themes related to inspection was 11, themes related to repair was 5, and two themes were categorized as others.

**Table 1** Overview of technological exhibition

| Venue | Date | Time | Number of participants |
|---|---|---|---|
| Kanazawa Institute of Technology | 6-Nov-17 | 10 - 12 | 139 |
| Toyama citizens plaza | | 15 - 17 | 86 |

(1) Kanazawa



(2) Toyama

**Fig. 1** Situation of technological exhibition

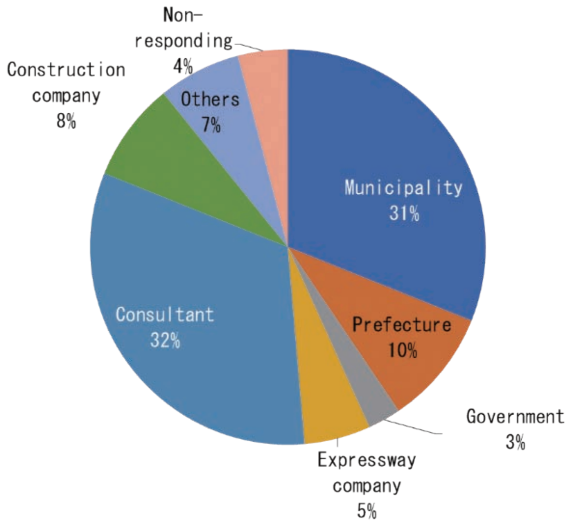



**Fig. 2** Standpoint (occupational category) of participant to technological exhibition

**Table 2** List of exhibition theme

| | Theme | Category |
|---|---|---|
| A | 3D high-speed running type tunnel inspection system | inspection |
| B | Hitting inspection system using artificial intelligence | inspection |
| C | Bridge inspection robot camera | inspection |
| D | Flying robot with hitting inspection for inspection of bridge and tunnel | inspection |
| E | Flight type infrastructure inspection robot system | inspection |
| F | Bridge inspection system with tablet | inspection |
| G | Preventive maintenance with surface penetrant material | repair |
| H | Surface coating method with special urethane resin | repair |
| I | Repair method that prevents re-deterioration | repair |
| J | Deterioration investigation technology of structure | inspection |
| K | Synthetic repair technology of concrete and steel structures | repair |
| L | Chloride attack monitoring technology | inspection |
| M | Maintenance technology for bridge | repair |
| N* | Remote taking picture using drone and radio controller board | inspection |
| O | Monitor system that used business wireless line | inspection |
| P | Technology of alkali silica reaction simplicity judgment and frost attack resistance judgment | inspection |
| Q | Concrete fall measures and latest anchor technology | other |
| R | Healthy judgment support system that uses artificial intelligence technology | other |

* only Kanazawa venue

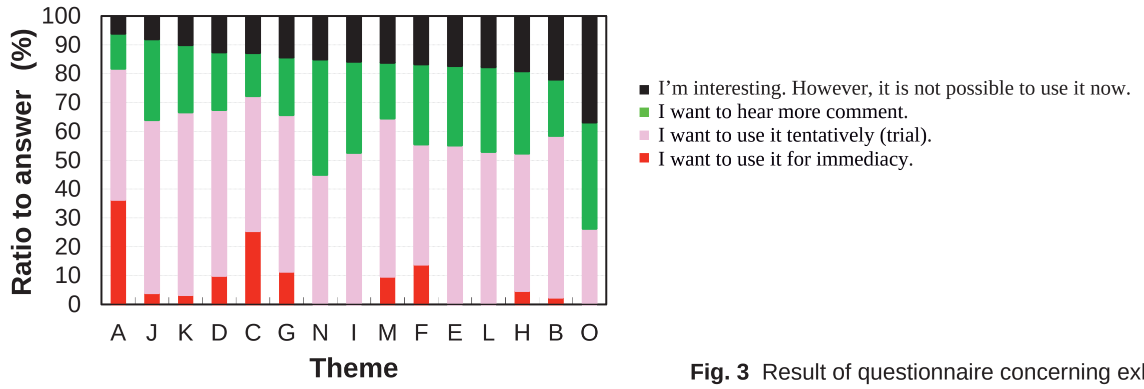



**Fig. 3** Result of questionnaire concerning exhibition theme

Figure 3 shows the result of the questionnaire concerning the exhibition theme. Herein, the theme with positive answers was arranged from the left end such as "I want to use it for immediacy," "I want to use it tentatively (trial)," and "I want to hear more comment." According to this figure, there were a lot of positive answers in themes related to inspection (A, C, D, and J). In particular, not the advanced inspection that only the engineer with high special equipment and ability was able to use but a simple inspection was desire for. On the other hand, positive answers to themes related to repair were comparatively few. This is because in a current municipality, the inspection of road bridges is an obligation. Even if the part that required repair was discovered, the repair cost is not available easily. As a result, it is difficult to repair.

Figure 4 shows the impression of an exhibition. A significant technological exhibition accounted for approximately 80% according to this figure. Furthermore, a preferable frequency of the exhibition is shown in Figure 5. There were a lot of answers that about once per year was good according to this figure.

## Holding such seminars

The frequency of technical workshops conducted by the academic society is also low in the Hokuriku region. Based on such a background, seminars and site excursions for the municipality staff in the Hokuriku region were conducted as shown in Table 3, Fig.6 and Fig.7.

The questionnaire was distributed to the participants in the seminar that was held on March 14, 2017. Figure 8 shows the results of the study concerning maintenance (selection type and multiple answers allowed). In addition, the chance of the seminar concerning maintenance is shown in Figure 9. According to these figures, it can be confirmed that some municipality staff member felt the necessity of a study concerning the maintenance of road bridges. However, such chances were insufficient even though there were various situations. Therefore, it can be judged that these seminar and site excursion are expected for holdings.

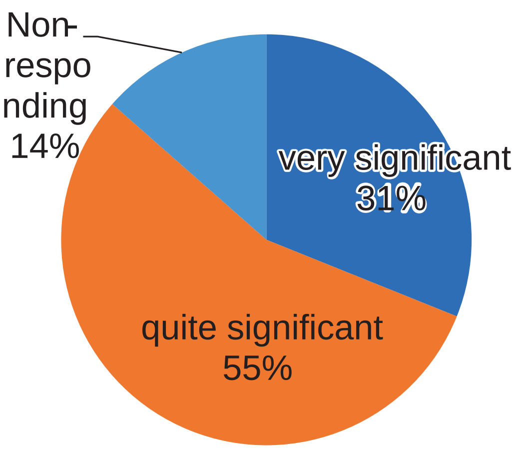



**Fig. 4** Impression of exhibition

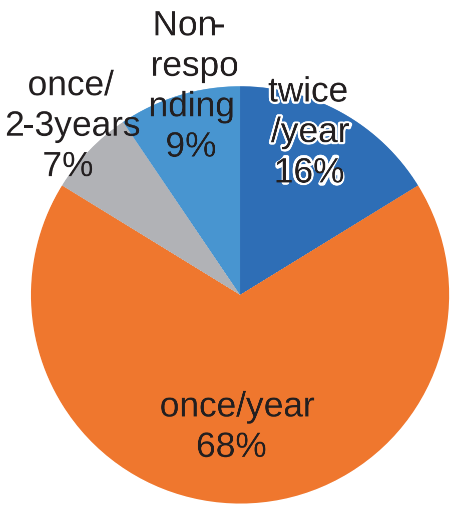



**Fig. 5** Preferable frequency of exhibition

**Fig. 6** Situation of seminar

**Fig. 7** Situation of site excursion

**Table 3** List of seminars conducted by SIP in the Hokuriku region

| Date | Venue | Theme | Number of participants |
|---|---|---|---|
| 2014.12.9 | KKR Hotel Kanazawa | Kicking off symposium | 96 |
| 2015.3.27 | Kanazawa University | Examples of chloride attack deterioration and measurement using electric anti-corrosion method for concrete bridge | 112 |
| 2015.8.28 | Toyama Prefectural Civic Center | Lecture for municipality staff in Toyama Prefecture | 40 |
| 2015.9.1 | Industrial Technology Center of Fukui | Lecture for municipality staff in Fukui Prefecture | 38 |
| 2015.9.25 | Kanazawa University | What to do for settlement of ASR issue in Hokuriku region now? | 106 |
| 2015.10.1 | Ishikawa Industrial Promotion Center | Lecture for municipality staff in Ishikawa Prefecture | 50 |
| 2016.6.3 | Kanazawa University Satellite Plaza | Approach that evolves inspection and investigation for efficient maintenance | 70 |
| 2016.7.29 | Kanazawa University | Use of flyash concrete | 120 |
| 2016.9.13 | Kanazawa Miyako Hotel | Symposium about bridge management | 80 |
| 2016.9.30 | KKR Hotel Kanazawa | Aim at solution of problem concerning ASR in Hokuriku region. | 140 |
| 2017.3.14 | Kanazawa Institute of Technology | Guidance of activity results by WG1 | 230 |
| 2017.3.24 | University of Fukui | Open experiment about performance decrease of aging bridge | 34 |
| 2017.5.18 | Kanazawa University Satellite Plaza | Special lecture about bridge asset management | 90 |
| 2017.6.1 | Kanazawa University | Aim at use of flyash concrete in Hokuriku region. | 130 |
| 2017.6.14<br>2017.7.19 | Kanazawa University | GIS workshop (first)<br>(second) | 13<br>17 |
| 2017.7.28 | Toyama Prefectural University | About performance decrease of aging bridge and movement for appropriate maintenance | 45 |
| 2017.12.7 | KKR Hotel Kanazawa | Guidance of activity results of SIP research result in FY2017 | 110 |
| 2018.4.27 | Ishikawa Industrial Promotion Center | How to promoted talent who maintain in the future? | 200 |
| 2018.9.7 | KKR Hotel Kanazawa | Regional mounting of flyash concrete | 120 |
| 2018.11.21 | Fukui Prefecture Kenmin hall | Think about technology for maintenance in the future | 360 |
| 2019.2.15 | Sky Intec TOWER111 | What is necessary for technology and talent who supports maintenance in the future? | 200 |

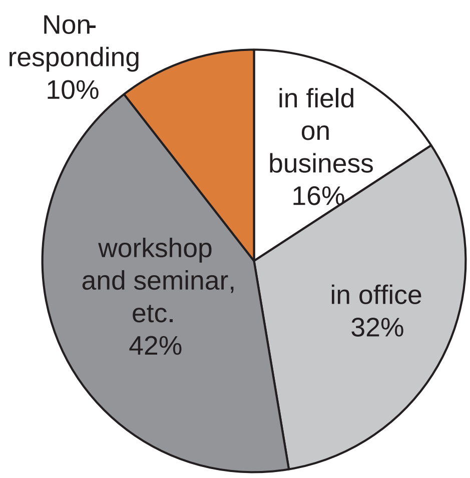



**Fig. 8** Study method concerning maintenance of municipality staff

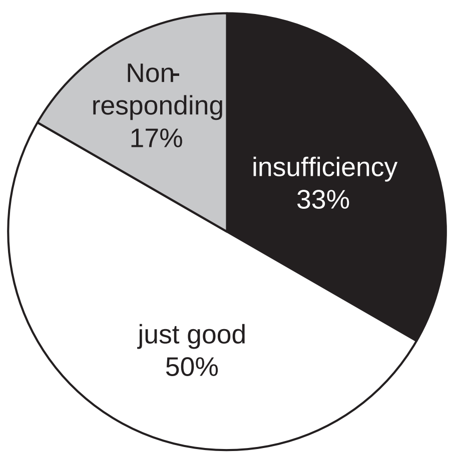



**Fig. 9** Chance of study concerning maintenance of municipality staff

D-4

# Report on support for regional implementation: "Super Michimori" concept for new technology implementation

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## Summary of Michimori (road maintenance) training program and activities of certified persons

Nagasaki University's Michimori training program, which began in FY 2008, is now registered by the Ministry of Land, Infrastructure, Transport and Tourism as a private qualification for inspection and diagnosis. The educational program of Michimori training is based on accumulated study units, and consists of three steps for engineers: a Michimori assistant course, a specified Michimori course, and a Michimori course. (See Fig. 1.) As of April 2018, this program has trained 260 persons as Assistant Michimori, 62 persons as Specified Michimori, and 31 persons as Michimori. The number of persons for training was determined in consideration of the number of bridges and road slopes maintained by each of the promotion bureaus, in collaboration with Nagasaki Prefecture in the construction industry; therefore, these persons are being trained all over the prefecture, and the number of trainees reflects a regional balance.

## Proposing the use of new technologies

At a January 2015 conference for industry-government-academia collaboration on securing and training human resources in the construction industry, which was organized by the construction industry federation of Nagasaki Prefecture after the Ministry of Land, Infrastructure, Transport and Tourism established registration of persons with Michimori certification as a

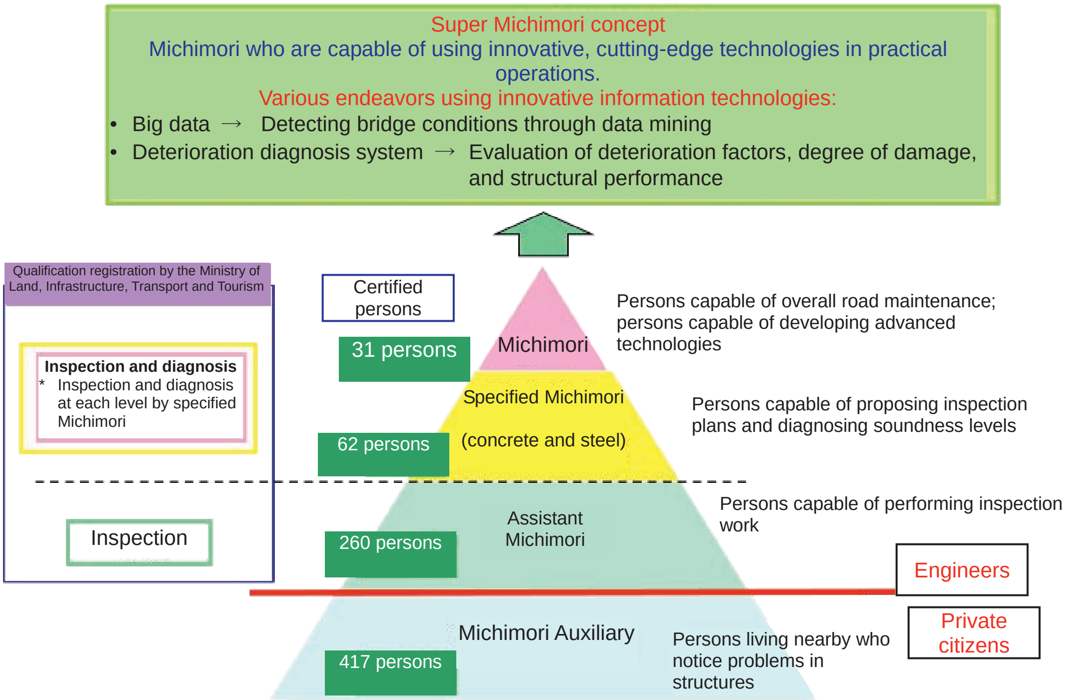


**Fig. 1** Content and stages of Michimori training courses

private qualification in FY 2014, Hiroshi Matsuda of Nagasaki University proposed the utilization of persons with Michimori certification, and a working group was established to study Michimori utilization.

Its business plan includes studying the introduction and dissemination of new technologies, in addition to training human resources in the maintenance of public infrastructure and making use of their qualifications, based on collaboration among industry, government, and academia. As a result of utilizing new technologies, if persons with Michimori certification engage in maintenance and construction work while making use of the latest technologies developed by universities, etc. for inspection, diagnosis, and repairs, this can be expected to produce benefits such as ensuring quality while reducing costs, improving the competitiveness of the regional construction industry, and creating jobs.

## Super Michimori concept

Just at the stage of promoting actual utilization of new technologies, a public invitation was issued for regional implementation support of SIP infrastructure (abbreviated as "SIP"), and as an institution handling regional implementation of SIP development technologies, etc., Nagasaki University proposed a plan based on persons having Michimori certification. In collaboration with other entities including Nagasaki Prefecture, we conducted training for "Super Michimori" by holding technical lectures for persons with Michimori certification, in order to train persons having Michimori certification to utilize new technologies in inspection, diagnosis, repair, etc. (See Fig. 1.) When the regional implementation support project was begun, in preparation for Super Michimori training, we informed persons having Michimori certification of the SIP technology information sessions and the planned field demonstration tests, and invited them to attend. Persons with Michimori certification were present at each of the information sessions, etc., and actively offered advice concerning the utilization of new technologies, based on their own practical work experience.

**Table 1** Did you know that research and development is being conducted on maintenance, updating, and management technologies under SIP? (N=69)

| Response | % |
|---|---|
| Yes, and I looked into the content of the technologies subject to R&D. | 31 |
| Yes, but I am not aware of the content of the technologies subject to R&D. | 39 |
| No. | 30 |

## Questionnaire survey for persons with Michimori certification

We will discuss the results of a questionnaire survey on familiarity with SIP and Super Michimori targeting 93 persons with Michimori certification who were considered candidates for the Super Michimori training (Specified Michimori and Michimori). As shown in Table 1, when asked whether they knew about the research and development that is being conducted on maintenance, updating, and management technologies under SIP, 70% said "yes," and 31%, or about one third, stated that they had looked into the specific content of the technologies subject to research and development. Concerning the role of Nagasaki University, 54% knew that it is a base for regional implementation support in the Kyushu-Yamaguchi region, and had learned about the content of its activities by participating in technical information sessions and field demonstration tests, or by reading descriptions in publications, etc. (See Table 2.)

**Table 2** Did you know that Nagasaki University is a base for regional implementation support in the Kyushu-Yamaguchi region? (N=69)

| Response | % |
|---|---|
| Yes, and I attended technical information sessions or field demonstration tests. | 17 |
| Yes, and I read about the content in a publication or newspaper, etc. | 19 |
| Yes, but I do not know about the content of its activities. | 18 |
| No. | 46 |

At that stage, we had not yet provided specific information such as the program for the Super Michimori course, but we asked their views concerning the Super Michimori concept and obtained the results shown in Fig. 2. Positive reactions were obtained from 47%, or about half. Very few had negative reactions, but about 49% responded "I can't judge" because of the lack of information as a basis for judgment at that time. When asked about their interest if a Super Michimori course is offered, 36% stated that they would like to attend.

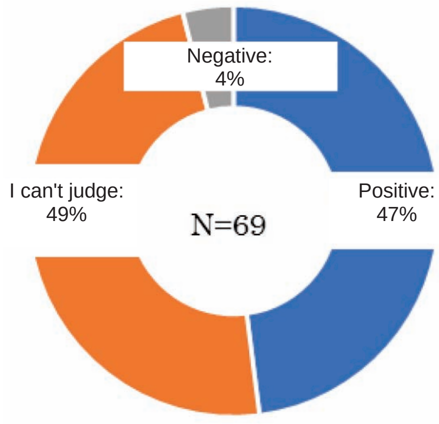


**Fig. 2** How do you feel about the Super Michimori concept?

Persons with Michimori certification have developed a better awareness concerning SIP through the SIP regional implementation support activities, but there is still room for improvement. The next step will be to put the Super Michimori concept into practice as it becomes possible to use SIP development technologies in the field.

# From Okinawa: Bridge inspector training to improve practical bridge inspection skills

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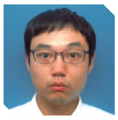

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## Bridge inspector training

To ensure accuracy in periodic bridge inspection and improve the skills of bridge inspection engineers, a bridge inspector training program has been launched by the University of the Ryukyus' SIP program as a means of providing training to bridge inspection engineers, and the FY 2017 training session was held on November 18 and 19, 2017.

This training is designed for technical personnel who perform close-up visual inspection as part of periodic bridge inspections, with the purpose of enabling them to conduct accurate, appropriate bridge inspections in Okinawa Prefecture by acquiring the knowledge and inspection skills needed for bridge inspection and developing an understanding of the characteristics of fatigue damage caused by strong winds and damage from salt corrosion due to the environment of Okinawa.

The content of training is as follows. The first day was used for classroom learning, with general information concerning bridge inspection, an overview based on the periodic bridge inspection guidelines issued by the Ministry of Land, Infrastructure, Transport and Tourism in June 2014, a description of specific cases of damage seen in Okinawa in concrete bridges, steel bridges, etc., and information concerning the latest maintenance technologies. On the second day, participants learned practical skills (hammer sounding test, damage diagram sketching, etc.) and were tested at the end of the training session, and those who passed the test were given the title of "bridge inspector." In addition, researchers of SIP development technologies were invited to introduce their work. The bridge inspector certification examination covers knowledge necessary for investigation and inspection work during actual bridge inspections, and confirms that inspections are performed accurately. The lecturers are faculty members of the Civil Engineering Program at the Faculty of Engineering, University of the Ryukyus, and specialized engineers employed by the national government, prefectural government, municipal governments, or private companies, etc. Most of the training participants are engineers involved in periodic bridge inspection work, and engineers in charge of bridge inspections at ordering institutions can also participate.

## Questionnaire survey of training participants

Classroom learning, practical skill training using an actual salt-damaged girder, and an examination were carried out over a two-day period in FY 2017 (Photo 1). There were 44 participants in the training session, and 14 of them passed the examination (success rate: 31.8%). Based on a questionnaire survey of training participants, most of the participants were supervisors and people in charge of performing actual inspection work at prime contractor and subcontractor firms. Based on responses concerning their actual duties, participants were responsible for a variety of tasks, including preparation of inspection plans, preparation of damage diagrams in the field, and preparation of inspection records and reports. In their responses concerning the training session, many participants indicated that they would welcome classes for ongoing skill improvement, and that they find it useful to participate in sessions that include practical skill training. Based on these results, the content of the training session appears to be consistent with the actual work duties of participants, and ongoing education of technical personnel through training sessions is considered to be important in improving technical capabilities and inspection accuracy in bridge inspection in Okinawa Prefecture.

**Photo. 1** Training session (left: classroom learning; right: practical training)

Table 1 shows participants' comments concerning the inspection guidelines used in the training session. Many respondents stated that it was difficult to decide how to judge and classify damage, and that the results would tend to vary among individuals. Table 2 indicates responses to a questionnaire conducted on the first day of the training session with regard to a SIP development technology concerning research and development on an inspection system based on flying robots using close-up visual inspection and hammer sounding. In their responses, many participants stated that they hope to use SIP development technologies in actual inspection work, that they would find it useful to have technology that can reduce individual variability in inspections, and that they would welcome further technological development. These responses indicate that participants have high expectations concerning new inspection services that will utilize new technologies.

**Table 1** Comments concerning the inspection guidelines

✓ It is difficult to determine the countermeasure classification.
✓ I think confusion would arise regarding judgments at the stage of practical work.
✓ Objective evaluation is difficult in some cases, including the extent of damage.
✓ Subjectivity cannot be avoided in close-up inspection, etc. It is necessary to have a detailed understanding of the content in order to minimize that element of subjectivity.
✓ There need to be a lot more diagrams and photographs showing examples of damage. As it is, results would vary widely among individuals who conduct inspections.
✓ If there were models of inspection records (examples of how to fill them out), it would be easier to understand about the results of periodic inspections.
✓ I think it would be very helpful to have many photos of examples.
✓ How to classify in cases where members have a three-dimensional arrangement (arranged vertically and horizontally) when assigning member numbers inside a box girder.
✓ I think it would be easier to understand if there was something like a flowchart explanation based on photos, as far as a determination of damage.
✓ Photos of damage cases would make it easier to understand.
✓ It is difficult to draw a distinction in the determination of Corrosion versus Degradation of anti-corrosion function, and there would be differences among individuals.
✓ Phrasing to describe similar kinds of damage.
✓ When there is significant deterioration in a bridge pier's RC lining, steel plate adhesion, and adhesion of carbon fiber sheets on the lower surface of a floor slab, etc., how should inspection of the main bridge structure be handled?
✓ What should be done when a surface is covered by plants?
✓ The boundary for determining whether the reduction in plate thickness is a large or small depth of damage due to corrosion.
✓ Determination in cases where deterioration is local in scope and rust spots have appeared in Corrosion and Degradation of anti-corrosion function.
✓ Training for eliminating variability among individuals in damage determinations. Also, different companies have different approaches to assigning element numbers.
✓ Determinations are difficult, and individual differences exist.
✓ Damage evaluation (what extent would constitute c1 or c2, etc.)
✓ How to assign element numbers in sections having irregular installation, such as elements (gutters underneath) to prevent dripping from drain pipes (cables, concrete blocks, widening elements).
✓ One is not always sure of how to classify the extent or degree with regard to damage evaluation criteria.
✓ It is difficult to make overall judgments of the damage evaluation criteria because there are only a few inspection tests. I hope to see many more sites and try hard to avoid overlooking anything or making inappropriate assessments.

**Table 2** Comments concerning SIP development technology

- ✓ I would like to see the use of wireless power transmission in investigation at the visual inspection level.
- ✓ What is the planned price for leasing and purchase?
- ✓ Can the equipment be made more compact?
- ✓ Isn't there any other inspection method than hammering (such as infrared, laser, ultrasound, etc.)?
- ✓ The explanations focused mostly on concrete bridges, but is this also being considered for use in the inspection of steel bridges?
- ✓ The use of hammer robots for hammer sounding could be expected to reduce inspection errors due to individual differences in inspection using hammer sounding. This could be useful in future investigation methods if there is a way to preserve investigation results from hammer sounding in written form, in addition to merely checking in the field.
- ✓ I think this method is very effective in terms of economic efficiency and the shortage of human resources, as well. I am concerned about how it could be used in places with high winds such as sea bridges, and about the supply of inspection robots if orders increase. With regard to hammering technology, because this would eliminate the variation in evaluations by engineers, I hope development will also be pursued for this as an alternative to test hammers and handheld equipment.
- ✓ I am concerned that it takes more time to conduct investigation using drones than when conducting an ordinary investigation. Also, I think that in an investigation using drones, it would be wonderful for the inspection record forms to be prepared automatically by computer.
- ✓ It was very interesting to hear about the inspection system using flying robots. When it becomes possible to use this in practice, I will want to hear more details based on the cost and operability. It currently appears that the drones and the inspection system equipment would be together as a set, but I would like to find out whether the kinds of inspection system equipment that are already owned by companies could also be installed on drones.
- ✓ It appears that it would be difficult to use SIP along with third-party inspection, so I'd like to try using it in inspection of intermediate portions between the scope of substructure that can be handled by inspection vehicles and the scope that can be handled by shipboard and aboveground inspection. I wonder if operation would be difficult in cases where the bridge to be inspected is a motorway and there is a national highway intersection under the bridge, with no sidewalks on the bridge, where it would not be acceptable to have objects falling under the bridge (like the middle part of the substructure and the box girder cross-section part). Could this really be used in Okinawa in place of rope access? These are my personal impressions.

## Expectations for new technologies and skill improvement through training

We found a high level of motivation among engineers for improving their practical capabilities for inspection work through training sessions, and there appears to be a significant role for training sessions as a means of ongoing training for technical personnel. There are also high expectations for new technologies in inspection work, and efforts to improve technical capabilities through continued training and make effective use of new technologies in the field are expected to result in greater efficiency in inspection services.

# Collaboration among industry, government, and academia in Okinawa, a harsh salt damage environment, to train bridge maintenance meisters and verify new technologies

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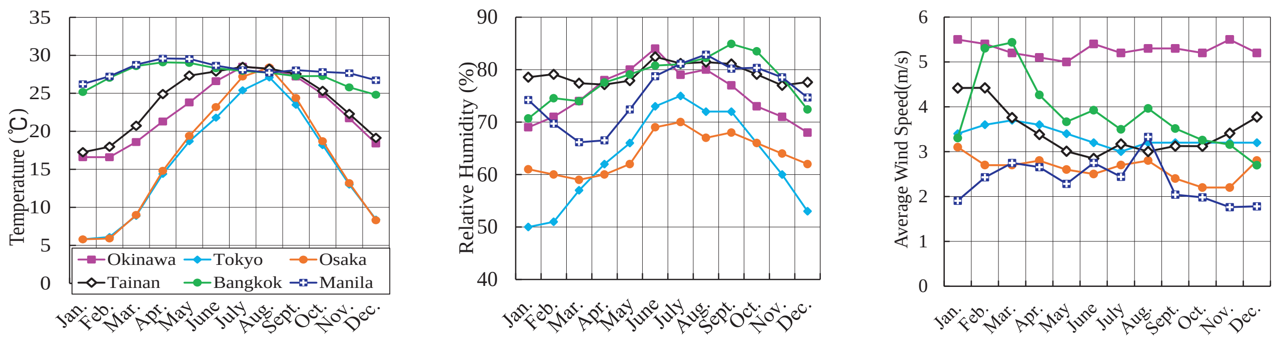
## Need for human resource development in Okinawa

With high temperatures, high humidity, and strong winds, Okinawa has a harsh environment for salt damage (Fig.1). Many of its bridges were built at a rapid pace without adequate consideration for suitable materials, including construction before the 1975 Okinawa Ocean Exposition, and there has been a rapid increase in the number of bridges showing deterioration due to salt damage in recent years. For the appropriate maintenance of deteriorated bridges, which will continue to increase in the future, it is necessary to train engineers with practical diagnostic skills for evaluating the residual performance of structures as well as practical capabilities for selecting suitable methods of repair and reinforcement. This paper describes a program to train bridge maintenance meisters in Okinawa Prefecture.

## Training of bridge maintenance meisters

For damaged bridges to be maintained in an appropriate and accurate method, there is a need for "bridge maintenance meisters" who have learned how to diagnose the mechanisms of progressive deterioration, determine residual performance, and select methods of repair and reinforcement. Along with Okinawa General Bureau, which administers bridges, the University of the Ryukyus is providing training for bridge maintenance meisters through the inspection and diagnosis of deteriorated bridges.

A subcommittee on infrastructure degradation prediction and residual performance diagnosis has been established, consisting of the University, Okinawa General Bureau (bridge maintenance meisters), West Nippon Expressway Company Limited, and the private sector, in collaboration with the Okinawa branch of JSCE West Japan; and we are providing training in the principles and operation of various types of diagnostic equipment and analysis and diagnosis based on the measurement results, through investigation, inspection, and diagnosis of bridges having actual deterioration due to salt damage and selection of suitable repair and reinforcement methods. Engineers trained in this program are expected to acquire the ability to determine the mechanisms of progressive deterioration and evaluate the results of inspections and analyses for the sake of appropriate and accurate maintenance of aging infrastructure.




(a) Average temperature (b) Average humidity (c) Average wind speed

**Fig. 1** Comparison of average temperature, humidity, and wind speed

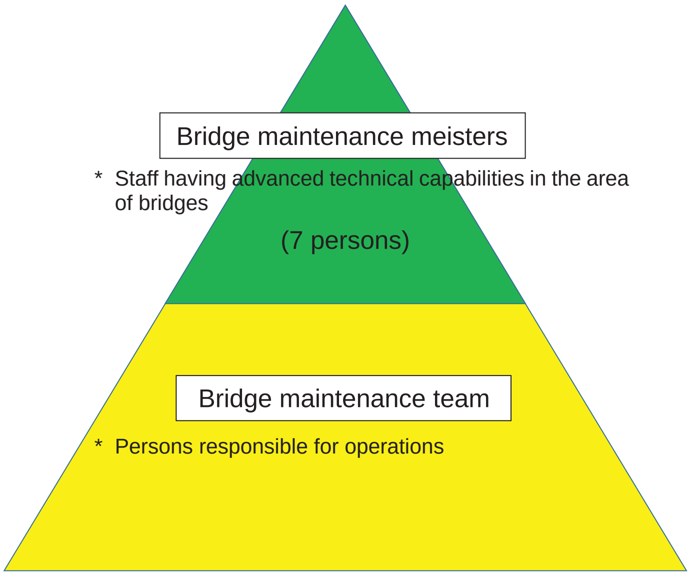



**Fig. 2** "Bridge maintenance meister" concept

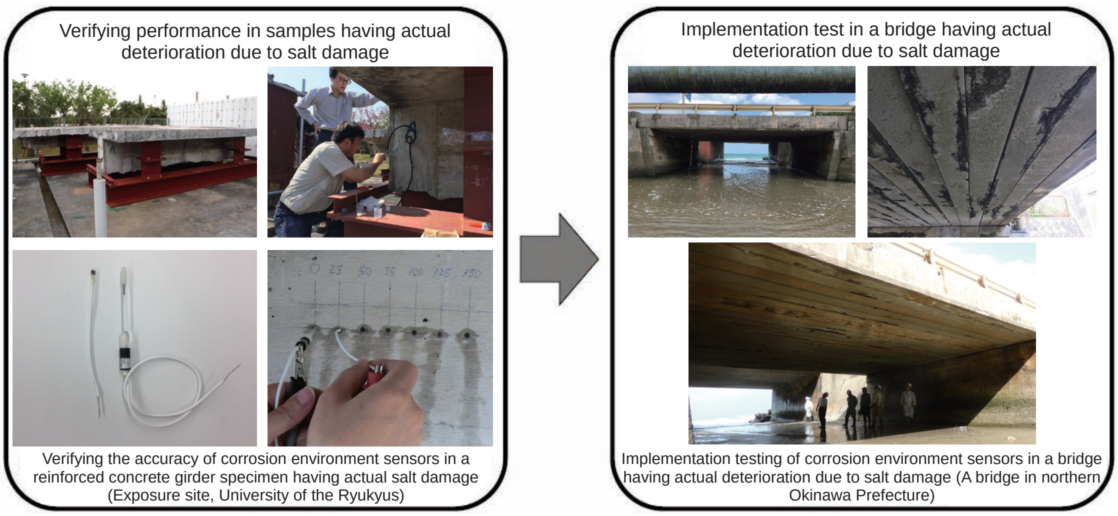



**Fig. 3** Implementation and verification process for SIP technologies

## Implementation and verification of new technologies

The subcommittee's activities also include verifying the performance of new technologies, and as an implementation of SIP technology, we are engaged in implementation and verification of corrosion environment sensors that are capable of measuring the corrosion environment of rebar in the interior of reinforced concrete. First, we installed corrosion sensors in specimens at the University of the Ryukyus having actual deterioration due to salt damage, recorded measurements, and identified important considerations concerning the measurement process, in addition to verifying the accuracy of the sensors. There are plans to use such sensors in PC bridges having severe deterioration due to salt damage.

By verifying new technologies in this kind of collaboration among industry, government, and academia, it is possible to ascertain the needs of administrators, practitioners, and others and identify issues related to implementation. Therefore, this is an effective approach from the standpoint of developing and implementing technologies that have a high level of practical applicability.

# Infrastructure Museum provides educational resources for engineers

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## Infrastructure Museum

To provide opportunities to learn about the structural and functional aspects of civil engineering structures, an Infrastructure Museum is being developed by the Center for Infrastructure Asset Management Technology and Research (CIAM), which is affiliated with Gifu University's Faculty of Engineering, along with Gifu University's SIP implementation project, adopted under the Strategic Innovation Promotion Program (SIP) of the Cabinet Office in the area of infrastructure maintenance, renovation and management technologies. The Infrastructure Museum includes models of a tunnel cross section, a prestressed concrete (PC) bridge, a steel bridge, and an embankment. (See Fig. 1.)

## Comprehensive facilities to learn about structural and functional aspects of various types of structures

Because engineers need to understand the structural and functional aspects of structures in relation to increasingly complex issues of maintenance, the models that embody these structures and functions were constructed. The museum's facilities include not only models of bridges, but also other types of structures, such as tunnels and embankments. Engineers employed by local government organizations are rarely assigned to just one type of structure, such as only bridges, or only tunnels. Therefore, they need to understand the structural characteristics of all types of structures.

In this report, each of the models in the Infrastructure Museum of Gifu University will be introduced.

## Tunnel cross section model

The tunnel cross section model is designed to provide a visual understanding of two tunnel construction methods, including the sequences of their construction processes. These are the Sheet Pile Method and the New Austrian Tunneling Method (NATM), which have different principle in supporting systems. Partial tunnel cross sections (approximately 4.5m x 3.5m) are laid to represent each method. The Sheet Pile Method model is on the left side, and the NATM model is on the right side. (See Fig. 2.)

In the Sheet Pile Method, steel supports and timber sheet piles are used in combination. This method was used as a standard method for mountain tunnels 1970s. This method employs the basic principle to support the loosened ground load with steel supports

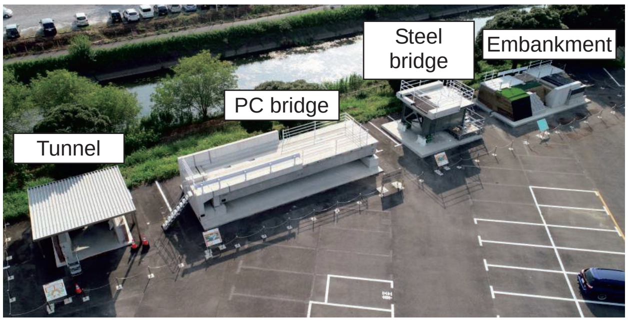


**Fig. 1** Overview of the Infrastructure Museum

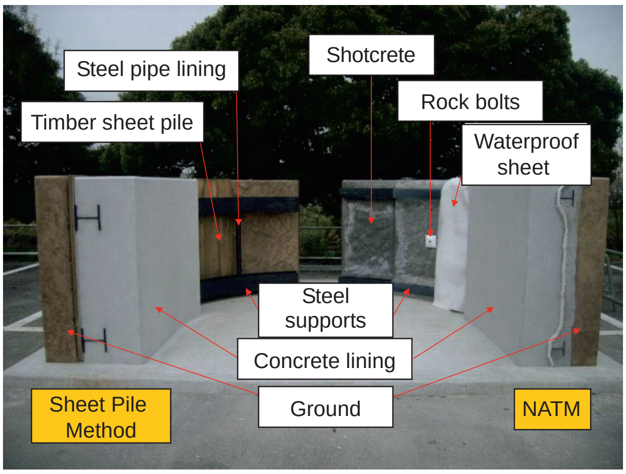


**Fig. 2** View of the tunnel cross section model

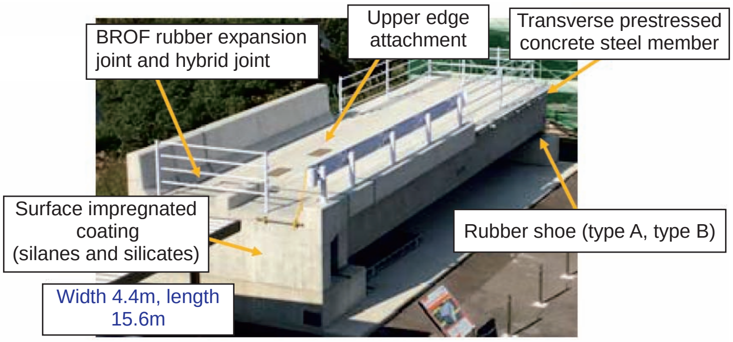


**Fig. 3** View of the PC bridge model

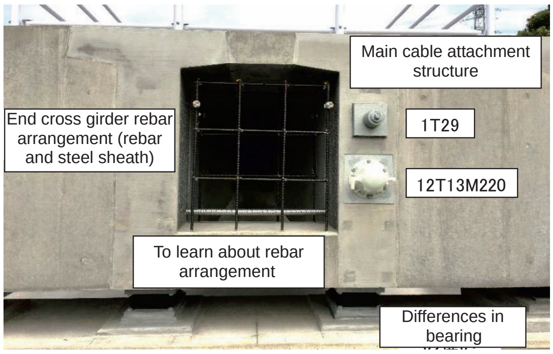


**Fig. 4** End of girder and cross girder rebar arrangement

and concrete lining.

The New Austrian Tunneling Method (NATM) was introduced in the beginning of 1970s from Europe. This method takes the principle of taking full advantage of ground supporting capacity. Therefore, shotcrete and rock bolts are placed to stabilize the ground around the tunnel face.

## PC bridge model

The PC bridge model is a prestressed concrete T-shaped girder bridge (four main girders), as shown in Fig. 3. Its basic structure uses the pre-tensioned method. However, to provide an opportunity to learn about the post-tensioned method, a portion of the girder has fixation components and cables that use the post-tensioned method.

As shown in Fig. 4, both ends of the main girder are exposed, making it easy to see the girder end attachment portion. This model includes rubber bearings, expansion mechanism, wall railing, guardrail, catch basin, slab drain, and other accessories, making it possible to learn about key aspects of maintenance.

## Steel bridge model

The steel bridge model represents the girder end portion of a plate girder, 5m in length. This model incorporates a variety of details, in addition to an end cross frame, and an intermediate cross frame and cross girder. The steel bridge model is shown in Fig. 5. The following steps were taken to provide an understanding of various details used in steel bridges, including the sequences of their construction processes and nondestructive inspection of welding defects found in steel bridge fabrication.

- Showing the difference between a non-composite girder and a composite girder (differences in upper and lower flange width, and arrangement of slab anchors and headed studs)
- Showing bridge jacking for bearing replacement (installation of reinforcing stiffener)
- Showing differences of detail of sole plates for fatigue improvement (un-tapered and tapered type)

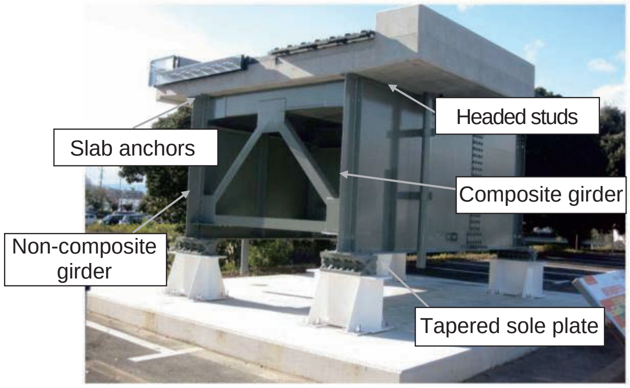


**Fig. 5** View of the steel bridge model

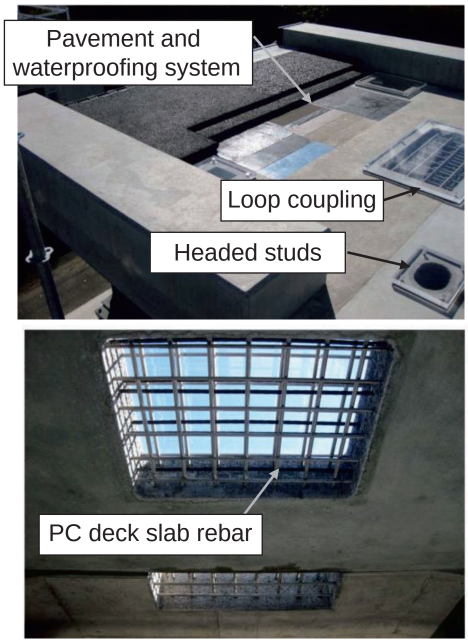


**Fig. 6** Pavement structure (top), and RC and PC deck slab (bottom)

- Showing end cross frame, intermediate cross frame, and intermediate cross girder
- Showing some details for using construction processes and bridge maintenance (hanging hardware for slab deck, hanging hardware that is also used for slab deck concrete frame work, and hanging hardware for scaffolding)

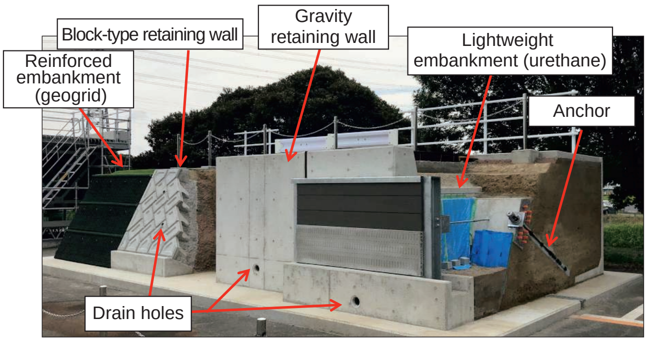


**Fig. 7** View of the embankment model

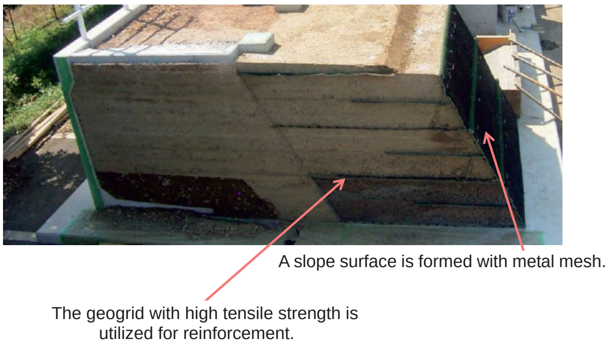


**Fig. 8** Layered cross section of geogrid reinforced earth

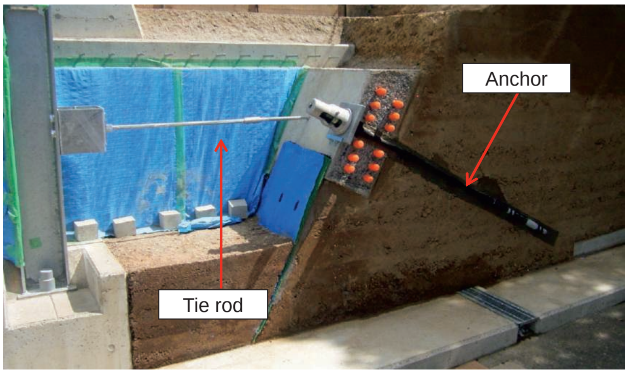


**Fig. 9** Lightweight embankment structure

• Showing painting layers and a bridge record plate

In addition, the upper part of the steel bridge model provides an educational resource for learning about reinforced concrete deck slabs and pre-stressed concrete deck slabs. (See Fig. 6.)

## Embankment model

The embankment model (See Fig. 7.) consists of a combination of the various types of retaining walls in general use. Specifically, this model displays the geogrid reinforced embankment, the block-type retaining wall, the gravity retaining wall and the lightweight embankment using urethane form.

Several types of L-shaped concrete walls are used on backside to keep the shape of this model. In the geogrid reinforced embankment (See Fig. 8.), the geogrid with high tensile strength is utilized to stabilize an embankment as shown at the side in this model.

The lightweight embankment (See Fig. 9.) uses a urethane foam area instead of soil for bearing load. This embankment model is good for learning about a structural approach using an anchor, a surface wall and a pressure plate. This model provides a visual understanding of the arrangement of an anchor, a pressure plate and so on.

## Giving shape to changing technologies

In this report, the models that have been constructed at the Infrastructure Museum of Gifu University to provide opportunities for learning about the structural and functional aspects of structures were summarized. As infrastructure is remaining in service for longer and longer periods, it is also important to learn about technologies of the past; therefore, we will continue to enhance the museum's facilities.

# International promotion and human resource development in infrastructure maintenance technologies and systems

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## Introduction

One of the important goals of SIP is to internationally promote the technologies it has developed and the knowledge it has acquired. In addition to communicating Japanese technological excellence to the rest of the world by such means as proposing international standards for infrastructure maintenance, there is a high level of potential for contributing to developing countries in Asia and Africa that will face similar issues in infrastructure maintenance in the near future. The technologies that are being developed at SIP are also suitable for needs in other countries, and some of them can be expected to be deployed overseas. In this Section, we will focus mainly on international promotion activities under a project in which the authors are participating, which is a comprehensive study for development of the road infrastructure management cycle and its domestic and overseas implementation (representative: Koichi Maekawa, the University of Tokyo).

## Summary of international promotion activities

The four main areas of activities for international promotion in this project are as follows: (1) Creating bases for information and research on infrastructure maintenance in Asia; (2) Compilation and communication of information on infrastructure maintenance; (3) Implementation of infrastructure asset management systems in Asian nations; and (4) Study of international standards concerning infrastructure asset management.

For international promotion, it is important to have a base. We are cooperating with Thammasat University in Thailand, which is a counterpart in this project, as an overseas base. We are involved in several endeavors for communicating information, such as holding seminars in various countries (seminars have already occurred in Thailand, Vietnam, Cambodia, and Myanmar successfully), and organizing special sessions at international conferences and symposia in Asia related to structural engineering and concrete engineering. We are engaged in promoting the implementation of infrastructure asset management systems in three countries, based on their levels of infrastructure development and maintenance technology; these are Thailand, Vietnam, and Myanmar. Our efforts toward implementation of maintenance technologies and systems are ongoing, based on the concept of asset management including life cycles of assets, in accordance with the economic situation of each country as well as the above conditions.

With regard to international standards, even before this project was begun, Japan proposed standards regarding life cycle management of concrete structures in ISO/TC 71 (Concrete, reinforced concrete, and prestressed concrete). Adding the concept of asset management to this could make it a widely shared international standard, in addition to enhancing the presence of Japan.

## JICA activities for road and bridge maintenance

JICA is currently engaged in technical cooperation projects that contribute to capacity building in the operation and maintenance of road and bridge infrastructure in about 20 countries. In many developing countries, new road construction is the priority, and little funding is budgeted for maintenance. Minor damage is left unrepaired until large-scale repair or even reconstruction work is needed, creating a vicious cycle that gives rise to additional costs. Awareness of maintenance tends to be low in the first place, and JICA is implementing measures aimed at establishing the PDCA cycle of maintenance in order to promote a shift from corrective maintenance to preventive maintenance. In addition, government officials who will become leaders in building their countries' infrastructure can come to Japan for human resource development based on the transfer of advanced knowledge and technologies. JICA provides training on various subjects in about six courses every year, and about 150 people participate every year to learn Japanese expertise.

## Core human resource development for road asset management

Road asset management is structured according to the PDCA cycle, including maintenance work, and its functioning is based on establishment of the cycle. In the area of road asset management, JICA is involved in strategic planning and implementation of technical cooperation projects, short term training programs, and long term training (international student) programs, with the goal of making a contribution to human resource development in developing countries (Fig. 1).

This will include implementation of training (short term and long term) programs in collaboration with universities and other institutions that are engaged in advanced research in the SIP project. In the training program, large numbers of personnel will be trained intensively through training courses that are specifically designed for each country in response to their respective issues. Thereafter, the goal will be to provide continuous human resource development through issue-based training to share general, wide-ranging knowledge. The long term training (international student) program will include education and research suited to the situation of the respective countries with regard to promoting asset management and extending the service life of infrastructure, and participants will be supported so that they can serve in leadership positions after returning to their home countries. Hokkaido University and Nagasaki University, which are participating research institutions in the SIP Infrastructure Program, admitted participants from Laos in FY 2017; and the University of Tokyo provided training program for Vietnam in asset management in FY 2017. JICA intends to expand the long term training program to more countries and more cooperating universities in FY 2018, and JICA will continue to pursue further collaboration with the participating institutions of the SIP project.

[Reference]
1) Yokota, H. and Nagai, K.: ISO and international promotion of concrete structure management in the Strategic Innovation Promotion Program (SIP), JSCE ISO Journal, Vol. 27, pp. 12-18, 2017.

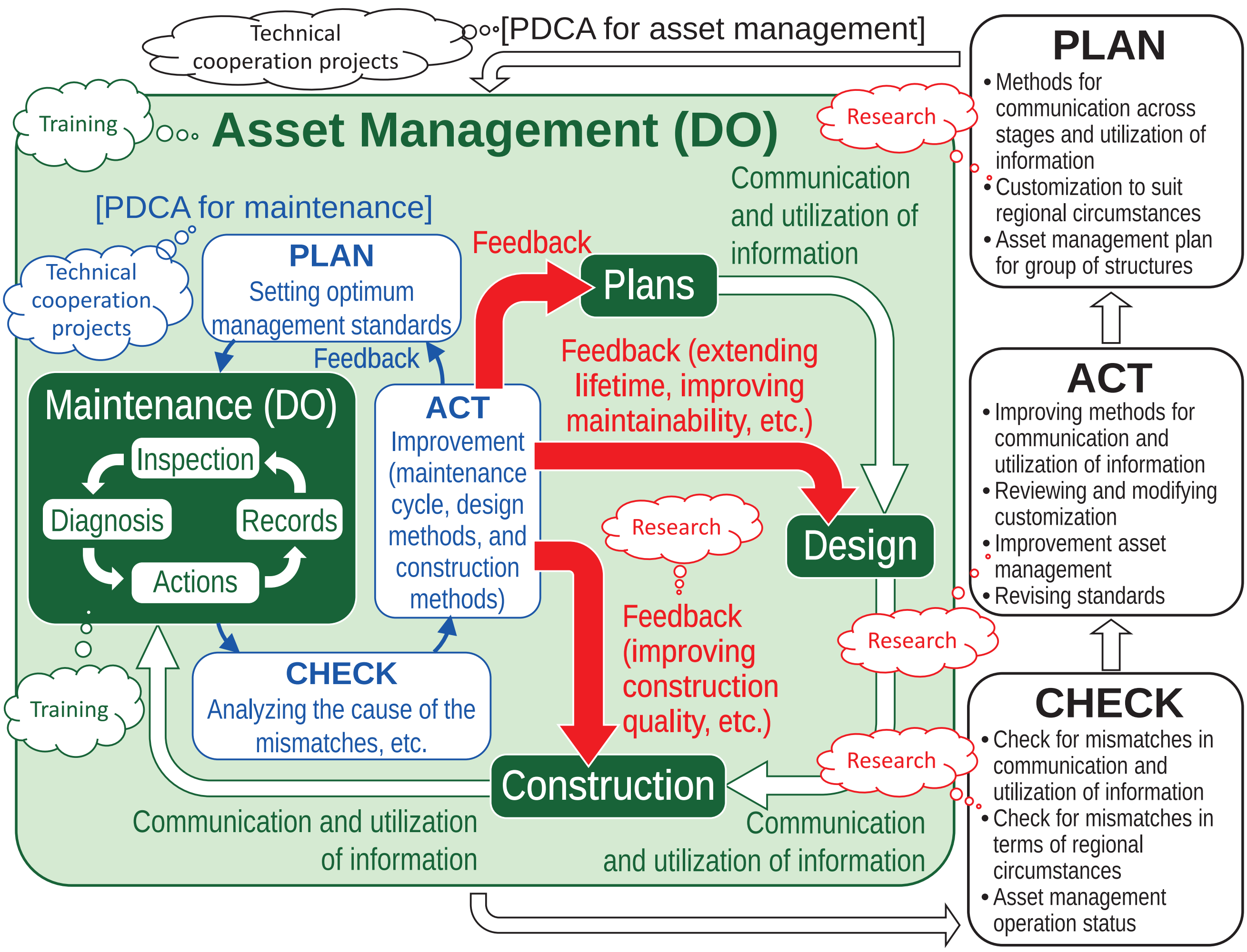


**Fig. 1.** Effective input to help promote asset management

# Overseas implementation of infrastructure maintenance technologies accelerated by cooperation between JICA and the SIP infrastructure program

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## Cooperation between the SIP Infrastructure Program and JICA's Road Asset Management Activities

Demand for infrastructure development in developing countries has increased in recent years, and infrastructure needs in developing Asia and the Pacific will exceed $26 trillion through 2030, reported by the Asian Development Bank (February 2017). In so-called emerging economies, even more infrastructure facilities are being built in a short period of time than in Japan's own era of rapid growth. Meanwhile, by the second half of the 2020s, developing countries, like Japan, will have an increasing volume of infrastructure that has been in use for 50 years, and the road infrastructure that Japan has supported in developing countries will also be aging. There is still a low level of awareness concerning maintenance in developing countries, which tend to prioritize new construction projects; however, events such as the collapse of a suspension bridge in Myanmar in April 2018 have contributed to a growing recognition of the importance of maintenance. To ensure that the future costs of maintenance and repair do not become a massive burden on national budgets, steps must be taken to establish road asset management technologies/systems in developing countries as well.

In about 20 countries, mainly in Asia and Africa, JICA is conducting technical cooperation that will contribute to strengthening operation and maintenance capabilities for road infrastructure, which is the most fundamental type of infrastructure in the transportation sector. To enhance the efficiency and quality of these projects, JICA launched a road asset management platform in October 2017, and has established a system that compiles Japanese advanced technologies and measures by Japanese local governments and makes it possible to respond flexibly to issues faced in developing countries. Based on this platform, we are planning training projects linked to technical cooperation as a means of providing efficient and effective support. One of these projects, which utilizes long-term training (scholarship program) for human resource development, is intended to make use of graduate schools in Japan for the strategic human resource development who can play a role in establishing road asset management technologies/systems in developing countries.

A memorandum of cooperation concerning JICA road asset management was concluded between the SIP Infrastructure Program and JICA in October 2017 for the purpose of obtaining the latest knowledge and cooperation in this field. Since signing this memorandum, JICA has had discussions with researchers of 19 topics concerning matters such as acceptance of JICA trainees and the possibility that the technologies they are developing could be used in technical cooperation. We have developed a cooperative framework with universities in regional implementation support teams of SIP program, and have requested their cooperation with respect to involvement and advice, etc. for technical cooperation projects and training projects including long-term training.

We have had discussions with researchers concerning the technologies they are developing, touching on matters such as their development situations, the possibility of overseas implementation, and methods of utilization. We will introduce technologies having the potential for overseas implementation on a trial basis in JICA projects and verify their effects, with the goal of disseminating and deploying them after the end of the project. A technology called DRIMS/i-DRIMS (a system to estimate the international roughness index (IRI) of a road surface based on vehicle response; JIP Techno Science Corporation) and a robotic camera for bridge inspection (Sumitomo Mitsui Construction Co., Ltd.) have already been introduced in JICA projects, and technical guidance was provided on maintenance using these devices. With regard to other advanced

**Table 1** Hosting of long-term trainees

| Country | Research topic | Host university and faculty advisor | Start time | Remarks |
|---|---|---|---|---|
| Laos | Effects and impacts of overloading countermeasures and weight measuring technologies in asset management | Michael HENRY, associate professor, Hokkaido University | October 2017 | To enter the master's program in April 2018 |
| Laos | Application of Lifetime extending Maintenance model for Steel Bridge | Takafumi NISHIKAWA, associate professor, Nagasaki University | October 2017 | To enter the master's program in April 2018 |
| Laos | Bridget inspection and assessment methods for asset management | Shozo NAKAMURA, professor, Nagasaki University | October 2017 | To enter the master's program in April 2018 |
| Cambodia | Utilization and analysis of bridge inspection data | Kohei NAGAI, associate professor, University of Tokyo | April 2018 | Master's program |

technologies, we will hold technical information seminars for the consulting firms that lead JICA projects and encourage them to learn about and utilize the advanced technologies.

In the training project, long-term trainees have been accepted from two countries, Laos and Cambodia (Table 1). The goal is to train core human resources who can play an active role in promoting the establishment of road asset management technologies/systems on the medium to long term after obtaining graduate degrees in areas of research that can contribute to the promotion of asset management.

We are working on the selection of candidates from four countries (Philippines, Mongolia, Bangladesh, and Egypt) to begin studies in April 2019. Persons related to universities with an interest in accepting trainees (Hokkaido University, the University of Tokyo, Kanazawa University, Kanazawa Institute of Technology, Gifu University, Nagasaki University, and University of the Ryukyus) have traveled to these countries, and we are providing the prospective host universities with matching services such as interviews with candidates and confirmation and consultation concerning research topics.

In the short-term training, we implemented a training program in collaboration with the international asset subprogram team for "integrated research on road infrastructure management cycle development and implementation in Japan and abroad." This training involves a great deal of practical learning, including analytical practice using actual inspection data, budget plan simulation based on inspection data, and other exercises such as predicting soundness trends, and the training is focused on helping participants develop an understanding of how to use inspection data. We intend to conduct this kind of training to provide ongoing opportunities for human resource development in the future.

In technical cooperation projects, persons involved in regional implementation support teams also participated in the surveys to determine the content of cooperation, providing advice and support based on their experience with implementation in Japan. This was conducted in two countries (Bhutan and Zambia) in FY 2018.

## Case 1: Project for capacity building of road slope protection technology in Bhutan (Table 2)

Roads constitute the most important means of transportation for people and cargo in Bhutan, which consists mainly of mountainous areas. The main highway network is composed of National Highway 1, which runs east-west across Bhutan, and four national highways (Highways 2–5) which run south as far as the border with India; and because most of them pass by steep slopes, there are frequent instances of slope collapse during the rainy season, hindering the movement of people and cargo within Bhutan (Fig. 1). The Department of Roads (DoR) of the Bhutan Ministry of Works and Human Settlement (MoWHS) has devised slope countermeasures based on a combination of vegetation planting and reinforcement, but due to a lack of technical capabilities, it has not been easy to conduct adequate slope countermeasures. Technical cooperation was requested because slope countermeasures are an urgent need.

**Fig. 1** Slope collapse on National Highway 1 in Bhutan

**Table 2** Summary of project for capacity building of road slope protection technology in Bhutan

| |
|---|
| 1. Project site / Target region |
| Bhutan nationwide / National highways under the jurisdiction of the Lobesa and Trongsa Regional Offices implementing OJT |
| 2. Project beneficiaries (target groups) |
| Direct beneficiaries: Department of Roads (DoR) staff members and engineers at a total of nine regional offices<br>Final beneficiaries: Road users |
| 3. Project implementation period |
| Planned for January 2019 – December 2022 (48 months total) |
| 4. Overall goal |
| For road slopes in Bhutan to be developed and managed appropriately, using measures improved through the project |
| 5. Project goal |
| To improve the capabilities of DoR concerning road slope protection technology |
| 6. Outputs |
| Output 1: The conditions for advance traffic restrictions will be made clear.<br>Output 2: Vegetation planting measures suitable for prevention of sediment slope collapse will be selected.<br>Output 3: The standard earth cutting slope gradient will be revised with respect to sediment slope collapse and rock slope collapse.<br>Output 4: Implementation of suitable countermeasures for rock slope collapse (falling rocks) will become possible.<br>Output 5: Suitable countermeasures will be introduced with respect to debris flows.<br>Output 6: The information system on road slope disasters and traffic restrictions will be improved. |

The basic policies were that it would be difficult to implement countermeasures in all dangerous locations due to budgetary considerations, and that for the sake of sustainability at DoR, the focus would be placed on introducing inexpensive countermeasures such as vegetation planting and falling rock protection, along with "soft" countermeasures such as monitoring dangerous locations, rather than expensive countermeasures such as anchors.

Based on the memorandum of cooperation concluded between the SIP Infrastructure Program and JICA, we held discussions with researchers engaged in R&D under the SIP Infrastructure Program concerning a system to predict and detect surface and slope collapses and issue warnings (OYO Corporation and Chuo Kaihatsu Corporation); and in addition to discussing the possibility of using this technology, this led to an arrangement for Gifu University, which is involved in implementation of the technology in Japan, to cooperate in the preliminary survey.

The content of cooperation will be a pilot project using Japanese technologies, with the goals of strengthening the capabilities of DoR regarding road slope protection and promoting appropriate development and maintenance of road slopes; this will be achieved through clarification of the conditions for placing traffic restrictions in advance, capacity development regarding countermeasures for sediment slope collapse, rock slope collapse, and debris flows, and improvement of information systems relating to road disasters and traffic restrictions. At present, roads are only closed in Bhutan after an incident such as slope collapse has already occurred; but in order to promote understanding and adoption of advance traffic restrictions, which can protect road users from damage before it occurs, it will be necessary to study restriction thresholds having a technical and logical basis according to the correlation between rainfall volumes and amounts of slope displacement. We anticipate the continued advice and support of Gifu University in activities such as data analysis and restriction threshold setting as well, along with collection of rainfall data using an early warning system for slope collapse, which is a development technology under the SIP infrastructure program.

Implementation of boulder removal by a method that has been used on a national highway in Gifu Prefecture has been proposed as a measure against falling boulders. The usual approaches for dealing with large masses of rock on a slope are to fasten them in place with wire or the like, to stabilize them by attachment to the rockbed, or to break up the rock masses and remove them before they can collapse; but in this method, rock masses were dropped down to the national highway which had been lined with large sandbags, and were then broken up and removed. This is a safe and inexpensive method, and its use is promising in this technical cooperation project as well. More so than in the past, the content of the cooperation project has been studied with an eye to local circumstances, and expert advice was used to propose the implementation of this rather primitive method, rather than only proposing advanced technologies.

## Case 2: Project for bridge maintenance capacity building phase II in Zambia (Table 3)

Zambia's road network has a total length of about 67,000 km nationwide. This includes major inter-city roads having a total length of about 18,600 km, and about 60% of them are paved (as of 2012). The surfaces of major roads are in good condition, and in a three-stage evaluation (good, fair or poor), 99% of road segments were evaluated as "good" or "fair" (in 2011). However, many bridges were built in the 1970s or earlier, and bridge deterioration has advanced due to a lack of maintenance work. The Road Development Agency (RDA), which manages major roads, established a bridge emergency restoration department in 2013 and began working on inspections and repairs (outsourced); however, there is a lack of engineers and a lack of knowledge such as planning and construction supervision, and it is important to improve the bridge maintenance capabilities of RDA staff.

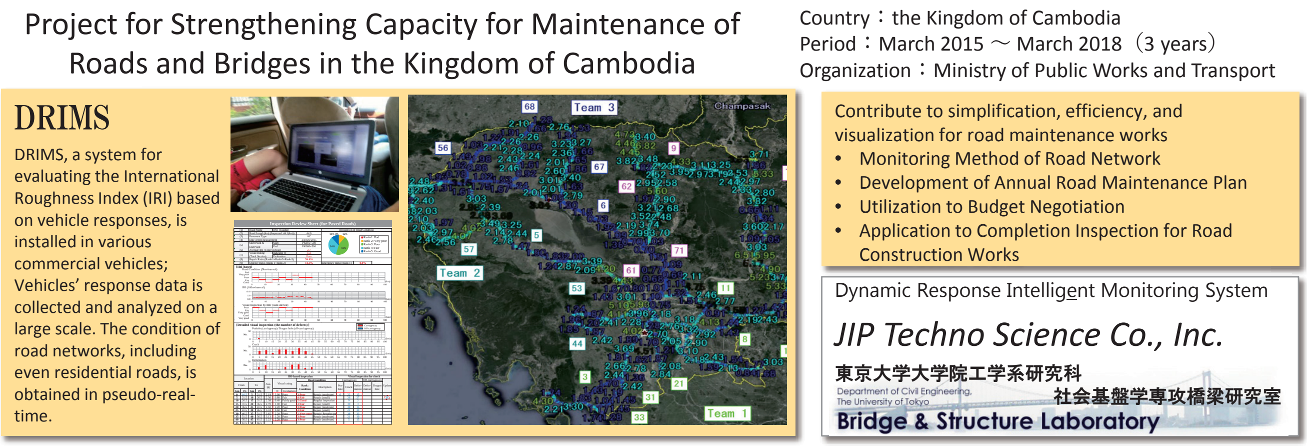


**Fig. 2** Example of using Japanese technology in Cambodia

**Table 3** Summary of project for bridge maintenance capacity building phase II in Zambia

1. Project site / Target region
   Zambia nationwide
2. Project beneficiaries (target groups)
   Direct beneficiaries: Bridge engineers at the central office of the Road Development Agency (RDA) and regional RDA offices targeted in the pilot project
   Final beneficiaries: Road users
3. Project implementation period
   Planned for January 2019 – December 2022 (48 months total)
4. Overall goal
   To improve the condition of bridges managed by RDA
5. Project goal
   To improve bridge maintenance operations at the central office and regional offices of RDA
6. Outputs
   Output 1: Improved capabilities of engineers involved in daily bridge maintenance at the central office and regional offices of RDA.
   Output 2: Improved capabilities of engineers involved in bridge repairs at the central office and regional offices of RDA.
   Output 3: Improved capabilities of engineers involved in bridge inspection at the central office and regional offices of RDA.

From February 2015 to August 2017, JICA implemented technical cooperation (Phase I) to improve bridge maintenance capabilities, endeavoring to promote the development of various guidelines and ensure that maintenance work becomes an established practice at the sites concerned. However, additional technical cooperation has been requested, as it is essential to disseminate and build on the results of Phase I activities, establish the PDCA cycle for maintenance, and improve capabilities with regard to repair techniques and the maintenance of special (long, large-scale) bridges.

RDA was experiencing issues with continuing engineer training, so we requested cooperation from Gifu University to introduce cases of engineer training in Japan.

One of the activities in this technical cooperation is to be the establishment of a bridge maintenance engineer training course in Zambia and development of a system for engineer training at the University of Zambia, including counterpart institutions. Initially, Zambian engineers will participate in the ME training course at Gifu University or other classes and training programs for bridge maintenance engineers in Japan, while a curriculum is developed that will be suitable for technical purposes in Zambia, with reference to those courses. Later, in the second half of this technical cooperation, the goal is for the University of Zambia to train engineers from RDA by themselves while obtaining support from Gifu University.

## Case 3: Technical cooperation using Japanese technologies

In Cambodia and Kenya, in addition to technologies being developed under the SIP Infrastructure Program, JICA is providing support for the implementation of technologies possessed by small and medium-sized businesses in Japan to promote the dissemination of these technologies after project completion (Fig. 2). DRIMS/i-DRIMS, a technology that has been introduced in Cambodia and Kenya as a simple means of measuring the IRI (International Roughness Index) of pavement, was developed with R&D under the SIP Infrastructure Program. We are currently working on a mechanism for this technology to be sold in Kenya to facilitate its widespread adoption after the completion of technical cooperation in that country.

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# Toward a future of attractive infrastructure maintenance: Looking back at support activities for regional implementation of new technology

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## Expectations for regional implementation support teams

The introduction of new technology to the job sites of infrastructure maintenance is strongly desired to make the work in this field more attractive, efficient, and sophisticated. However, developers of new technology often wonder why the amazing new technology they developed is not being widely used. On the other hand, local officials in charge of managing public infrastructure fret over what technology they should introduce in what manner to resolve budgetary and manpower shortages (Fig. 1).

To meet the need for resolving the problems of both sides, SIP Infrastructure Regional Implementation Support Teams were selected in August 2016 as part of the technology for infrastructure maintenance, renovation, and management ("SIP infrastructure") (PD: Prof. Yozo Fujino), a project under the Cabinet Office's Cross-ministerial Strategic Innovation Promotion Program (SIP). Twelve teams including local universities have been undertaking various activities to have local municipalities use (implement) new technologies developed by "SIP Infrastructure." These included supporting the introduction of seeds, supporting fulfillment of needs, coordination within regions, establishing networks, and cultivating human resources. The Japanese Congress for Infrastructure Maintenance (JCIM), which was organized in autumn of 2016 as well, has been working toward the creation of an infrastructure maintenance market and formulation of a framework and system for implementing new technology, primarily through regional forums. The support teams for regional implementation have carried out their activities in close cooperation with JCIM.

This report summarizes the results of the activities of these support teams. At the end of the report, this article reviews the activities of the teams, describing what were found and obtained through the activities, referring to the content of the report, to assist future activities.

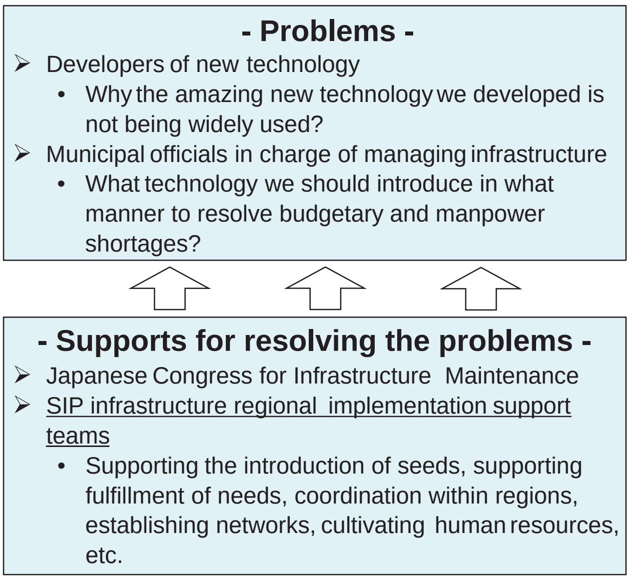


**Fig. 1** Problems and support activities for regional implementation of new technology

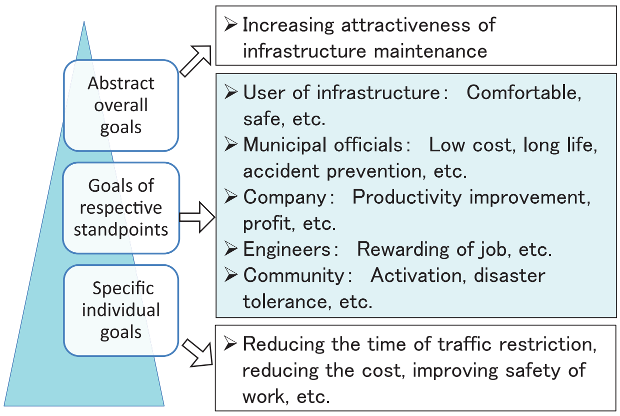


**Fig. 2** Typical goals of infrastructure maintenance

## Goals varying from one standpoint to another

Figure 2 shows typical goals of infrastructure maintenance. No one opposes abstract overall goals of “increasing attractiveness” and “increasing efficiency and sophistication.” As pointed out by Chun of Ehime University (article A-2 of this report), however, the goals of infrastructure maintenance are not the same when viewed from different standpoints. Efforts to be made for the introduction of new technology also vary depending on the standpoint.

Accomplishment of some of the specific individual goals, such as “reducing the time of traffic restriction” and “reducing the cost,” are easy to evaluate in numerical terms. However, others among the goals of respective standpoints are difficult to evaluate. For example, “safe and comfortable” and “rewarding,” etc., are difficult to evaluate numerically. In contrast, future “accident prevention” is difficult in the sense that one can do nothing now but to strive for the goal, with judgement of whether or not the goal was achieved only being possible in the future.

## Possibility of support activities by local universities

Information exchange between the public and private sector tends to be inhibited partly due to the erroneous belief held by municipal officials in charge of infrastructure management that the Ethics in Government Act prohibits even information exchange between them and private technology developers. For this reason, information “seeds” of new technology tends to remain unrecognized by municipal officials, while the needs of the officials are unlikely to be known by technology developers. Nevertheless, municipal officials, corporate engineers, and technology developers had lively exchanges of information and opinions at briefing sessions and open field tests held by local universities (C-1, etc.). Furthermore, these activities initiated by local universities led to the definition of performance requirements, evaluation of performance, and formulation of guidelines for new technology that are currently lacking (C-6). These activities of the support teams demonstrated the usefulness and possibility of implementation support for new technology, with local universities playing the key role in the collaboration among industry, municipalities, and academia. This is one of the accomplishments of the support activities for regional implementation.

In order to have the support activities for regional implementation of new technology take root in the civil engineering field of local universities, it is crucial to establish a sustainable cycle of the following steps: (1) incorporation of these activities in the Japan Society of Civil Engineers (JSCE); (2) publication of their results as peer-reviewed papers; (3) granting of academic degrees including master’s and doctoral degrees on the basis of these achievements; and (4) acquisition of research funds including government research grants. The “SIP Infrastructure Program Coordination Committee” chaired by Tadayuki Tazaki has already been organized in JSCE, in which Subcommittee on Promoting Regional Implementation of New Technologies chaired by Keitetsu Rokugo was formed in fiscal 2018. The foundation for the above-mentioned cycle is thus being laid.

## Seeds-driven and needs-driven

In this report, Obayashi (A-6) points out that projects can be expressed as combinations and chains of seeds and needs as shown in Fig. 3 of A-6 (page: 28) and that developments are classified into two types: seeds-driven and needs-driven. By developing this insight, it is understood that seeds to meet needs do not have to be in the form of new technology but rather can be anything, such as existing technology with track records, or information, people, organizations, or rules instead of “technology” in a narrow sense. In short, it can be interpreted that anything can be used in various new combinations to resolve the needs that have been difficult to meet by conventional approaches and combinations (Fig. 3). In the activities of the Gifu University team to apply robotic technology (RT) to periodic inspection of Kakamigahara Bridge (C-6), not only a combination of robot inspection techniques was provided but also draft guidelines were formulated by organizing a committee consisting of members from various positions. Furthermore, the team fulfilled the needs by combining various factors such as a proposal for conducting preliminary research assisted by RT prior to visual inspection at a close distance.

In the local support activities by Ozawa et al. of the University of Tokyo team (C-4), specific needs of each municipality selected were taken up to be resolved in cooperation with supporters (construction consultants). This approach is new, but the so-called implementation of new technology is not highlighted. This can therefore be regarded as needs-driven regional support. On the other hand, Hisada et al. of the Tohoku University team (C-3) disseminated a database system that is a new technology developed by “SIP infrastructure” to municipalities, making various adaptations. This can be regarded as seeds-driven regional support. The above-mentioned activities of the Gifu University team to apply RT to periodic inspection of Kakamigahara Bridge (C-6) can be regarded as an intermediate type between seeds-driven and needs-driven types.

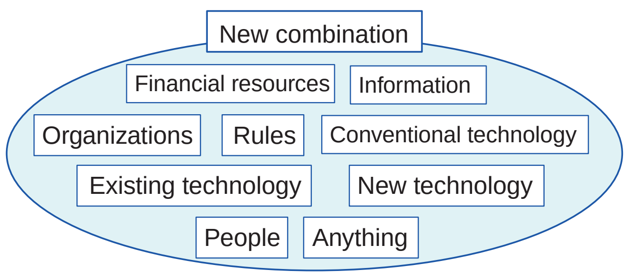


**Fig. 3** New combination to resolve the needs

**Table 1** Obstacles to the implementation of new technology perceived from different standpoints

| Positions | Major causes | |
|---|---|---|
| Ordering parties | Attitudes of people in charge widely vary | - The organizational mission is unclear.<br>- Enthusiasm gap between head and local offices.<br>- Resistance to changes. |
| | Significant energy and effort are required for introduction | - Fairness should be ensured.<br>- Basis for external explanation (account audit) is necessary.<br>- Basis for internal explanation (organizational consensus) is necessary. |
| | Great risk in the event of trouble | - Who takes responsibility is unclear.<br>- Constant and continuing support is not assured. |
| Developers | Investment decision for development is difficult | - First-mover advantage from development is not assured.<br>- Investment recovery in a short time is difficult.<br>- It is difficult to grasp the market (scale, continuity). |
| | Required specifications are unclear | - Needs for new technologies (required performance/precision) are unclear.<br>- Appropriate cost for ordering parties is unknown.<br>- Content and period of technical support required are unknown. |
| | Government's situation is unknown | - Each organization or local government is in a different situation.<br>- Method of order placing and introduction conditions are difficult to understand.<br>- Attention to industry officials is required. |

## Promotion of implementation by distributing and mitigating responsibilities

Table 1 (simplified Table 2 of A-4) gives various examples of obstacles to the implementation of new technology perceived from different standpoints. These were collected through listening surveys conducted on the order-placing parties and technology developers. Obstacles on the side of technology developers include the ambiguity of the needs of the order-placing party with regard to the performance requirements and accuracy. Unclearness about the method of order placing and conditions of introduction also discourages implementation. Obstacles on the side of order-placing parties mainly consist of psychological stress, such as resistance to change, the nuisance of providing explanations to account auditors, and uneasiness due to a lack of clarity about where responsibility lies. Measures shown in Fig. 4, including "expansion of administrative right," "positive attitude of the head of the organization," and "evaluation and certification of technology," are easy to understand when viewed as measures to distribute/mitigate the psychological stress (particularly responsibility) of the order-placing parties. This brings to mind various other measures. Note that the idea of "distribution"

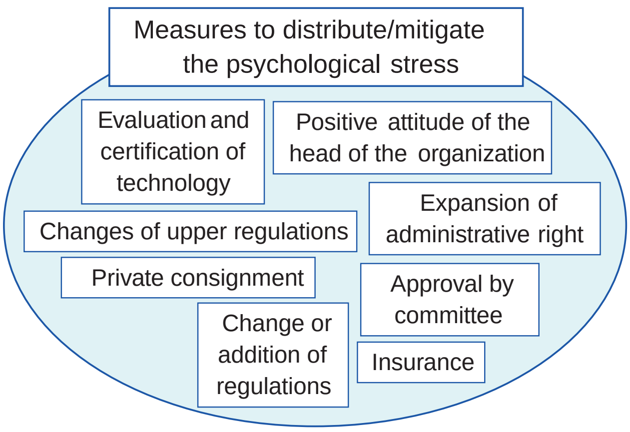


**Fig. 4** Distribution/mitigation of the psychological stress of the order-placing parties

was given from Mr. Tadayuki Tazaki. In this report, Takamatsu (A-9) points out the importance of expanding the independence and discretion of localities.

## Problems and countermeasures of and efforts for implementation of new technology

Table 2 gives examples of problems and countermeasures when implementing new technology. As stated above, many implementation support teams for regional implementation carried out briefing sessions and open field tests to transfer information on seeds of new technology to municipal administrators and local maintenance engineers, who are the users, while transferring the needs of the users to technology developers. These were appreciated by both technology developers and users. In the activities regarding the application of RT to periodic inspection of Kakamigahara Bridge (C-6), the support team formulated draft guidelines to compensate for insufficient standards, presented performance requirements to facilitate understanding of the RT to be used, evaluated the RT by field testing, and proposed a method of utilizing robotic techniques in an optimal combination. The team pointed out that the inspection cost can be reduced by changing the "preliminary research by RT followed by thorough visual inspection at a close distance" to "screening research by RT followed by visual inspection at a close distance only where required" and utilizing AI. Generally speaking, difficulties hard to predict from experience tend to arise when applying new technology or a new approach. To avoid or minimize such difficulties, sufficient measures should be taken, such as to begin slowly with trial use on a small scale and to collect information on such difficulties from similar cases. Education is also important to foster positive-minded staff who can enjoy changing and being changed for the better.

Table 3 gives examples of efforts for implementing new technology by different standpoints. It is advisable that municipal officials administrating structures

**Table 2** Problems and countermeasures when implementing new technology

<table>
<tr><th>Problems</th><th colspan="3">Examples of countermeasures</th></tr>
<tr><td>Needs not encountered with seeds</td><td colspan="2">Hold briefing sessions and open demonstration tests</td><td rowspan="5">Activities by SIP infrastructure regional implementation support teams</td></tr>
<tr><td>Nonconformity to standards</td><td>Improve or establish standards</td><td rowspan="3">Carried out for Kakamigahara Bridge</td></tr>
<tr><td>Hard-to-understand technology</td><td>Define performance requirements, conduct performance evaluation, present methods of utilization</td></tr>
<tr><td>Cost</td><td>Estimate the cost, suggest methods of cost reduction</td></tr>
<tr><td>Difficulty in ensuring fairness</td><td colspan="2">Include a neutral body</td></tr>
<tr><td>Trouble</td><td colspan="3">Begin with a small-scale trial, take sufficient preliminary measures, collect information on troubles in similar cases, emphasize experience, purchase insurance</td></tr>
<tr><td>Psychological factor</td><td colspan="3">Distribute and mitigate psychological stress, foster positive-minded staff who can enjoy changes</td></tr>
</table>

**Table 3** Examples of efforts for implementing new technology

| Position | Examples of efforts |
|---|---|
| Municipal official in charge of infrastructure management | - Express their wish for technology to save cost and labor for solving the problems of budgetary, manpower, and technical shortfalls<br>- Also demonstrate that the solution to the problems may not necessarily involve new technology |
| Ministry of Land, Infrastructure, Transport and Tourism MLIT | - Organize standards, performance requirements, methods of evaluation, estimation, and order placing (most important) |
| Developer of new technology | - Formulate a development plan with a clear intention for practical implementation (For instance, add new technology to conventional technology currently in use; accumulate experience at companies not under national audit, etc.) |
| Supporter for implementation (university, etc.) | - Regard support for implementation as an area of research activity (Improve the management of academic societies, judgment of theses, and distribution of research funds) |
| Contractor | - Actively utilize new technology for proposal making, etc. |

demonstrate more strongly that, while they wish to resolve shortfalls in budget, manpower, and technology, the solution may not necessarily include new technology. New technology, particularly unfamiliar sophisticated technology, requires organization of its standards, performance requirements, and methods of evaluation, cost estimation, and order placement. The role of officials from the Ministry of Land, Infrastructure, Transport and Tourism in the position of being able to move these matters forward is very important. For developers of new technology, it is important to advance development with a clear intention of practical implementation, such as to add new technology to conventional technology currently in use, accumulate field experience at companies in the fields of railways, electrical power, etc., that are not under national audit, and carry out technical development together with the users of the technology. As stated above, further improvements are desired in the management of academic societies, judgment of theses, and distribution of research funds, so that researchers at universities and other institutions, who are in a neutral position, feel comfortable in supporting regional implementation. It is desired to establish a system, such as proposal making, in which active utilization of the new technology by the contractor will lead to an increase in orders.

## No single magic bullet

The planned period of the activities of "SIP infrastructure," as well as the support activities for regional implementation included in it, is going to end in March 2019. The support activities for regional implementation of new technology under the initiative of local universities are currently in the stage where their effectiveness has been demonstrated. It is hoped that the support activities take root in local universities in collaboration with the activities of NCIM. Public funding is essential for support activities for the time being. It is also hoped that the findings obtained from the support activities for regional implementation in Japan are utilized for enhancing the efficiency and sophistication of infrastructure maintenance in developing countries in Asia and Africa in cooperation with the Japan International Cooperation Agency (JICA) (D-9).

From the next fiscal year, it is strongly hoped that the approaches listed in Table 3 will be put into practice and more of such attempts will be made. There is no single magic bullet for making the infrastructure maintenance field more attractive and implementing new technology on a regional level. Knowing that people at different positions think differently with different goals, it is important to continue to make efforts at respective positions, working toward a change for the betterment of the entire infrastructure maintenance field.

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# Editorial Postscript

Universities and other organizations throughout Japan played a leading role in activities to support the regional implementation of new technologies during a period of more than two years, from the latter half of FY 2016 to FY 2019. We have prepared this report with the aim of recording and sharing the content of these interesting activities. We have had multiple committee members check the content of the articles, not as peer review but to ensure that the articles are easy to read. We would like to express our gratitude to all those who have worked diligently to write and compile the report within a short period of time. We hope that regional universities and other organizations will continue to develop and expand their activities to support the regional implementation of new technologies as a means of contributing to their communities.

Keitetsu ROKUGO, chair
Shin'ichi MIYAZATO, secretary-general
Subcommittee on Promoting Regional Implementation of New Technologies

**Report of SIP Infrastructure Regional Implementation Support Teams: Promoting Innovation in Regional Infrastructure Maintenance**

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