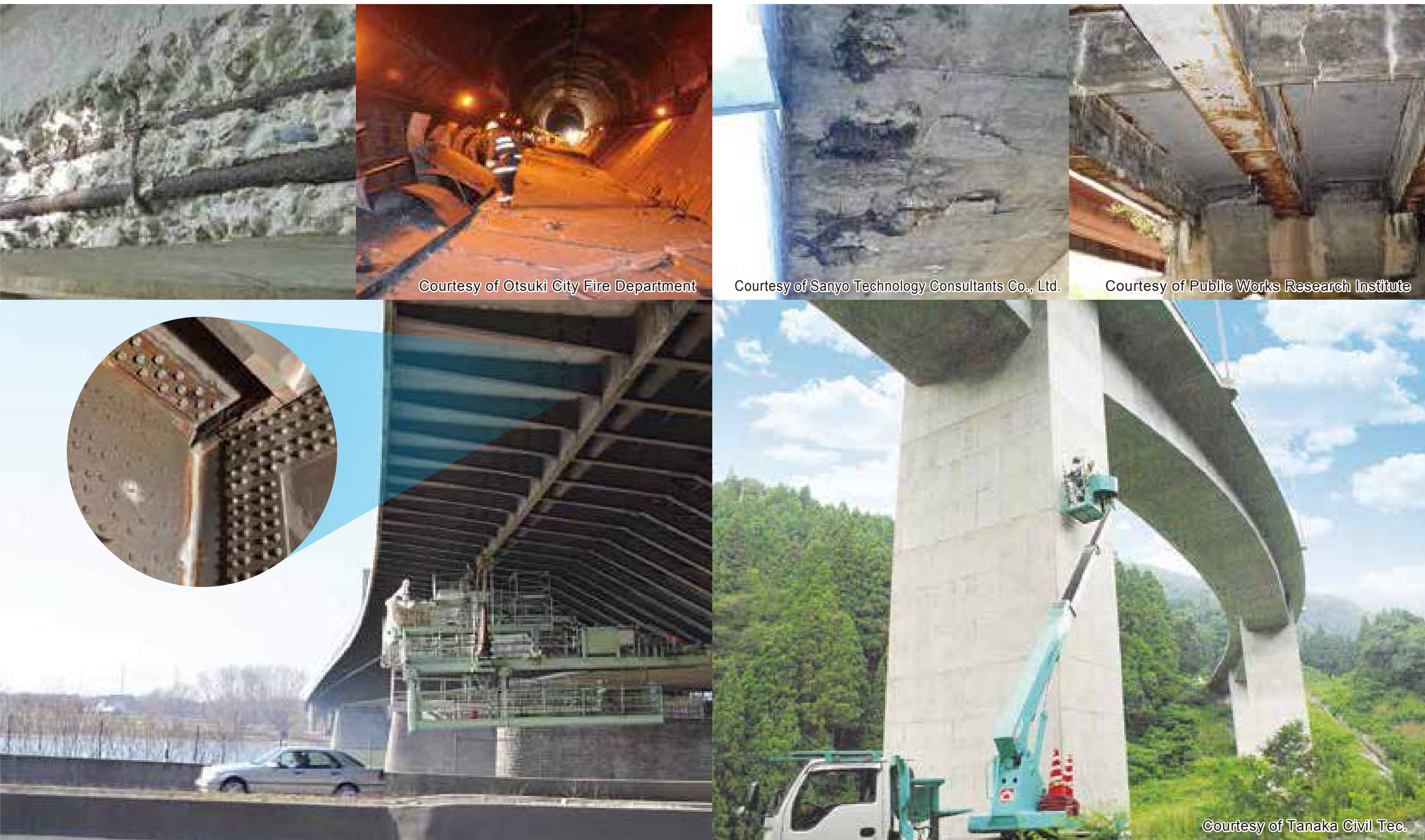
2017.3

Infrastructure Maintenance, Renovation and Management



Toward Safer and more Secure Civil Infrastructures driven by Developing Technologies

SIP Cross-ministerial Strategic Innovation Promotion Program

CONTENTS

The contents are as of March 2017 unless otherwise noted.

Introduction; The R&D Project of Infrastructure

Greeting

For Safe and Secure Infrastructure Systems

The Cross-Ministerial Strategic Innovation Promotion Program (SIP), in which the Council for Science, Technology and Innovation (CSTI) plays the role of playmaker, has been established to realize scientific technology innovations. As a cross-ministerial and cross-field program, SIP will drive forward with the focus ranging from basic research to commercialization/industrialization. "Infrastructure maintenance, renovation and management" (hereinafter referred to as "SIP infrastructure") is one of the issues currently under the focus of the programs.

Civil infrastructures, such as roads, railways, harbors and airports, support our everyday life and social economic activities. Many of them, however, were built during the high economic growth period. As they get older, the increase in maintenance and repair expenditures, along with the possibility of a serious accident occurring during the service, become serious social issues. This program aims at preventing accidents and reducing the burden of maintenance by constructing a systematic infrastructure management that utilizes the most advanced information and robotics technologies.

Unlike mass-produced products, such as vehicles and laptop computers, infrastructures are single products that are designed, constructed, and manufactured individually. Initial conditions of infrastructures vary depending on the time and condition they were built . As a result, in addition to the difference in usage environment, the speed of infrastructure deterioration also varies. Some infrastructures that have been used for several tens of years may pose a higher risk of accident due to damage. To allow for an effective and efficient preventive maintenance management of infrastructures and to establish a safe and secure infrastructure system, it is therefore crucial to have technologies that can precisely diagnose and take appropriate measures by closely examining large number of infrastructures individually on-site. It is also essential to minimize the hazards and risks associated with manual handling in the workplace. For infrastructure management run by local governments, cost reduction is also a particularly important viewpoint. Currently, infrastructures are being constructed across Asia; however, maintenance has already become a big issue. "SIP infrastructure" aims at introducing new exciting advanced technologies into the range of infrastructure management technologies. Specific examples include the following: support from or replacement with robots for infrastructure inspection; on-site damage detection inside concrete members; inspection of tunnels and bridges by mobile sensors that do not require traffic control; technologies to aerially detect damage/deformation of river levees, dams, and harbors; highly accurate deterioration estimation technology for concrete; developing ultra-high durable repair materials; efficient infrastructure management technology using big data processing; and artificial intelligence.

Japan's infrastructure stock is estimated to be over 800 trillion yen. Infrastructures should function for several decades. Our responsibility to the future is to create an infrastructure information platform and to pass on the infrastructures that can be used safely with a minimum maintenance burden to the next generation. The objective of "SIP infrastructure" is to establish the system and we will work hard to achieve it.

PD (Program Director)

Yozo Fujino

Distinguished Professor, Institute of Advanced Sciences, Yokohama National University

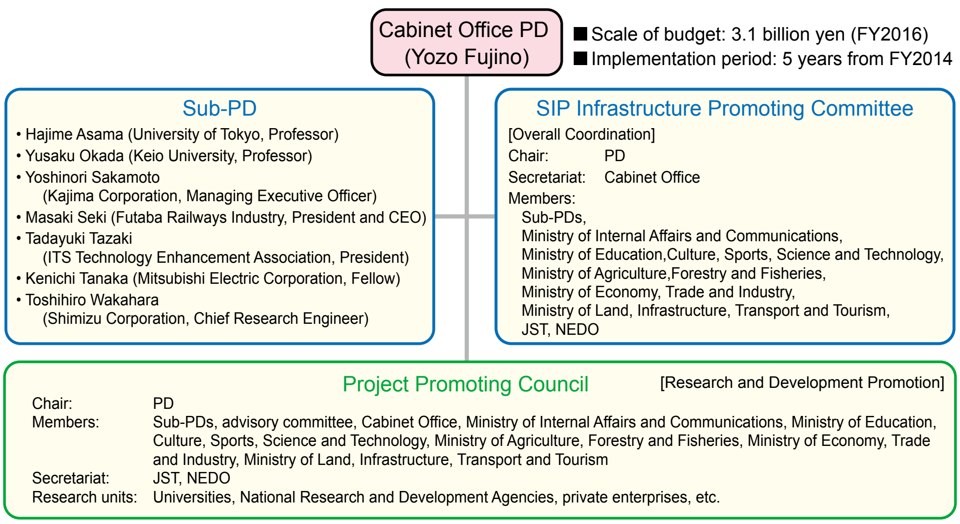
Biography

Yozo Fujino graduated from Department of Civil Engineering, at the University of Tokyo in 1972. After completing his Master's degree (Civil Engineering) at the University of Tokyo, he received the Doctor of Philosophy from the University of Waterloo in 1976. He joined the Earthquake Research Institute at the University of Tokyo; the Institute of Structural Engineering at the University of Tsukuba; and Department of Civil Engineering at the University of Tokyo. In 1990, he was appointed as a professor of Department of Civil Engineering at the University of Tokyo. In 2014, he joined the Yokohama National University, and has served in his current position from October 2014. He is a Professor Emeritus of the University of Tokyo. His expertise includes structures, vibration control and monitoring of civil infrastructures with emphasis on bridges. He was awarded the Medal with Purple Ribbon of Honor from the Emperor of Japan in 2007, and the 2015 Hattori Hoko Award (The Hattori Hokokai Foundation), among others.

Outline

In Japan, amid the aging of infrastructures, emerging risk of a serious accident such as the Sasago tunnel accident in 2012, and the increase in maintenance and repair expenditures are topics of concern. Systematic infrastructure management utilizing new technologies is essential both for preventing accidents based on preventive maintenance system and minimizing life cycle cost of infrastructures under the conditions of the tight financial grounds and the decreasing number of skilled engineers. Particularly, technologies that utilize the world's most advanced ICRT* are expected to create new business opportunities in the existing infrastructure maintenance market and to offer business expansion opportunities into Asian countries that face similar problems

To achieve this, we will improve the standard of maintenance by using low-cost preventive maintenance while stressing the necessity to match the needs of infrastructure maintenance with the seeds of technical development, and developing new technologies into more attractive technologies that can be used on-site. By achieving this, we aim at contributing to regional revitalization, as well as maintaining the important internal infrastructures to high standard while backing up a variety of regional economic activities. Furthermore, we will create an attractive and ongoing maintenance market and build a base for overseas expansion based on successful regional examples.



*ICRT: ICT (Information and Communication Technology) + IRT (Information and Robot Technology)

Maintenance, Renovation and Management

Overall Plan

To minimize the opportunity loss of regional revitalization resources such as logistics, service, and tourism, it is vital to implement efficient and highly economical maintenance, renovation, and management. This is important considering that infrastructures such as roads, railways, harbors, and airports are public assets and domain whose functions should always be maintained.

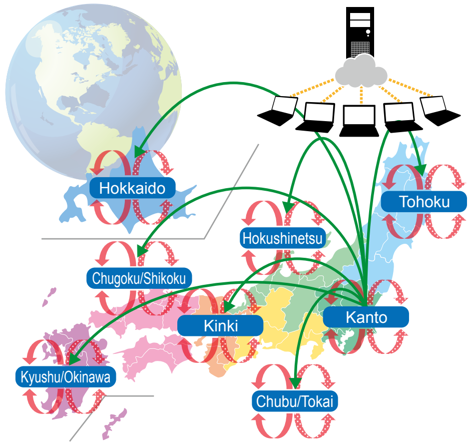
The following points are important in achieving the efficient maintenance and management of infrastructures, which are estimated to be worth a total of 800 trillion yen.

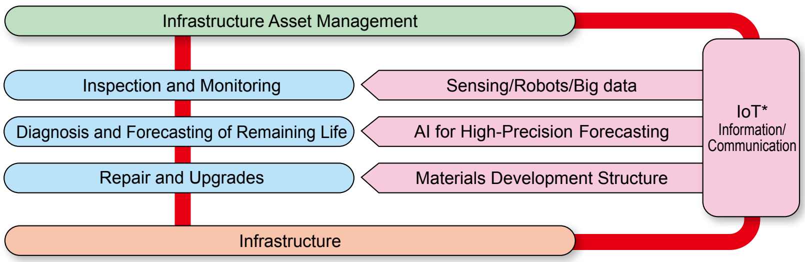
- Cooperation with a wide range of advanced technology fields including civil engineering and ICT/robotics technologies
- Coordinating technologies based on adaptations on-site
- Technical specification menu based on the various different situations of end users
- Technical managerial viewpoint including organization management to utilize the technology appropriately
- Sustainable support system for technical development

Without relying only on the results of technical development at each ministry, national research institute, university, and private company, an unprecedented cooperation system is also needed to achieve the above goals.

Further, we believe that we must actively roll out a new viewpoint concerning infrastructure maintenance through the related ministries and local governments to various users and residents.

This includes providing the society with new values created by appropriate maintenance of infrastructures such as the safety of users and our reputation as judged by users, as well as directly solving issues regarding the current methods of infrastructure maintenance.





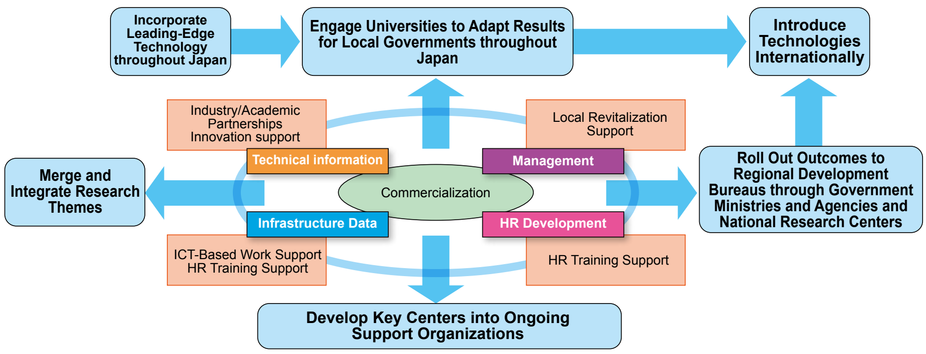
Achieve Society 5.0, the world's first super smart society

*IoT: Internet of Things

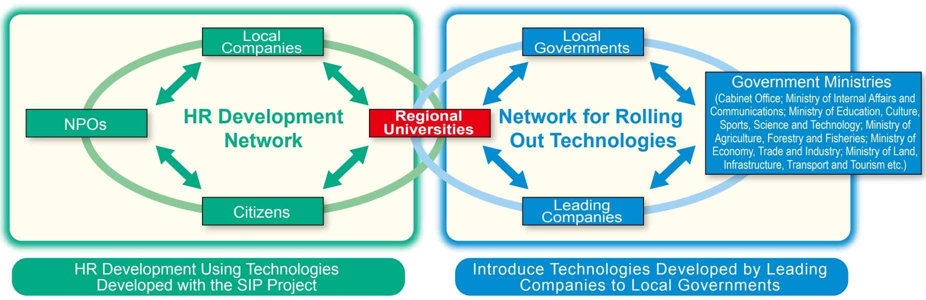
Exit Strategies

Since there is a diverse range of situations, targets, and technologies of infrastructure maintenance, we intend to implement infrastructure maintenance by optimally putting individual technical development together in the asset management phase. In the meantime, the development of IoT and other related technologies is remarkable, and construction of a platform that includes networked heterogeneous technologies, such as monitoring and sensing by robots and traveling vehicles, is rapidly becoming more of a real possibility. As a result, this has become a major strength that will allow us to drastically reform infrastructure maintenance. Therefore, we will advocate the promotion and cooperation with newly developed individual technologies by constructing an IoT platform to develop a scheme which will advance the integration of technologies through both asset management and the IoT platform.

As the base of this exit strategy, we will actively cooperate with key universities, regional universities, national research institutes, the Ministry of Agriculture, Forestry and Fisheries, the Ministry of Land, Infrastructure, Transport and Tourism, and local governments to create a unique framework for infrastructure related research. Specifically, we are considering the following business deployment patterns: "unique technological developments that have an individual theme," "deploying business to local governments through regional universities," "deploying business to the state administrative system through national research institutes," "establishing a permanent organization system to support industries," and "exporting and globally deploying technology." Of these patterns, we place greatest importance on "custom-made technical implementation support that suits regional characteristics," and investigate a technical support system from the base institutes, a fund support system, and the establishment of various technologies and sustainable support in local governments. In addition, we plan to implement a business model that will both help regional revitalization, and prepare an environment for business, by establishing a technical strategy plan based on reputation management.



Basic Aspects of Infrastructure Maintenance, Renovation, and Management Exit Strategies



Roll Out Infrastructure Maintenance and Renovation Management in the Regions

Universities, etc.

SIP

Cross-ministerial Strategic Innovation Promotion Program

The 5 Research and Development Topics for Infrastructure Maintenance

Asset Management Technologies

Implement infrastructure management for the technologies produced from individual research results. Develop asset management technologies for efficient operations management making the most of limited financial and human resources

Structural Materials, Deterioration Mechanisms, Repairs, and Reinforcement Technologies

Develop simulation technologies to assess the deterioration mechanism of structural materials; create a structural deterioration forecast system.

Inspection, Monitoring and Diagnostics Technologies

Develop technologies that provide efficient, effective inspection and monitoring capabilities to assess infrastructure damage.

Information and Communications Technologies

Develop data management technologies utilizing enormous volume of information generated by infrastructure maintenance, management, renovation, and repair systems.

Robotics Technologies (For Inspection, Disaster Measures, etc.)

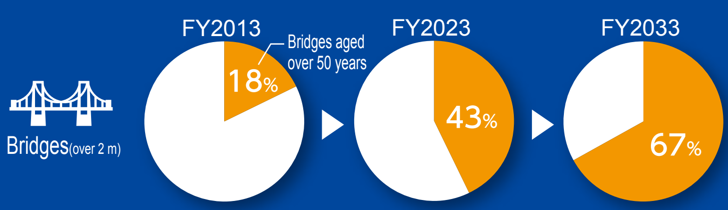
Develop robotics technologies to inspect, diagnose, operate, manage, and repair infrastructure elements efficiently and effectively; develop robots to perform surveys and excavation in dangerous situations such as disaster areas.

Companies

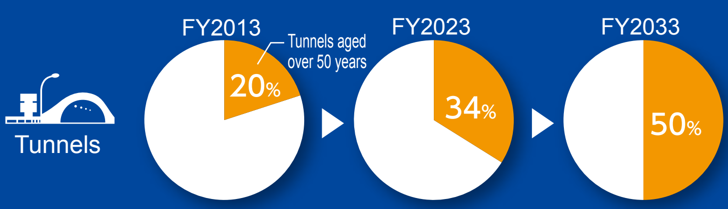
Cooperation

Ministries of Japan

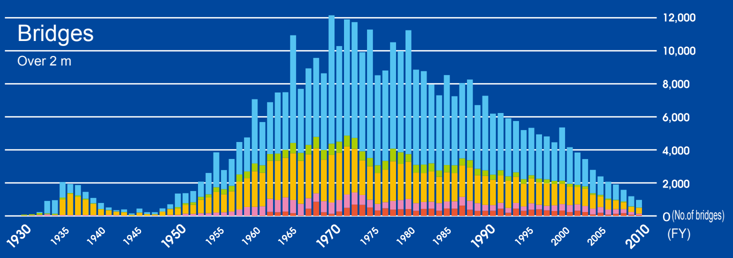
Implement for Domestic and Overseas Infrastructures



Transition ratio of bridges/tunnels over 50 years old



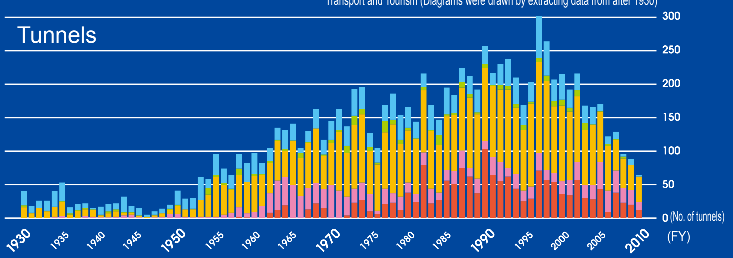
Bridges/Tunnels with an unknown construction year have been excluded.
Source: Diagrams were made based on materials from the Ministry of Land, Infrastructure, Transport and Tourism



Number of bridges/tunnels by construction year: Local Governments / Ordinance-designated City / 47 Prefectures / State / Expressway Companies

Bridges/Tunnels with an unknown construction year have been excluded

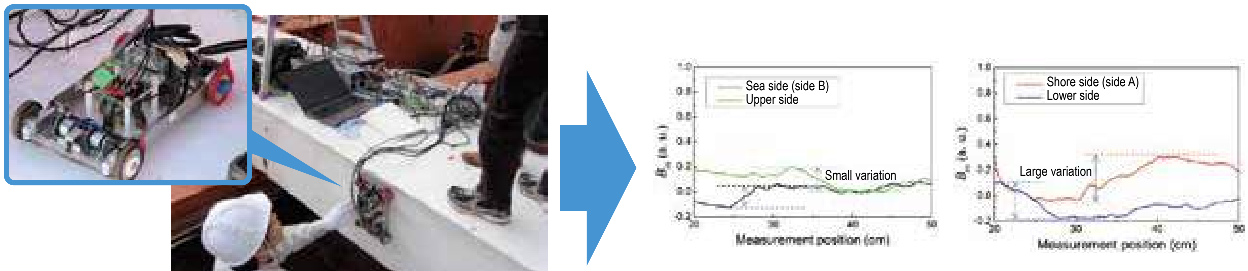
Source: Diagrams were made based on materials from the Ministry of Land, Infrastructure, Transport and Tourism (Diagrams were drawn by extracting data from after 1930)



Inspection, Monitoring and Diagnostics Technologies

Inspection, monitoring and diagnostic technologies have been developed to fully estimate damages of civil infrastructures. R&D subjects such as an internal defect inspection technology using supersensitive magnetic nondestructive testing, an integrated diagnostic system using high-speed traveling noncontact radar, remote diagnostic technology using supersensitive near infra-red spectroscopy, a pavement inspection system, floor slab deterioration detection using onboard underground probe radar, and the displacement monitoring technique for infrastructures using Satellite SAR (Synthetic Aperture Radar) are in progress.

Ultrasensitive magnetic nondestructive testing for deterioration evaluation and creating a preservation plan of infrastructures

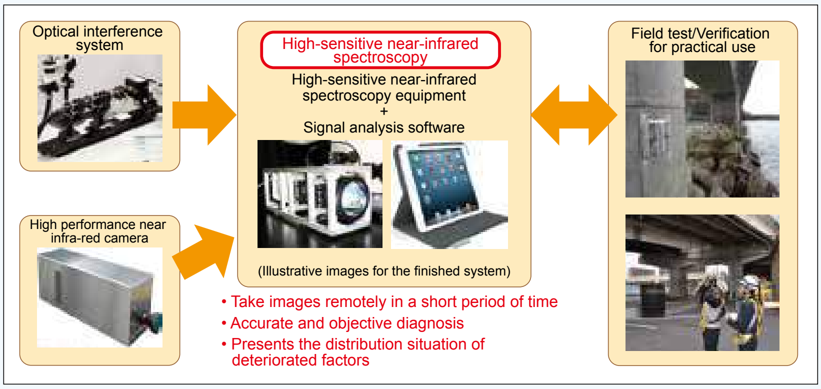


Minor internal corrosion | Major internal corrosion

Inner defects inspection for tunnel lining using rapidly scannable non-contact radar and synthetic soundness diagnosis system

Illustrative images for inspection and diagnosis using non-contacting radar

Remote sensing of concrete structure with the high-sensitive near-infrared spectroscopy



Near infra-red imaging technology that can analyze the deteriorated components of concrete remotely in a short period of time and at a low cost

Simple pavement inspection system utilizing an airport ground vehicle

A monitoring site demonstration on the runway of an airport

Wide area displacement monitoring for early detection of deformation or damage of civil engineering structures using satellite SAR[*1]

Efforts for site verification using Satellite SAR technology

[*1] SAR: Synthetic Aperture Radar

Detection of floor slab deterioration using the onboard underground probe radar

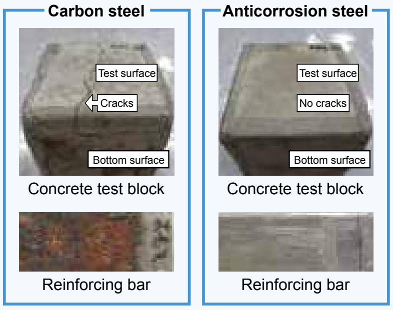
Detection of deteriorated portions inside a floor slab using an onboard high speed scan radar

Structural Materials, Deterioration Mechanisms, Repairs, and Reinforcement Technologies

Extensive R&D activities have been in progress amidt urgent social demands in this category of the SIP project in oreder to develop simulation models for the deterioration mechanisms of structural materials and innovative estimation system for deterioration progress of infrastructures, to organize a core base for R&D of structural materials to develop effective maintenance technologies, and to promote the commercialization and wider application of precast members using highly-durable concrete for society

Investigation of structural deterioration mechanisms and efficient maintenance systems

Comparison of two-year exposure test results between normal carbon steel and anticorrosion steel
(at Irabu Ohashi Bridge)



Cracks due to corrosion — No cracks due to corrosion

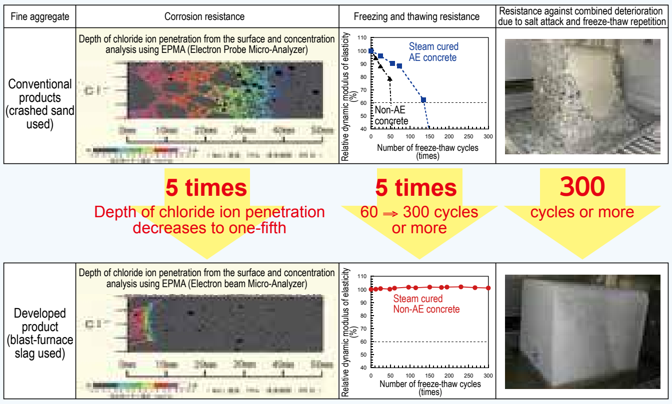
Exposure test of a PC test beam deteriorated by ASR[*2]

Fly ash concrete

Concrete with no fly ash mixed

[*2] ASR: Alkali Silica Reaction

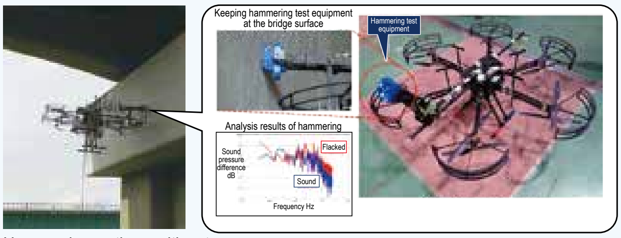
Precast products using high-durability concrete



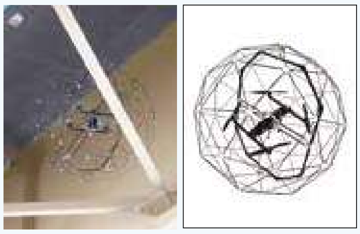
Robotics Technologies (For Inspection, Disaster Measures, etc.)

Various robots have been developed to inspect civil infrastructures, such as bridges and tunnels, safely and economically. At the same time, a wide range of R&D tasks are ongoing for a study of applicable structures for the introduction of robotics technologies, and establishing an integrated database to centrally manage the information for the effective utilization of robotics technologies. With these efforts, the implementation in society of robots for infrastructure maintenance is highly expectd.

Hammer test flying robot system for bridge/tunnel inspection



Hammer inspection multicopter

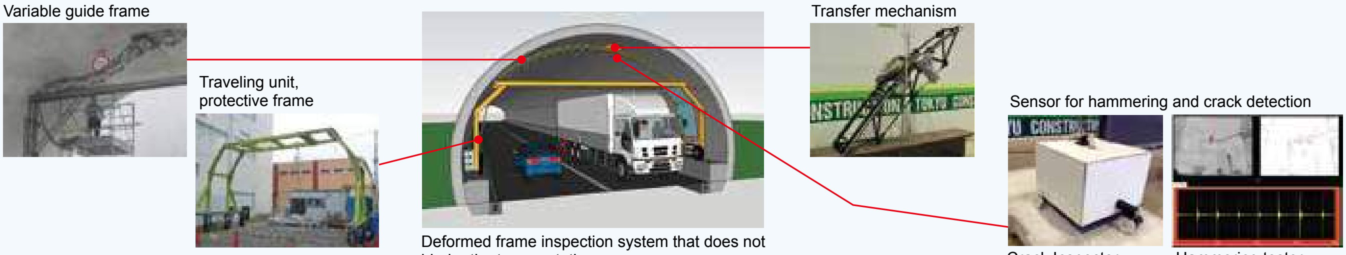


Multicopter with passive rotating spherical shell

Semi-submerged work robot using remote control

Transport robot for unmanned construction in the semi-submerged environment

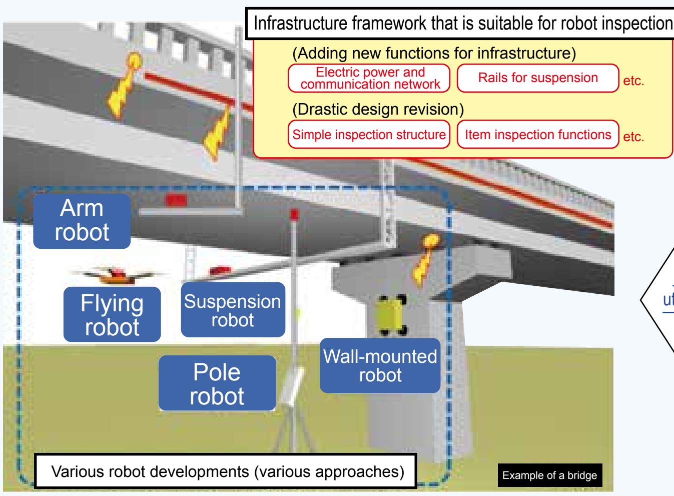
The variable guide frame vehicle for inspection of tunnel



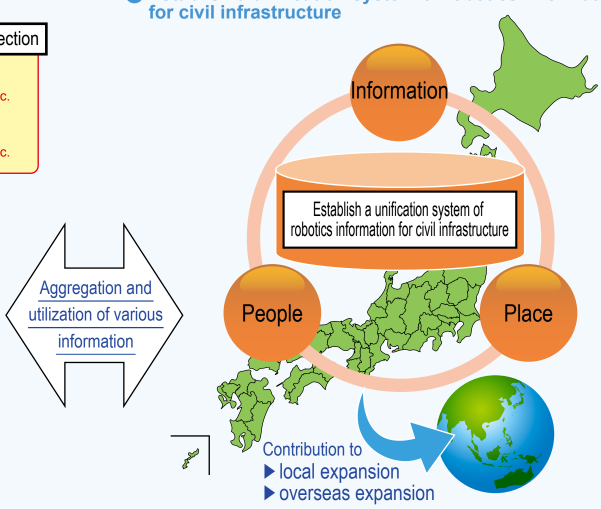
Deformed frame inspection system that does not hinder the transportation

Crack Inspector — Hammering tester

Infrastructure framework that is suitable for robot inspection



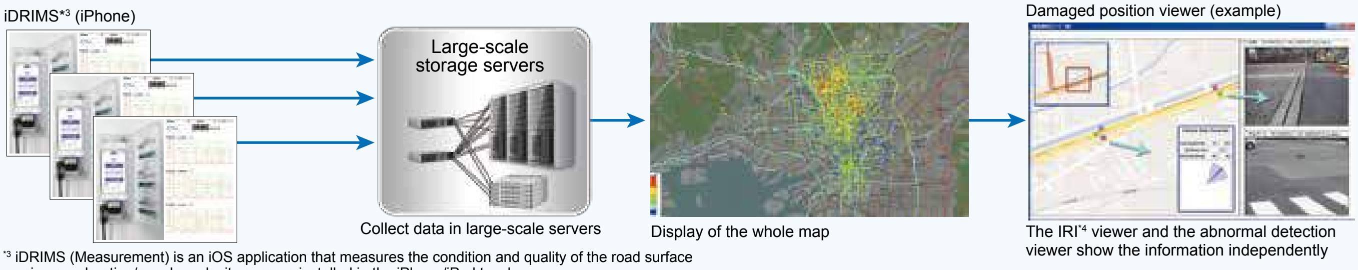
Establish a unification system of robotics information for civil infrastructure



Information and Communications Technologies

The main subject of R&D is to develop data management systems fully utilizing information and communication technologies (ICT) to take advantage of the enormous amount of information on maintenance, repair and renewal of civil infrastructures for contributing to the real application of advanced ICT for society. Specific R&D fields are data screening based on integrated large-scale sensor information for pavements and bridges and so on, data management enabling comprehensive control of a variety of information and data analysis and visualization technologies for making the stored data effectively applicable for real operation on-sites.

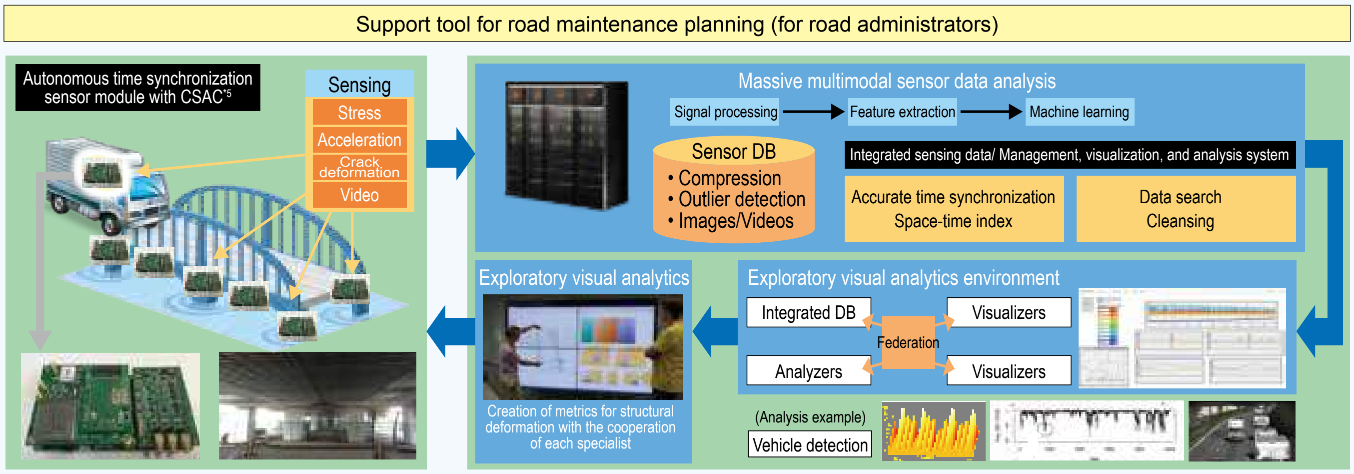
Research, development, and social implementation of screening technologies on pavement and bridges based on large-scale sensor information fusion toward preventive maintenance of infrastructure



*3 iDRIMS (Measurement) is an iOS application that measures the condition and quality of the road surface using acceleration/angular velocity sensors installed in the iPhone/iPod touch.

*4 IRI:International Roughness Index Ride comfort index

Integrated data management platform for civil Infrastructure sensing

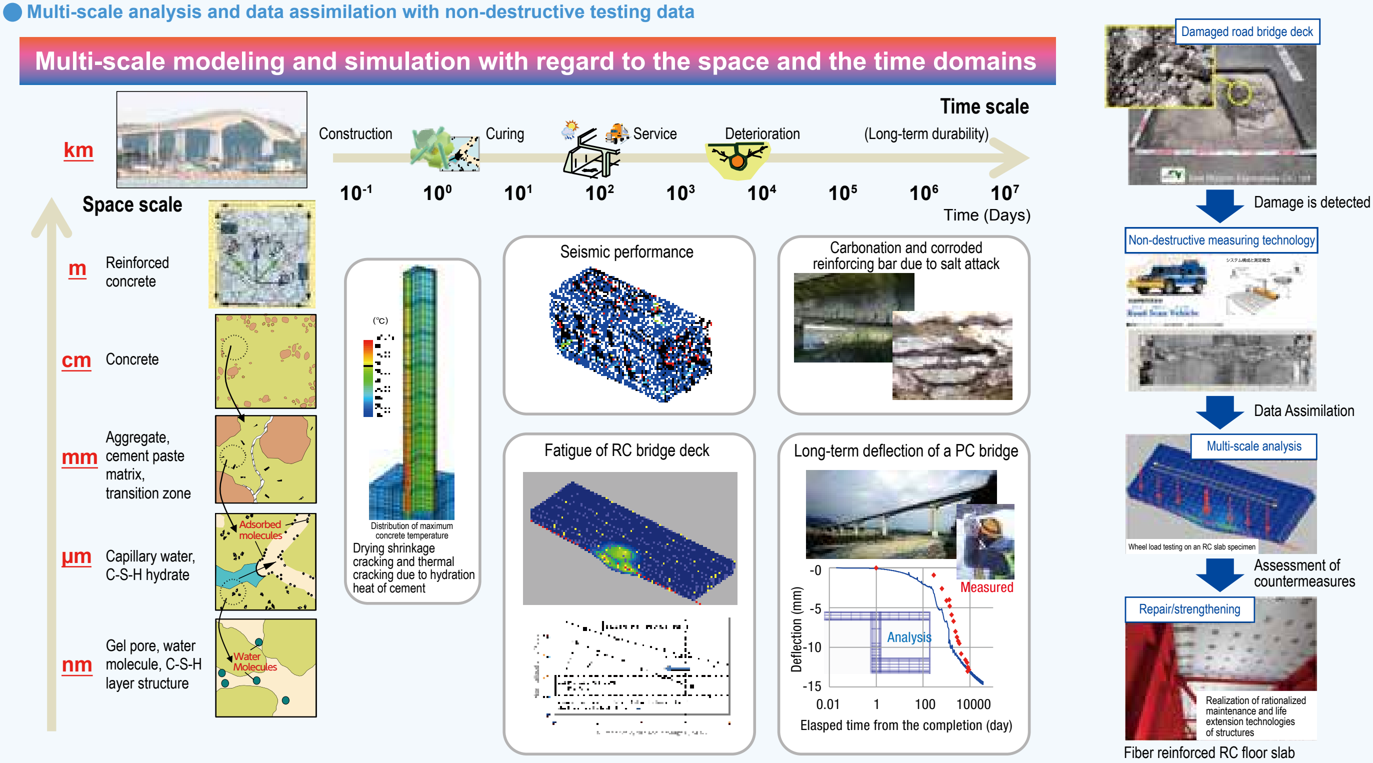


*5 CSAC: Chip Scale Atomic Clock

Asset Management Technologies

Along with real applications of R&D outcomes for society, SIP contributes to secured and safe infrastructures by cooperating with infrastructure administrators. The advanced technologies including non-destructive test methods and innovative numerical analysis have been developed for maintenance of road structures. In addition, SIP also proposes a highly sustainable asset management system from the viewpoints of contract scheme, human resource training, private sector utilization, and collaboration with the local residents to maintain enormous number of infrastructures which local governments should manage with a limited budget.

Multi-scale analysis and data assimilation with non-destructive testing data



Program Director

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* In Japanese syllabary order
* Affiliations are as of December 2016

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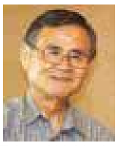
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Government Ministries

内閣府 Cabinet Office

- Ministry of Internal Affairs and Communications
- Ministry of Education, Culture, Sports, Science and Technology
- Ministry of Agriculture, Forestry and Fisheries
- Ministry of Economy, Trade and Industry
- Ministry of Land, Infrastructure, Transport and Tourism

Funding Agencies / Related Ministry

- Ministry of Land, Infrastructure, Transport and Tourism
- JST Japan Science and Technology Agency
- NEDO New Energy and Industrial Technology Development Organization

Research Units

- Universities
- National Research and Development Agencies
- Private Enterprises, etc.

	No.	Research and Development Theme	Principal Investigator (Affiliation)
(1) Inspection, Monitoring and Diagnostics Technologies	1	Interdisciplinary R&D of NDE Techniques for Innovative Maintenance	Masahiro Ishida(Public Works Research Institute)
	2	Development of the Laser Ultrasonic Visualization Technology for the Degradation Diagnosis of Steel Bridges	Junji Takatsubo(Tsukuba Technology Co., Ltd.)
	3	Ultrasensitive Magnetic Nondestructive Testing for Deterioration Evaluation and Creating a Preservation Plan of Infrastructures	Keiji Tsukada(Okayama University)
	4	R&D of Laser Directive Noncontact Diagnosis System for Maintaining Degraded Infrastructures	Katsumi Midorikawa(RIKEN)
	5	Development of Automatic Technology on Pavement & Embankment Survey and Evaluation	Atsushi Yashima(Gifu University)
	6	Non-destructive Inspection of Rebar Corrosion in Concrete	Kenji Ikushima(Tokyo University of A&T)
	7	R&D of Backscatter X-ray Imaging System for Concrete Inspection	Hiroyuki Toyokawa(AIST)
	8	R&D of Vibration Imaging Radar	Hitoshi Nohmi(Alouette Technology Inc.)
	9	Inner Defects Inspection for Tunnel Lining using Rapidly Scannable Non-contact Radar and Synthetic Soundness Diagnosis System	Toru Yasuda(Pacific Consultants Co.,Ltd.)
	10	Remote Sensing of Concrete Structure with the High-Sensitive Near-infrared Spectroscopy	Kazuhiro Tsuno(Shutoko Engineering Co., Ltd.)
	11	R&D of Learning-Type Hammering Echo Analysis Technology	Masahiro Murakawa(AIST)
	12	Inspection and Diagnosis System of Port Structure Using Radio Controlled Boat	Tetsuya Ogasawara(Penta-Ocean Construction Co., Ltd.)
	13	Development of the Special GPR Including a Chirp Radar in the Survey of a Cavity and a Settlement of the Back-fill Material	Shigeji Yamada(KAWASAKI Geological Engineering Co., Ltd.)
	14	Development of the Monitoring System for Port Facilities using Satellite and SONAR	Takeshi Nishihata(Penta-Ocean Construction Co., Ltd.)
	15	Monitoring by using Ground-Base Synthetic Aperture Radar and Array-type Ground Penetrating Radar	Motoyuki Sato(Tohoku University)
	16	Monitoring System for a Round of Airport Paved Road Inspection, Utilizing a Technique for Detecting Cracks Automatically from High-resolution Images	Toru Hara(Alpha Product INC.)
	17	R&D of the Crack Detection System for Runways with a 3D Camera and all Direction-moving Robot	Yasuo Kimura(NTT Advanced Technology Corp.)
	18	R&D of a Simplified System for Monitoring the Airport Pavement Surfaces Using Maintenance Vehicles	Yusho Ishikawa(The University of Tokyo)
	19	Development of Wide Area Displacement Monitoring for Early Detection of Deformation or Damage of Civil Engineering Structures using Satellite SAR	Masafumi Kondo(National Institute for Land and Infrastructure Management)
	20	Understanding the Scouring Situation by ALB (Airborne Laser Bathymetry)	Hiroaki Sakashita(PASCO Corp.)
	21	R&D of Monitoring System for Bridge Performance Assessment Based on Vibration Mode Analysis	Tadao Kawai(Osaka City University)
	22	Creation of Monitoring System using Equipment with Robotic Camera and etc. for Bridge Inspection	Yasuhisa Fujiwara(Sumitomo Mitsui Construction Co., Ltd.)
	23	R&D of Quantitative Evaluation System of Cracks on Distant Slabs by Digital Image Analysis Technology	Kenichi Horiguchi(Taisei Corp.)
	24	Field Validation of the Continuous Remote Monitoring System with Power saving Wireless Sensor	Hideshi Nishida(Omron Social Solutions Co., Ltd.)
	25	R&D of the Technology which Monitors the Displacement Rate of a Manmade Structure with High Accuracy and Efficiency	Minoru Murata(NEC Corp.)
	26	R&D of Monitoring System for Detecting Surface Failure by pore pressure sensor with inclinometer	Yasunori Shoji(OYO Corp.)
	27	R&D of Early Warning Monitoring System of Slope Failure using Multi-point Tilt Change and Volumetric Water Content	Lin Wang(Chuo Kaihatsu Corp.)
	28	Mole (Small Animals) Hole Detection System Attached to Large Weeding Machine	Kiyoshi Suzuki(Aero Asahi Corp.)
	29	Electric resistivity monitoring system for the state of water contents in river levee	Hideki Saito(OYO Corp.)
	30	R&D of Monitoring System Including a Detection of River Levee Deformation	Shunsuke Sako(Japan Institute of Country-ology and Engineering, General Incorporated Foundation)
	31	Effective Use of Satellite SAR Observation for River Embankment	Takeshi Katayama(Infrastructure Development Institute)
	32	Monitoring system for internal state of river levee utilizing geophysical exploration and ground water observation	Akira Shinsei(OYO Corp.)
	33	Improvement for More Advanced and Efficient Road Structure Maintenance using Monitoring Technology	Atsushi Homma(Research Association for Infrastructure Monitoring System)
	34	Maintenance and Management of Social Infrastructure utilizing IT (Inspections, Diagnosis)	Ministry of Land, Infrastructure, Transport and Tourism

	No.	Research and Development Theme	Principal Investigator (Affiliation)
(2) Structural Materials, Deterioration Mechanisms, Repairs, and Reinforcement Technologies	35	Deterioration Mechanism of Infrastructures and Materials Technology for Efficient Maintenance	Koichi Tsuchiya(NIMS)
	36	Developing Hybrid Mechanoluminescence Materials for Visualization of Structural Health	Chao-Nan Xu(AIST)
	37	Technology of Repairing the Corrosion Damage and Deterioration to Steel Structures using Newly Developed Flame Coating Material	Kenji Higashi(Osaka Prefecture University)
	38	Practical Application of PCa with Super-High Durability Concrete	Toshiki Ayano(Okayama University)

	No.	Research and Development Theme	Principal Investigator (Affiliation)
(3) Information and Communications Technologies	39	Research, Development, and Social Implementation of Screening Technologies on Pavement and Bridges based on Large-scale Sensor Information Fusion toward Preventive Maintenance of Infrastructure	Masataka Ieiri(JIP Techno Science Co., Inc.)
	40	R&D on Technologies for Collecting, Transmitting, and Processing Sensing Data of Civil Infrastructures (Underground Structures)	Shuichi Yoshino(NTT)
	41	R&D of Integrated Data Management Platform for Civil Infrastructure Sensing	Jun Adachi(National Institute of Informatics)
	42	Development of Technologies on Wide Variety of Data Processing, Storage, Analysis and Application to Achieve Advanced Infrastructure Management	Isao Ueda(East Nippon Expressway Co., Ltd.)
	43	R&D on Data Store/Management/Utlization Technologies for a Variety of Data Relating to Maintenance and Replacement of Civil Infrastructures	Toshihiro Kujirai(Hitachi, Ltd.)

	No.	Research and Development Theme	Principal Investigator (Affiliation)
(4) Robotics Technologies	44	Development of Infrastructure Inspection System using Semi-autonomous Multi-copter equipped with Flexible Electrostatic Adhesive Device	Tadahiro Hasegawa(Shibaura Institute of Technology)
	45	R&D of Diagnostic Technology Based on Measurement and Analysis by Multi-copter	Toshio Fukuda(Meijo University)
	46	Development of Intuitive Teleoperation Robot using the Human Measurement	Shigeki Sugano(Waseda University)
	47	Development of Bridge Inspection Robot System Supported by the Provisional and Flexible Scaffolding Structure	Shigeo Hirose(HiBot Corp.)
	48	R&D of Flying Robot for Bridge/Tunnel Inspection	Toshihiro Nishizawa(NEC Corp.)
	49	R&D of the Variable Guide Frame Vehicle for Tunnel Inspection	Satoru Nakamura(Tokyu Construction Co.,Ltd.)
	50	Development of Unmanned Aerial Vehicles for Observing and Hammering Aged Bridges at Short Range	Kazunori Ohno(Tohoku University)
	51	R&D of a Multicopter-based Inspection Robotic System with Visual Observation and Hammering Test Devices	Hideki Wada"(Shinnippon Nondestructive Inspection Co.,Ltd.)
	52	Development of a Bridge Inspection Support Robot System that uses Proximity-images with Geotag and a Two-wheeled Flying Robot	Naoyuki Sawasaki(Fujitsu Ltd.)
	53	New Development of Unmanned Construction ~Realization of Remote Operated Working System in Shallow Water Area~	Shin'ichi Yuta(New Unmanned Construction Technology Research Association)
	54	Research and Development of Infrastructure Structures and Inspection Devices for Advanced Inspection of Civil Infrastructure	Kenichi Fujino(Public Works Research Institute)
	55	Research and Development Concerning Mechanized Mobile Object Inspection Methods and Structure Forms that Aim to Save Energy and Improve Accuracy of Inspection	(Changed to Joint Research with the Public Works Research Institute)
	56	Establish an Unification System of Robotics Information for Civil Infrastructure	Ministry of Land, Infrastructure, Transport and Tourism

	No.	Research and Development Theme	Principal Investigator (Affiliation)
(5) Asset Management Technologies	57	Global R&D on the Management Cycle of Road Infrastructures	Koichi Maekawa(The University of Tokyo) *
	58	Resolution of Early-aged Deterioration Mechanism & Development of Total Management System Based on Evaluation for Material and Structure Quality Performance	Kazuyuki Torii(Kanazawa University) *
	59	Development of Life-cycle Management System for Port and Harbour Facilities - Integrated Framework from Inspection to Assessment	Ema Kato(National Institute of Maritime, Port and Aviation Technology)
	60	R&D of Development of Strategic Asset Management Technologies for Trunk Agricultural Water Facilities	Isamu Nakajima(National Agriculture and Food Research Organization)
	Regional implementation support team (including *)		
	61	Research on Regional Cooperation for Applications of Asset Management for Civil Infrastructuers	Yasushi Takamatsu(Hokkaido University)
	62	Conversion to a Regional-Autonomous System as Next-Generation Water Infrastructure Management	Ken Ushijima(Hokkaido Research Organization)
	63	Establishment and Promotion of the Tohoku Infrastructure Management Platform	Makoto Hisada(Tohoku University)
	64	Implementation of Effective SIP Maintenance Technologies by the ME Network	Keitetsu Rokugo(Gifu University)
	65	Framework of Infrastructure Maintenance in Kansai/Hiroshima Regions and Actual Deployment of New Technologies	Hitoshi Furuta(Kansai University)
	66	Development of Civil Infrastructure Maintenance Systems for Local Governments Through Multi-Phased Diagnosis	Tamotsu Kuroda(Tottori University)
	67	Development of Local Government Support Systems Focusing on Risks of Serious Accidents	Pang-jo Chun(Ehime University)
	68	Research and Development of Implementation in Society of Innovative Advanced Technology for Civil Infrastructure Maintenance	Hiroshi Matsuda(Nagasaki University)
	69	Development of Bridge Maintenance Technologies for Subtropical Islands and Training Diagnostic Experts	Yasunori Arizumi(University of the Ryukyus)
	70	Development of Models for Improving Service Life of Civil Infrastructures Through Cooperation between Business Administration, Science and Engineering, and Economics	Atsuomi Obayashi(Keio University)
	71	Research and Development Concerning Introduction of Asset Management Technologies to Local Governments, etc.	Toshihiko Doi(Japan Foundation for Regional Vitalization)

1 Interdisciplinary R&D of NDE techniques for innovative maintenance

Principal Investigator Masahiro Ishida (Chief Researcher, Public Works Research Institute)

Collaborative Research Groups The University of Tokyo, Riken

R&D Objectives and Subjects

Targets

Steel corrosion in concrete structures

Ducts unfilled with grout

Degradation of concrete slabs

Objectives

Develop **a diagnostic method** for concrete structures by **visualization techniques** using **X-ray** and **Neutron sources**

Subjects

- Develop a **portable visualization system using high-power X-rays** and use it on actual bridges
- Downsize the **water visualization system using small scale Neutron sources** and examine its feasibility for water detection in concrete slabs
- Develop **a diagnostic method based on visualization** to evaluate deteriorated structures

Current Accomplishments (1/2)

Suspected PC girder (wire fracture, etc.)

Events or issues	Information
Unfilled part with grout in ducts	void location
Corrosion of wires	Degree of corrosion
Fracture of wires	Fracture of wires
Loss of bearing capacity	Location of re-anchorage
Bridge collapse	Loss of bearing capacity

Partial CT Tomosynthesis

Complicated stress fields

Re-distribution of loads

Identify the unfilled area

Accurate evaluation of residual bearing capacity

Information about the whole bridge

Adequate counter actions for individual bridges

Suspected case of unfilled grout

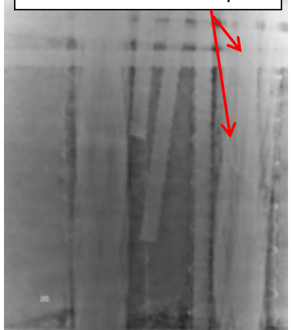
Inner corrosion difficult to find by visual inspection

Sudden collapse

Visualization by High-power X-ray

Visualization of inner steel with corrosion and fracture in an serviced bridge was successfully attained (using 950keV X-ray)

Corrosion or fracture part



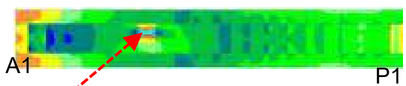
Visualization of inner steel by X-ray

Diagnostic technique based on visualization

Wire location between A1 and P1

Develop a analytical method based on visualization

Stress concentration

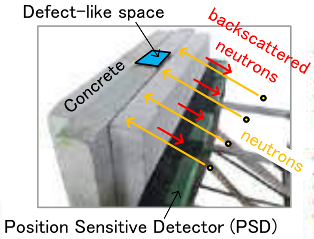


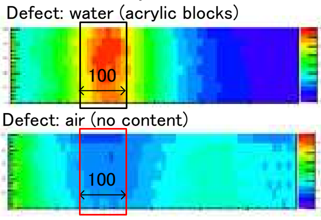
Bottom flange in bridge axis direction

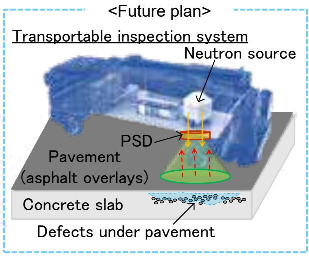
Current Accomplishments (2/2)

Defects visualization in concrete slabs

Optimum planning of slabs and pavement rehabilitation







* PSD is set on the same side of the neutron source.

Operational sequence

Bridge owner → (Order) → Inspector; Inspector → (Report) → Bridge owner

Inspector → (In case of PC girder) → Preliminary inspection by conventional methods → Inspection by X-ray and Neutron source → (In case of PC girder) → Structural analysis → Guidelines for Diagnostic analysis by high-end NDT (PWRI)

Suspected Post-tensioned PC girders

Pavement Degradation

Imaging: Specialized inspector ↔ Suspected Post-tensioned PC girders / Pavement Degradation; Specialized inspector ↔ Inspection by X-ray and Neutron source

Fabricators → (Selling / Rental) → Specialized inspector

U. of Tokyo, Riken → Fabricators

Neutron source (Riken)

- Defects under pavement were successfully captured by a new method using backscattered (reflected) neutrons.
- Development of more compact accelerator neutron source

X-ray source (U. of Tokyo)

- On-site imaging of actual bridges was successfully done. Safety and feasibility were also confirmed
- Verification of partial CT technique and Tomosynthesis

Evaluation (PWRI)

- Experimental verification of the proposed method was successfully carried out using a large-scale PC box girder with an artificial fracture
- Numerical model with re-anchorage wire was developed.

Goals

Implementation of developed techniques for domestic bridges

Final goals

- Establishing the fundamental technologies of X-ray transmission imaging and limited angle CT reconstruction through inspections of actual infrastructures using the portable high power X-ray sources.
  →Detection of fractures or corrosion of steel in millimeter resolution.
  →Securing radiation safety by controlling air dose under 250 mSv/3month at the boundaries of controlled areas.
  →Clarifying applicable conditions of the X-ray back scattering imaging.
- Investigate the on-site applicability of compact neutron sources through in-lab experiments on deteriorated existing structures
  → inspect the defects in concrete slabs with the imaging technique using backscattered (reflected) neutrons
  → develop a prototype of the transportable accelerator neutron source
- Develop an analytical method to simulate deteriorated PC girders with corrosion and fractures in PC wires
  - Re-anchorage of PC wires is properly considered
- Develop a diagnostic evaluation of deteriorated concrete bridges using visualized inner structures
  - propose guidelines for diagnostic analysis using visualization techniques

Exit strategy for practical application

- Downsize the system for more prompt activity to extend its application
- Endorse the proposed guidelines by organizing a public committee
- Promote the proposed techniques through the consulting activities with CAESAR, PWRI.
- Demonstrate its safety by conducting actual inspections lead by CAESAR as often as possible

Dissemination to the world

Find and collaborate with counterparts in countries where the system would be officially applicable in bridge inspection

2 Development of Laser Ultrasonic Visualization Technology for the Degradation Diagnosis of Steel Bridges

Principal Investigator Junji Takatsubo (Director, Tsukuba Technology Co., Ltd.)

Collaborative Research Groups AIST, Fukken Gijyutsu Consultants Co., Ltd.

R&D Objectives and Subjects

Objectives

- Current crack inspection of steel bridges is carried out using MT(Magnetic Particle Test) , but has the following problems:
  ① It takes time to tear off the coating
  ② Recoating is necessary after inspection
  ③ Internal cracks cannot be detected
- In order to solve the above problems, we will develop a remote measurement system using laser ultrasonic technology, which can efficiently detect cracks under coating

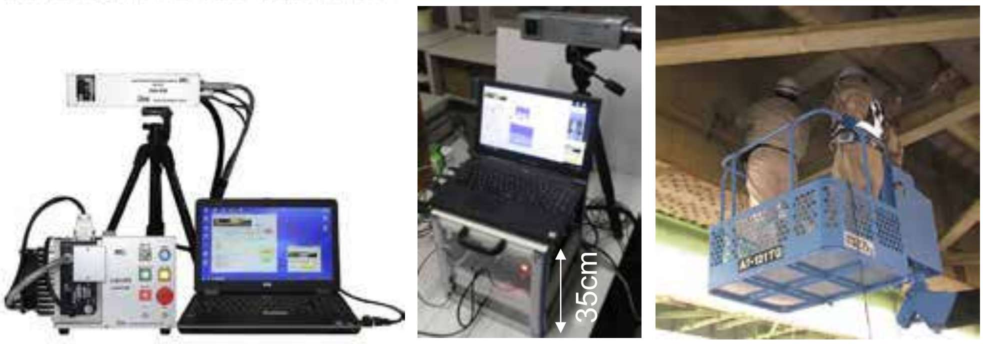
Subjects

- Development of a high-speed laser-scanning system to measure the video image of ultrasounds propagating in a bridge
- Construction of a laser optic system which enables remote measurement
- Manufacture of a small and light-weight laser ultrasonic visualization system
- Development of an image analysis method to detect the location and size of cracks

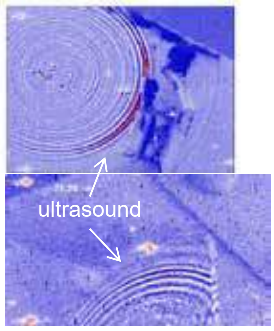
Current Accomplishments (1/2)

Prototype system can be carried in a small crane bucket with two persons

The only instrument in the world that can inspect a steel bridge on-site by a video image of the propagation of ultrasonic waves.

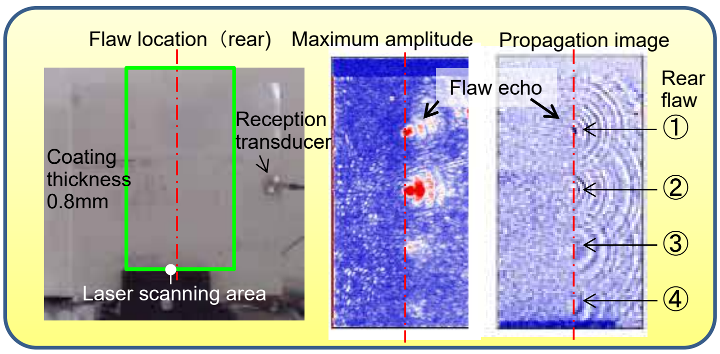


Portable system for field operations



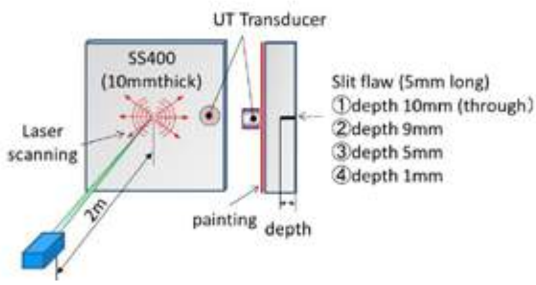
Measured images of ultrasonic propagation on a steel bridge

Slit flaws under coating can be detected from 2 m away



Inspection of coating

Inspection of internal cracks that are under coating

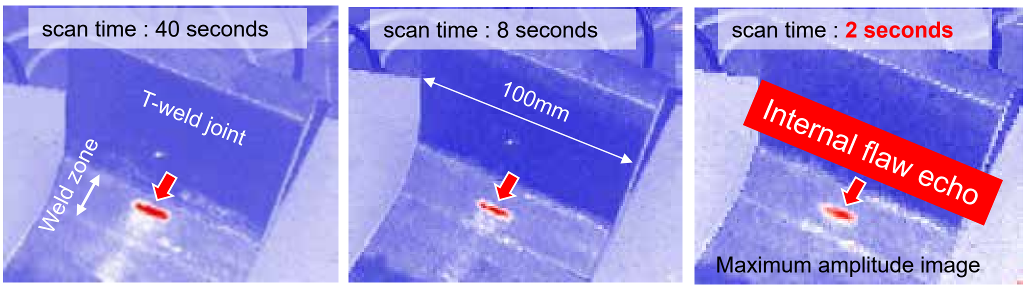


Current Accomplishments (2/2)

High-speed visualization

Laser scan speed: more than 5000 points/sec

visualized in 2 sec



Quick Inspection

Inspection area of 500 mm x 500 mm can be visualized in 22 sec

(scan speed: 5000 Hz, scan spacing: 1.5 mm)

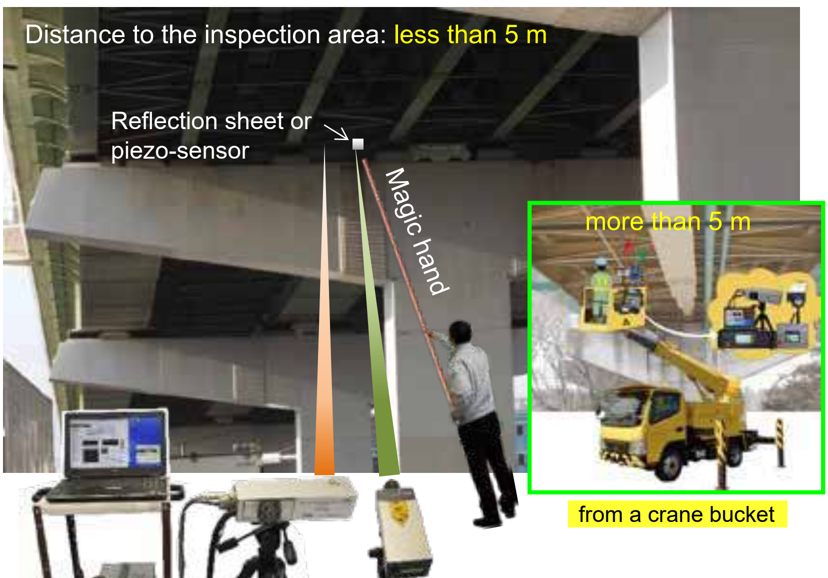
Efficient for steel bridge inspections

- Fatigue cracks that were coated could be detected
- Detected crack lengths agreed well with the MT results

Steel bridge on National Road No.50 | Inspection area (inside the green frame) | Visualized crack echo

Goals

Fifty-percent reduction in inspection duration and cost



International Plan

NON-CONTACT INSPECTION

Using reflection sheets
Remote Inspection System
Inspection object: Stiffening plate, Welding member

CONTACT INSPECTION

Using contact sensors
Portable Quick Inspection System
Inspection object: Steel floor

- Cracks of 5 mm in length under coating can be detected from a position 5 m away (by non-contact inspection).
- Cracks of 1 mm in length under coating can be detected (by contact inspection)

Road bridges, Highways, Railways, Industrial facilities

3 Ultrasensitive Magnetic Nondestructive Testing for Deterioration Evaluation and Creating a Preservation Plan of Infrastructures

Principal Investigator Keiji Tsukada (Professor, Okayama University)

Collaborative Research Groups SUSTERA, JAPEIC, Kyushu University

R&D Objectives and Subjects

Objectives

The purpose of this research is to develop a non-destructive testing (NDT) method using highly-sensitive magnetic measurements. Many infrastructural elements, such as bridges, are composed of steel, and the corrosion and cracking of steel can lead to serious problems. Conventional magnetic NDT methods are limited to only surface evaluation of steel structures. Therefore, in this study, we fabricate an inspection instrument that uses a magneto-resistive (MR) sensor and a SQUID sensor, which has the highest sensitivity among magnetic sensors, to realize a new NDT method using magnetic measurement to evaluate corrosion and cracking within and behind steel structures. Comprehensive development of the measurement and analysis method is carried out for detecting changes in magnetic signals due to corrosion and cracking of various steel structures, and a guideline for infrastructure management is established based on the developed NDT method.

Subjects

- **Basic magnetic inspection system**: To realize quantitative evaluation and visualization of flaws in a way that can be understood by anyone without expertise, a magnetic inspection system was developed that can detect flaws inside steel structures of various shapes, and the method of extraction and display of flaws was examined.
- **Instrument for field inspections and field tests**: Two types of inspection instruments were developed; a portable instrument using an MR sensor and a highly sensitive instrument using SQUID, and the structure of the inspection part and system size, including power supply, were optimized to install the actual device easily. Using these instruments, a field test was performed and the usefulness of these two instruments was clarified.
- **Social implementation**: We spread information about the usefulness of the developed new magnetic inspection method both inside and outside Japan, and promoted standardization for JIS and ISO.

Current Accomplishments (1/2)

Portable inspection equipment using magnetic sensors

The magnetic resistive sensor–based non-destructive inspection method can detect not only surface defects but also inner defects because it can analyze magnetic response over a wide range of frequencies from extremely low to high. Furthermore, power consumption of the developed portable inspection equipment is low.
The developed magnetic inspection methods are as follows:

- Extremely low frequency eddy current testing (**ELECT**)
- Unsaturated AC magnetic flux leakage testing (**USAC-MFL**)
- **ELECT** can detect thickness changes in corroded iron steel plates. At present, the detection limit is 16 mm in thickness.
- **USAC-MFL** can detect surface and internal cracks in iron steel. Cracks with depths lower than 10 mm can be detected.

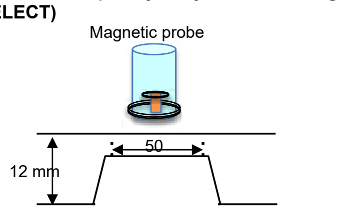
These developed magnetic non-destructive testing methods, ELECT and USAC-MFL, can be applied easily to painted and rusted surfaces.

Portable inspection equipment

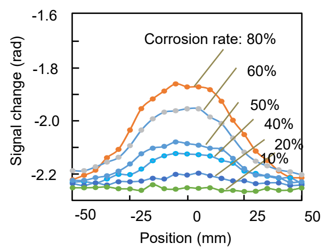
Magnetic probe for corrosion detection

Magnetic probe for crack detection

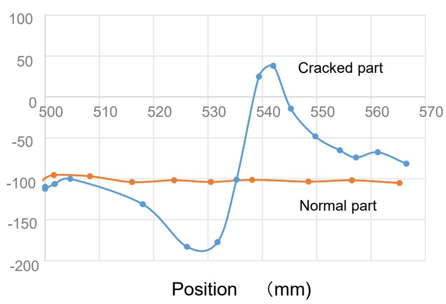
Ultra low-frequency eddy current testing (ELECT)



Cross sectional structure of corroded test sample



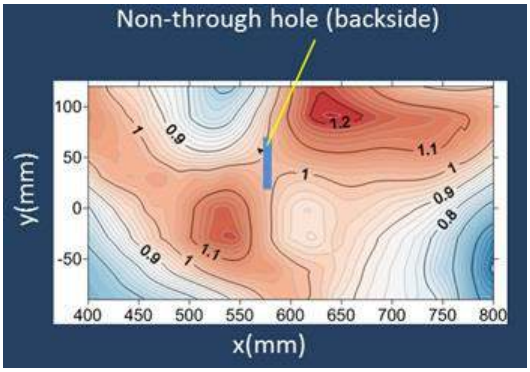
Unsaturated magnetic flux leakage (USAC)



Current Accomplishments (2/2)

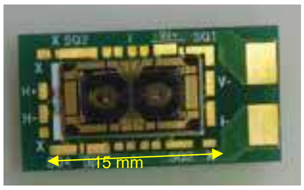
Development of NDE system with ultra-high sensitivity

Superconducting quantum interference device (SQUID) magnetic sensors using oxide superconductors have ultra-high sensitivity and can be used by easy cooling with low-cost liquid nitrogen. Recently, fatigue cracks in steel deck plates which originate at the backside welding points have been recognized as a large problem in maintenance of bridges and metropolitan highways. Magnetic particle inspection or ultrasonic testing from the backside of the deck plates are currently used for maintenance. By utilizing a SQUID magnetic sensor which has ultra-high sensitivity even at low frequencies, development of a non-destructive evaluation (NDE) system which enables inspection of small fatigue cracks and further non-through cracks in steel deck plates through an asphalt pavement is expected. So far SQUID magnetic sensors with high tolerance against magnetization in steel plates have been developed, and detection of non-through slit-like defects in test steel plates from the distance comparable to the thickness of asphalt pavement has been demonstrated. Recently, an inspection system which can be applied to inspection on roads has been developed and trial testing on steel deck plates has started.



Example of detection of a non-through slit in a test steel plate


Inspection system for trial use on a road



SQUID magnetic sensor

Goals

Project group

Technical transfer

Inspection equipment makers

Sales

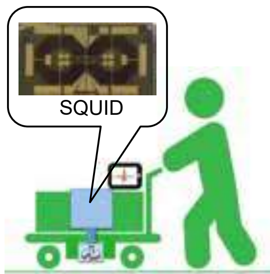
End user
- Infrastructure management company
- Inspection company, etc.

JIS, ISO standardization

Large structure such as dam


Portable equipment

Bridge



Ultra-high sensitive inspection equipment

4 R&D of laser directive noncontact diagnosis system for maintaining degraded infrastructures

Principal Investigator Katsumi Midorikawa (Director, RIKEN Center for Advanced Photonics)

Collaborative Research Groups QST, JAEA, ILT

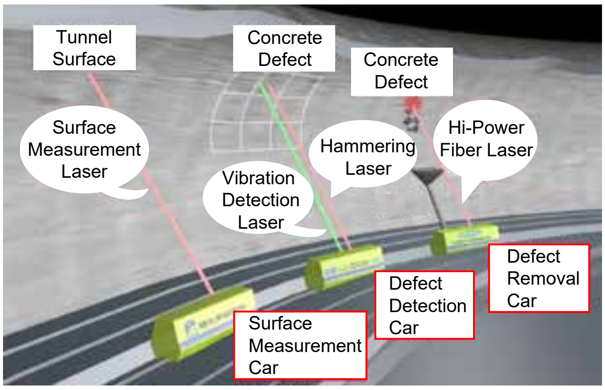
R&D Objectives and Subjects

Objectives

In Japan, large infrastructures such as tunnels and bridges constructed during the period of rapid economic growth in the 1960's will reach the end of their working lifetimes within 10 to 20 years. In order to solve this societal issue, we develop novel nondestructive inspection methods using laser technology.

Subjects

- Detection of 0.2 mm cracks by 3D remote measurement system by LIDAR and water detection by spectroscopy
- High speed inspection system by laser hammering
- Defect removal by remote drilling and cutting by QCW fiber laser
- Tunnel maintenance total system with existing technologies (a. mapping D/B b. MMS) and the above new methods



Current Accomplishments (1/2)

3D and spectroscopic measurement of inner wall of tunnel using frequency-shifted feedback (FSF) laser

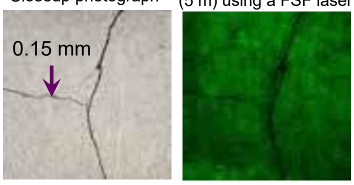
Measurement objectives: (1) Crack of 0.2 mm width (2) 0.1 mm difference level (3) Spectroscopic detection

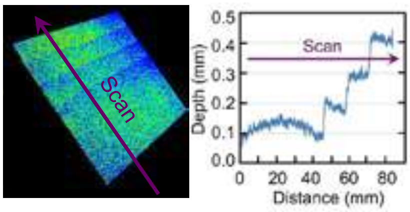
Measurement principle: LIDAR (Light detection and ranging)

Measurement of crack of 0.15 mm width	Measurement of 0.1 mm difference level	Spectroscopic measurement
LIDAR + measurement of light scattering	LIDAR + interferometric analysis	LIDAR + spectroscopic measurement

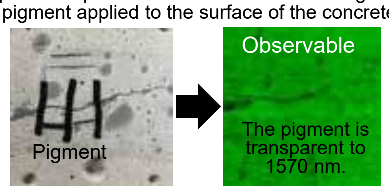
Closeup photograph

Remote measurement (5 m) using a FSF laser





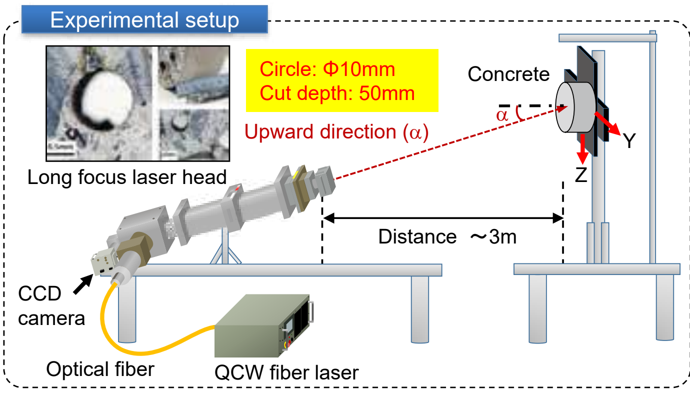
Spectroscopic measurement of crack through a pigment applied to the surface of the concrete.



Development of laser irradiation system to remove degraded parts of tunnels

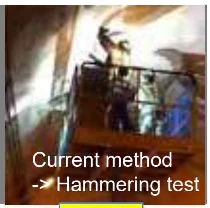
Significant features of drilling, cutting, and removal of concrete using a QCW fiber laser

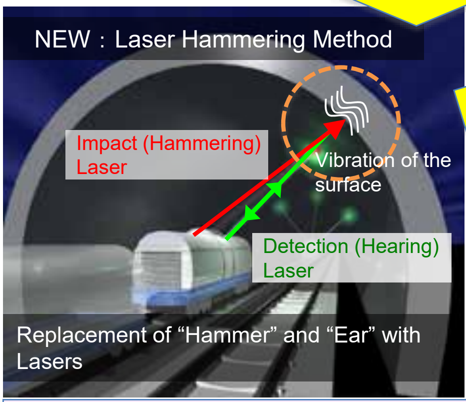
1. Remote and non-contact operation of drilling and cutting of degraded parts are feasible.
2. Control of a quasi-continuous wave laser enables suppression of heat affected zones and high processing efficiency.
3. Fast drilling speed is realized with optimization of laser irradiation conditions.



Current Accomplishments (2/2)

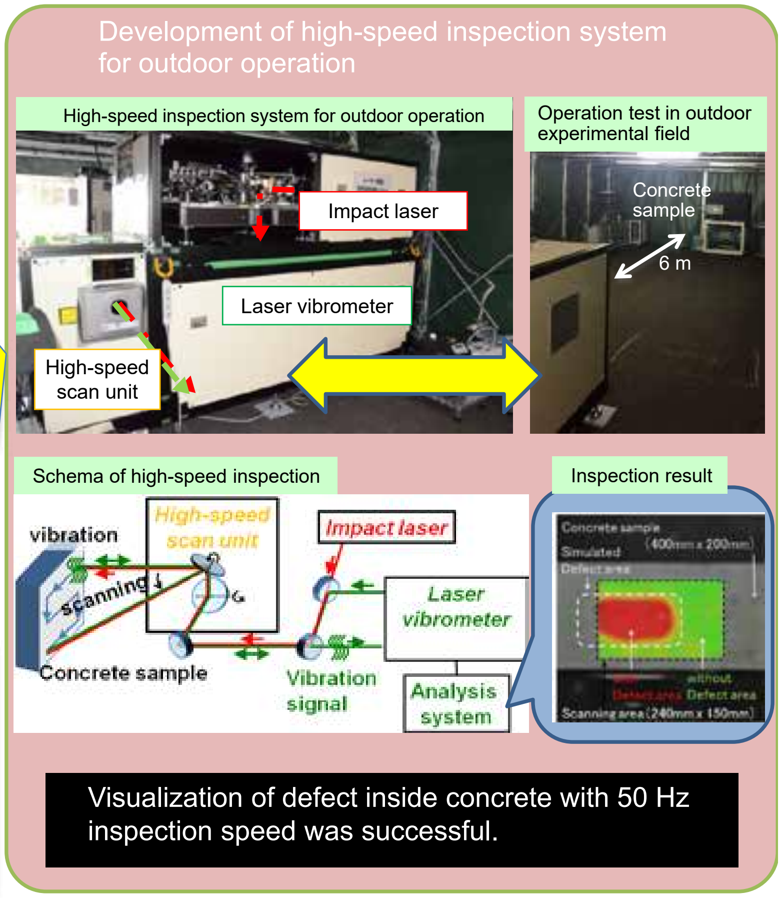
GOAL：Development of a high-speed and remote inspection method for lining concrete.





【Accomplishments】

- Development of compact, high repetition rate high power YAG laser by the improved system and unique optical layout
- 50 points/second measurement by using a lightweight, rigid, and large size scanning mirror
- Development of prototype high-speed inspection system for outdoor operation



Goals

Business scheme for social implementation

The goals attained at the end of SIP research and development are as follows.

① Technical final numerical target of research and development

a. Laser Surface Measurement System ： (Distance 5 m) 0.2 mm wide crack, illustration of 0.1 mm deep groove, discovery.

b. Laser hitting sound measurement system ： (Distance 5 m) Detection of peeling / internal cavity corresponding to manual hitting sound inspection.

c. Removal of weak parts by laser ： Construction of destruction test database of concrete.

② Outline of products and services

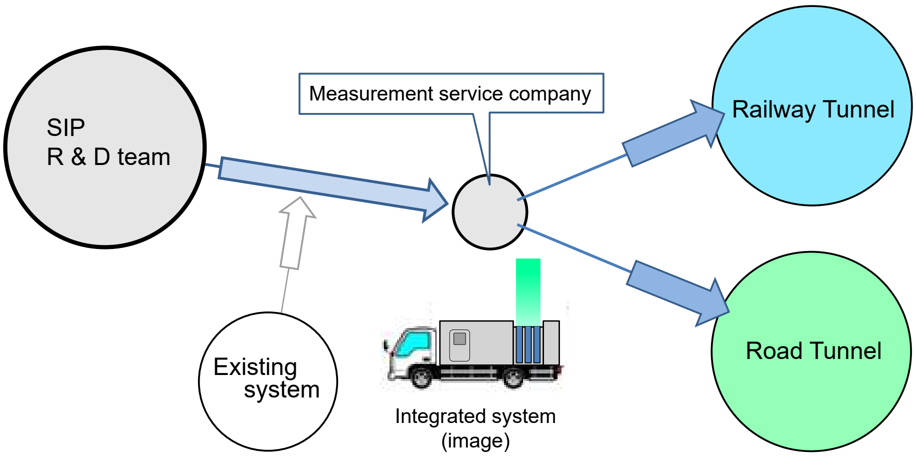
a. Products · Products ： We created an integrated system combining R & D achievement and existing system, and commercialized measurement service.

③ Social Implementation

a. Site Users： Railway companies and local government's road conservation department

b. Used Places： Railway tunnels and road tunnels managed by local governments

c. Procurement, Manufacture, and Sale： Integrated acceptance of tunnel measurement service



5 Development of Automatic Technology on Pavement & Embankment Survey and Evaluation

Principal Investigator Atsushi Yashima (Professor, Gifu University)

Collaborative Research Groups Celery Co. Ltd., Const. Res. Ctr. Gifu Pref.

R&D Objectives and Subjects

Objectives

The maintenance work of pavement is often planned based on rutting, cracking, IRI and FWD data. However, repeated damage to pavement are observed at many places. This surface damage to pavement partly originates from the weakness of the subgrade, damage to the embankment and infiltration of ground water. In order to avoid repeated maintenance work on pavement, the condition of embankment structures should be evaluated by an easy logging technique from the pavement surface. In this research, an automatic technology for surveys and evaluations of pavement, as well as embankment structures, is proposed by using surface wave logging and electric resistivity logging.

Collapses of road embankments due to large earthquakes and heavy rainfalls have also been reported. These collapses were also caused by inappropriate groundwater treatment and slaking/weathering of embankment materials. The proposed automatic technology for surveys and evaluations of embankments by using surface wave logging and electric resistivity will evaluate the stability of embankments during large earthquakes and heavy rainfalls.

Subjects

① Development of a fully-automatic survey & evaluation system for surface wave logging

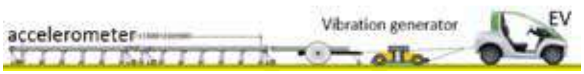
② Development of a fully-automatic survey & evaluation system of electric resistivity logging and an increase in investigation depth

③ Speed-up and generalization of preliminary analysis of field investigation data

④ Standardization of pavement & embankment stability by using S-wave velocity and electric resistivity

⑤ Development of a data base of survey & evaluation results

⑥ Development of a road management system with survey planning and maintenance planning (Web-GIS)



Current Accomplishments (1/2)

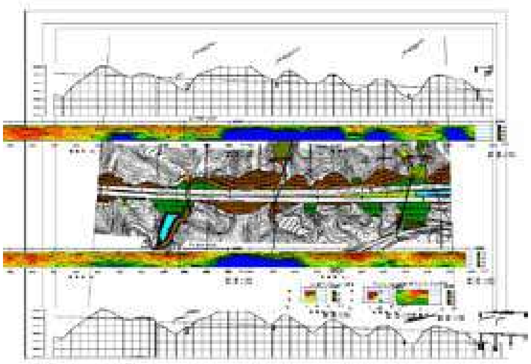
① The automation surface wave & electric resistivity logging system was designed and manufactured.

② The desired target inspection speed, 500 m per hour (mean speed) was achieved.

③ The stiffness (Vs) & electric resistivity (Ω) of the embankment was continuously obtained for many sections.

④ Hybrid survey by the automatic survey technique developed in this study and FWD was successfully carried out. Detailed information about the pavement, subgrade and embankment was simultaneously obtained.

① Automatic survey by EV and newly-designed cart



③ Shear wave velocity of expressway embankment

④ Hybrid survey system with FWD

Current Accomplishments (2/2)

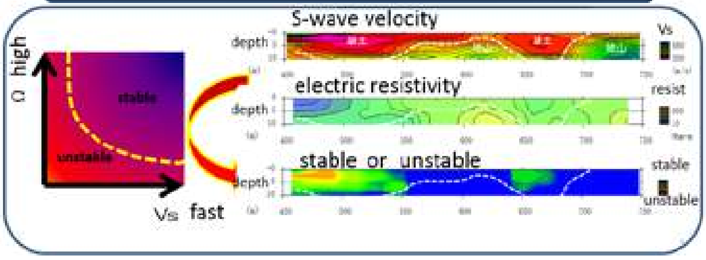
① There have been many reports on collapses of road embankments due to heavy rainfalls and large earthquakes. These collapses were caused by inappropriate groundwater treatment and slaking/ weathering of embankment materials. In order to evaluate the stability of an embankment, we have to know the stiffness, soil profile and groundwater conditions in the embankment.

② The stiffness, soil profile with fine content information and groundwater conditions were continuously obtained along the road embankment by Shear-wave velocity (Vs) & electric resistivity (Ω).

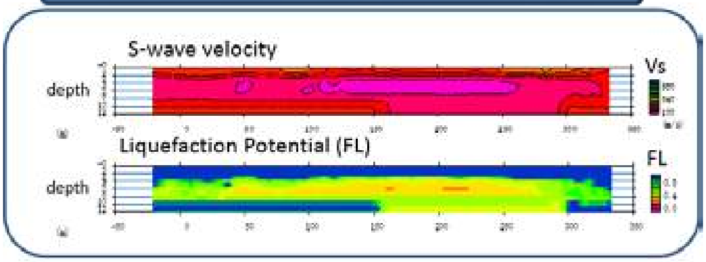
③ The stability of the embankment was evaluated by Vs and Ω. We were able to understand the stability levels continuously along the road embankment. This continuous information along the road will be utilized to narrow down further detailed investigation sections.

④ The liquefaction potential value (FL) of embankments were calculated based on the stiffness, soil profile with fine content and groundwater tables in the embankment/natural ground. That information was obtained by Vs and Ω.

②,③ Stability evaluation of embankment by Vs&Ω



④ Liquefaction potential of embankment by Vs&Ω



Goals

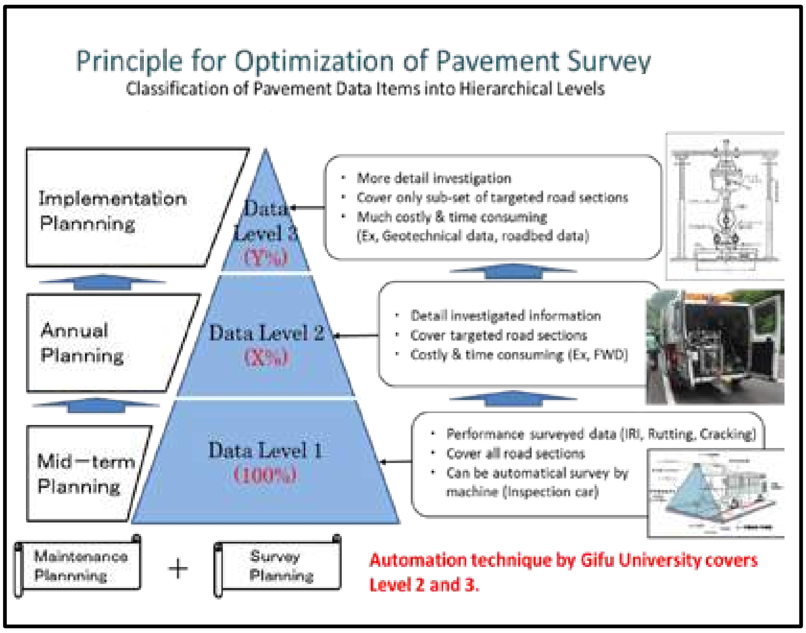
① Development of a fully-automatic survey & evaluation system of surface wave logging & electric resistivity logging

survey speed ≧ 500 m/hour
survey depth ≧20 m for Vs logging
survey depth ≧10 m for Ω logging
resolution for Vs logging;
0.2 m for pavement, 1.0 m for embankment

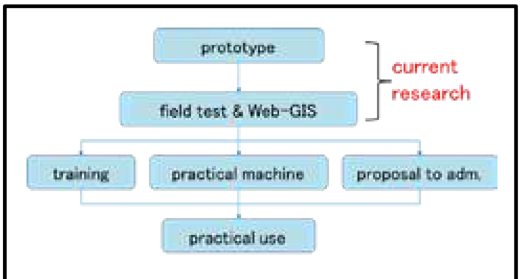
② Evaluation of pavement performance and the stability of the embankment

- Evaluation of the stiffness of the pavement & the embankment
- Evaluation of the stability of the embankment
- Evaluation of the liquefaction potential of the embankment resolution along the road; 2.0 m

Development of a road management system with survey planning and maintenance planning (Web-GIS)



Web-GIS management system



The road to practical use

6 Non-destructive Inspection of Rebar Corrosion in Concrete

Principal Investigator Kenji Ikushima (Associate Prof., Tokyo University of A & T)

Collaborative Research Groups IHI Inspection & Instrumentation Co., Honda Electronics Co.

R&D Objectives and Subjects

Objectives Creation of an Inspection Technique for Promoting Preventive Maintenance

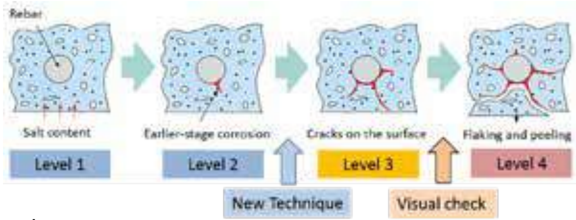
Target: Roadway infrastructure (particularly bridges)

Conventional maintenance :

◆Visual check : Observation of cracks on the surface of concrete.
Strength performance of RC structures has already been reduced.
=> Massive renovation and reinforcement are required.

Ideal maintenance :

◆Non-destructive detection of earlier-stage rebar corrosion
=> Small-scale maintenance => Cost reduction and life extension

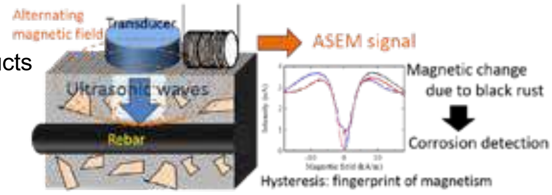


Subjects Corrosion Detection by Using Acoustically Stimulated Electromagnetic (ASEM) Techniques

ASEM method Detection of alternating magnetic fields excited by ultrasonic waves
=> Sensing of magnetic hysteresis behavior (Fingerprint of magnetism)
=> Identification of black rust formed on rebar

Development item

- Clarifying magnetic properties of corrosion products
- Developing dedicated instruments
- Determining the index parameters for identifying the corrosion stage
- Performing on-site verification



Current Accomplishments (1/2)

Analysis of Corrosion products

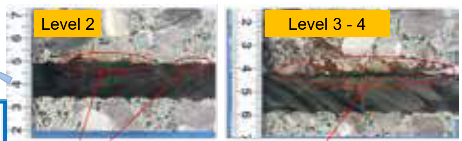
Thickness

Area ratio
Mass reduction

XRD

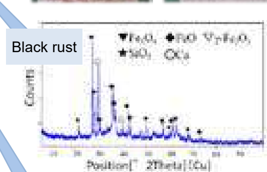
EDS

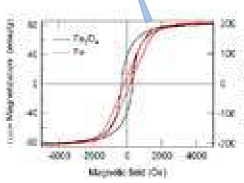
M-H Curve

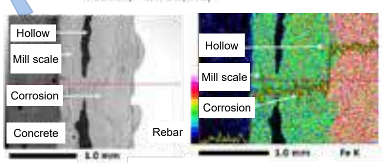


Black rust
Thickness 50 -500 μm

Black rust + Red rust
Thickness 300 -2000 μm



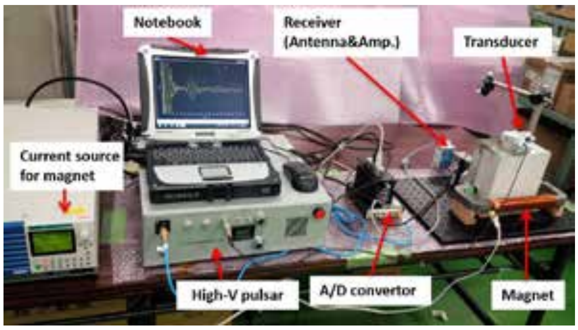




【Our measurement target】

- Thickness ~100 μm, Area ~100%, Mass reduction~ 3%
- The content rate of the target material, Fe_3O_4 is estimated to be 40 – 60 % in corrosion products.

Instrument



System

- High voltage pulsar (1000 V)
  Reverb suppression due to an FET shunt circuit.
- Fast waveform processing units
- Current source for the electromagnet

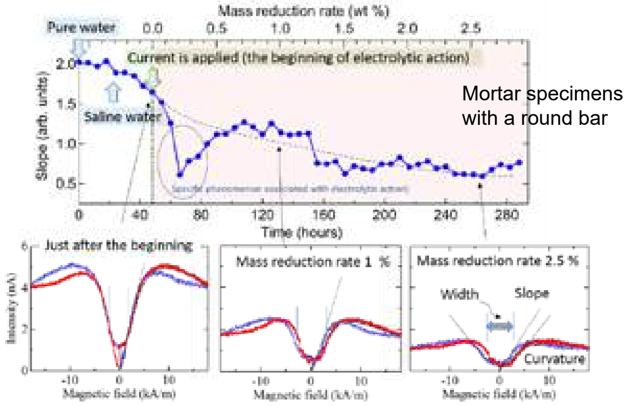
Probe Head

- Ultrasonic transducer
  200 kHz composite type.
  Double EM shield
- Receiving antenna
  Resonant circuit & low noise amplifier
- Acoustic delay line
  Acrylic or Teflon type
  Water type
- Specified electromagnet
  B = 0.47 T in steel bar.
  Weight < 2 kg.

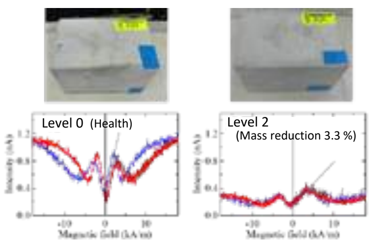
Current Accomplishments (2/2)

■ Index parameters for the corrosion stage

Monitoring of corrosion produced by electrolytic action



For deformed round bars



- Pronounced changes in magnetic curves around 3%-mass reduction.
- Index parameter => Curvature, width, slope in the magnetic curve
- This similar behavior is confirmed for a deformed round bar.

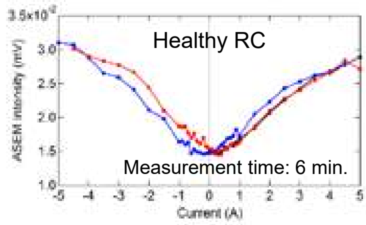
■ On-site verification

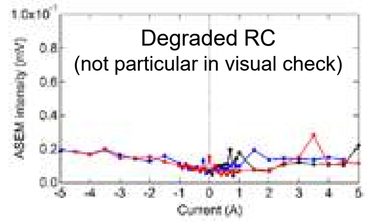
Corrosion extraction

Magnetic measurements
⇒ Fe_3O_4 content ~ 30%.
(typically 40 – 60% for corrosion produced in concrete)

- This suggests that Fe_3O_4 content is reduced with time.

On-site investigation





- Disclose the degraded conditions in concrete structures.

Goals

Target and reaching objective in SIP

Main Target	Reaching objective
Bridge Floor Covering depth: 30 mm - 50 mm	✓ Completion of the prototype instrument ✓ Index parameters for the corrosion stage ✓ Accumulation of on-site investigations

Bridge floor

Toward social implementation of this technology

① Induction of routine checks

Application of routine checks for bridges (once every five years).

--- Promoting a paradigm shift from visual checks to non-destructive evaluations with scientific evidence ---

② Device rental & sales

The enhancement of its visibility and reputation to consultants and inspection companies through rental services.
=> The establishment of the position as the representative tool that can detect rebar corrosion.

③ Technical training

Penetration in the association.
(The Japanese Society for Non-Destructive Inspection etc.)

④ Technological assistance and sales overseas

Cooperation and spread of activities with American bridge maintenance companies.

Conventional maintenance	Preventive maintenance
Routine check ↓ Evaluation ↓ Crack or leakage of rust ↓ Large-scale repair	Salt content ↓ Diagnosis ↓ Low-cost repair

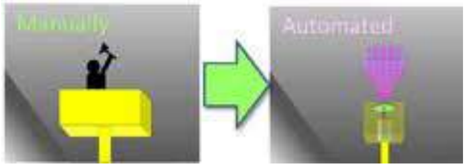
7 R&D of Backscatter X-ray Imaging System for Concrete Inspection

Principal Investigator Hiroyuki Toyokawa (group leader, AIST)
Collaborative Research Groups BEAMX Corp., Nagoya University

R&D Objectives and Subjects

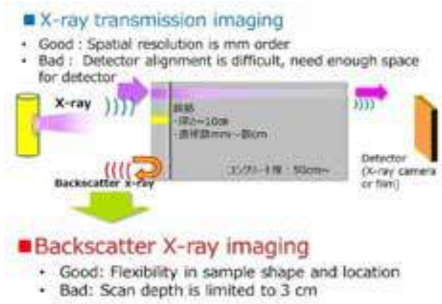
Objectives

Social infrastructures in Japan are aging rapidly. Sixteen percent of the 700,000 road bridges of 2 m or longer are 50 years or older, at present. This percentage increases to 40% in the next 10 years, and will be 65% in 20 years. We try to find damage and defects in concrete structures at an early stage so that we can make the lifetime of the concrete structure longer. There are expectations for the development of a novel method to evaluate defects in concrete structures non-destructively.



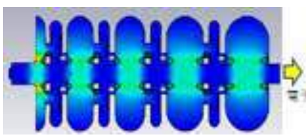
Subjects

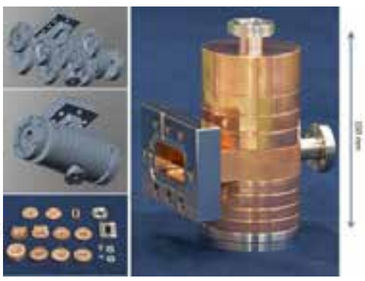
The development of x-ray backscatter imaging system is our technical goal. The system must be portable, robust, and reliable. A high-energy x-ray generator, which emits Bremsstrahlung x-rays of up to 1 MeV in electron energy will be developed. A novel x-ray imaging detector for backscattered x-rays with high efficiency and high spatial resolution has to be developed.

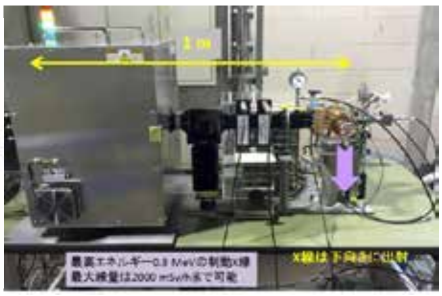


Current Accomplishments (1/2)

- **C-band X-ray, a portable x-ray generator based on an electron accelerator**

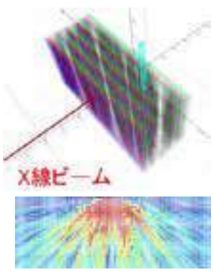

① Simulation


② Machining of cavity


③ C-band X-ray


④ Radiography

- **One-dimensional multi-slit x-ray imaging detector**

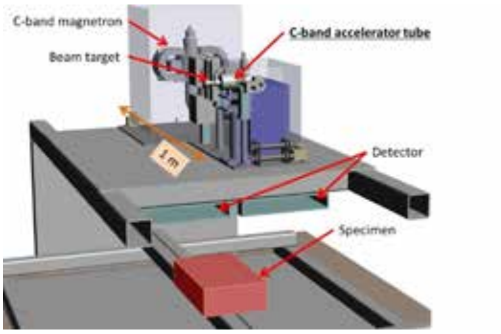


① Monte Carlo simulation


② Scintillator

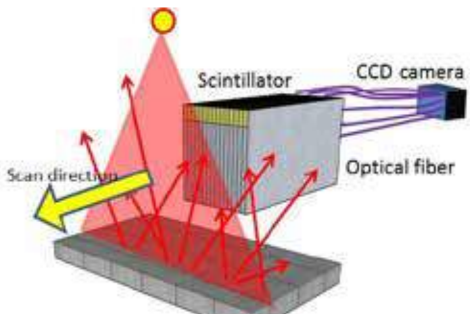

③ X-ray camera

Current Accomplishments (2/2)

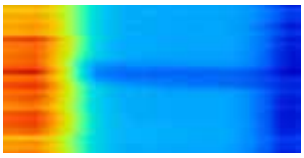


C-band x-ray: 700 – 900 keV, 2 Gy/h

We have succeeded in developing a table-top electron accelerator-based high-energy x-ray generator “C-band X-ray”, which generates x-rays of 900 keV or higher with 2 Gy/h.



One-dimensional multi-slit x-ray imaging detector



Backscatter x-ray image of a rebar in concrete

T. Tooyama, 76th JSAP Autumn meeting, September 2015

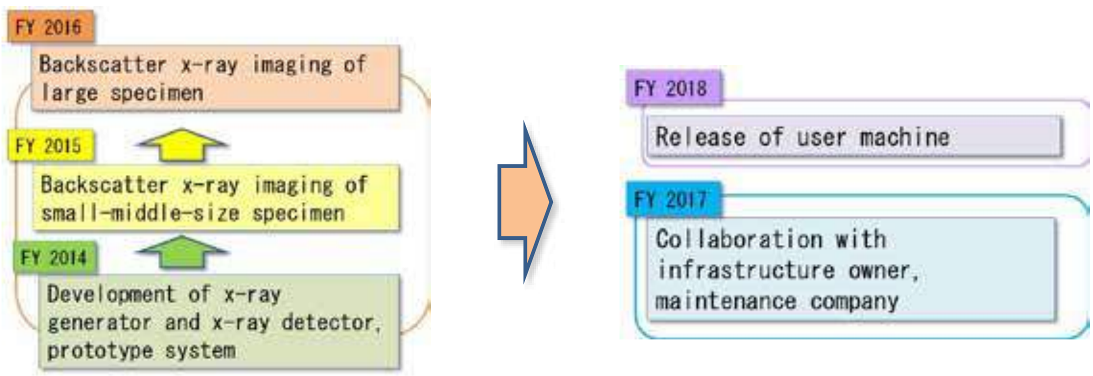
We have succeeded in developing a one-dimensional multi-slit x-ray imaging detector, which is like a line sensor for backscatter x-rays. A fan-beam x-ray is irradiated onto a concrete slab in area of 20 cm x 5 mm, and the backscattered x-rays from the concrete slab are distinguished by the novel detector.

Goals

Milestone / achievement level

Item	Milestone	Achievement
Imaging inside concrete	Recognize rebar of 1 cm diameter in concrete with cover depth of 10 cm	Cleared
Inspection of defects of a roadbed	Recognize 20% density degradation of concrete under asphalt of 8 cm thickness	Cleared
	Recognize pot-hole under asphalt of 8 cm thickness	Cleared

Roadmap being on the market



8 R&D of Vibration Imaging Radar

Principal Investigator Hitoshi Nohmi (CEO, Alouette Technology Inc.)

Collaborative Research Groups Waseda University, Saitama University, Tokyo University

R&D Objectives and Subjects

Objectives

By development of vibration visualization radar (VirA), we aim for improvement of safety and efficiency of inspection/monitoring of infrastructure, such as bridges and elevated roads.

Monitoring Capability : ・Extract vibrations in infrastructures from observed radar phase images
Safety and Efficiency : ・Measure vibrations without blocking traffic.
・Easy to transport and install.
・Non-contact vibration measurement system.

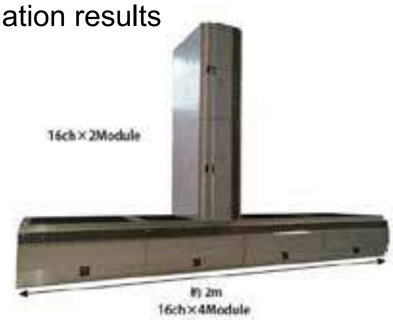
Subjects

- Develop vibration imaging radar system (VirA) using Digital Forming Technology. VirA observes infrastructures, such as bridges, as radar phase images up to 1000 times per second, and extracts vibrations at specific points. VirA measures (displacement) and variation as images with a vibration amplitude ≦0.1 mm, max. vibration frequency 500 Hz and an operational range of 100 m to 10 km.
- Develop a vibration analyzing algorithm and visualization program.
- Investigation of required measurement accuracy for infrastructure monitoring.
- Comparative verification with conventional infrastructure monitoring equipment.
- Application to infrastructure monitoring.

Current Accomplishments (1/2)

Contrast table of VirA Target specification and verification confirmation results

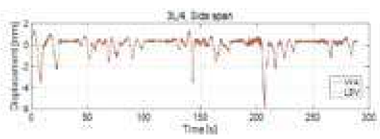
No		Target Spec	Result	
1	Observation Angle	EL : 30 degrees AZ : 45 degrees	EL : 30 degrees AZ : 45 degrees	
2	Observation Range	100 m～10 km	Confirmed range 30 m～4,500 m	There is no place to confirm for more than 4,500 m.
3	Azimuth Resolution	0.5 degrees	0.5 degrees	
4	Imaging Reputation Speed	500 times/Sec	500 times/Sec	
5	Vibration Frequency	250 Hz MAX	250 Hz MAX	
6	Vibration Amplitude	≦0.1 mm	≦0.1 mm	
7	Consumed Power	4 RX Module ≦300 W 6 RX Module ≦400 W	4 RX Module 250 Wtyp 6 RX Module 350 Wtyp	
8	Size	2,000 (W) x 1,500 (D) x 1,600 (H) mm ≦70 Kg (without mounting base) (6 Rx Module)		



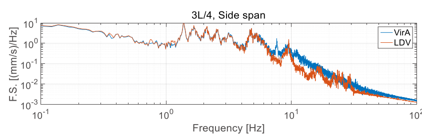
(RX Module)

(TX Module)

(Comparison measurement with LDV)



(Displacement comparison with LDV)



(Frequency histogram comparison with LDV)

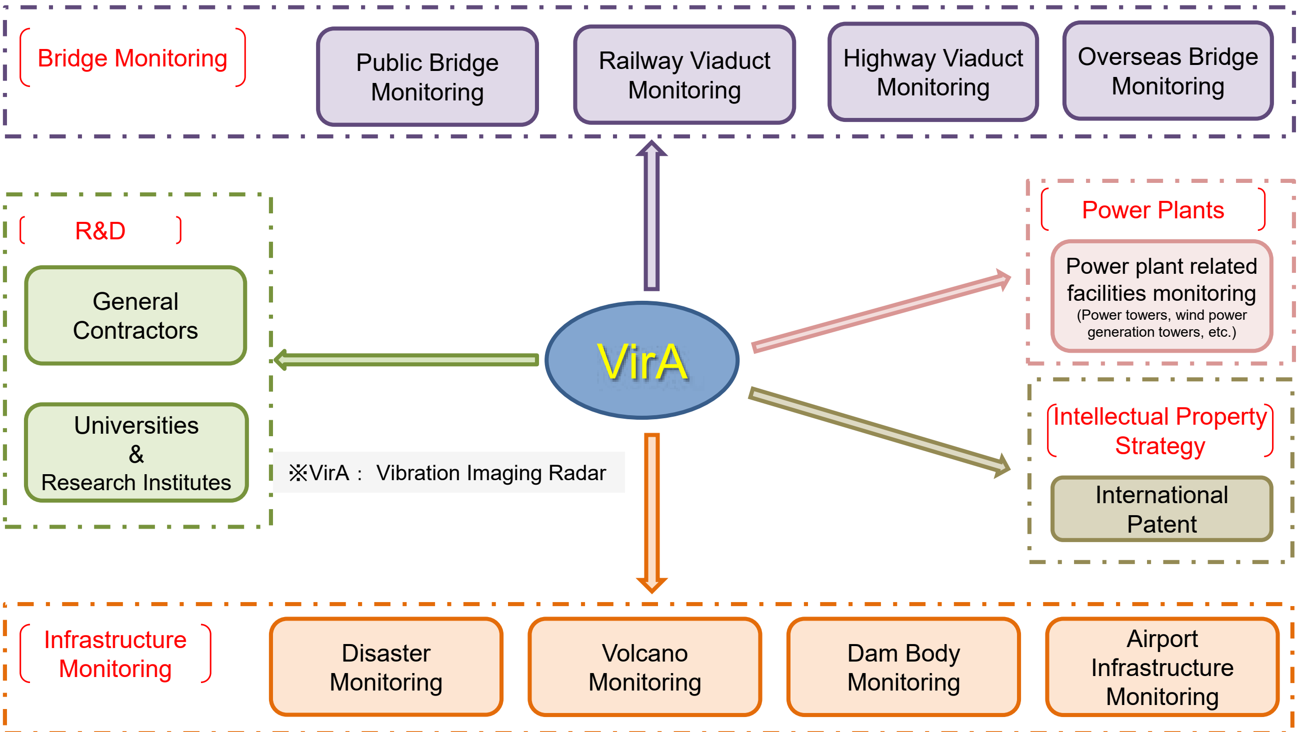
Current Accomplishments (2/2)

(Analyzed example of a bridge girder)

- Display acquired radar data as 1ms frame rate movie
- Graphical display – displacement, vibration with time graph of selected point

Vibration visualization and analysis software

Goals



9 Inner Defects Inspection for Tunnel Lining using Rapidly Scannable Non-contact Radar and Synthetic Soundness Diagnosis System

Principal Investigator Toru Yasuda (Technical Director, Pacific Consultants Co., Ltd.)

Collaborative Research Groups Walnut, iSystem Research, Sanei, Forum8

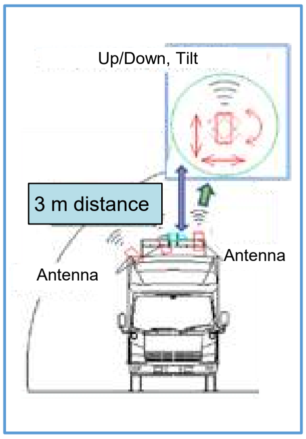
R&D Objectives and Subjects

Objectives

① The 1st Objective of this study is to develop an inspection technology detecting the inner defects for concrete lining using a rapidly scannable non-contact radar as a complement of hammering test.

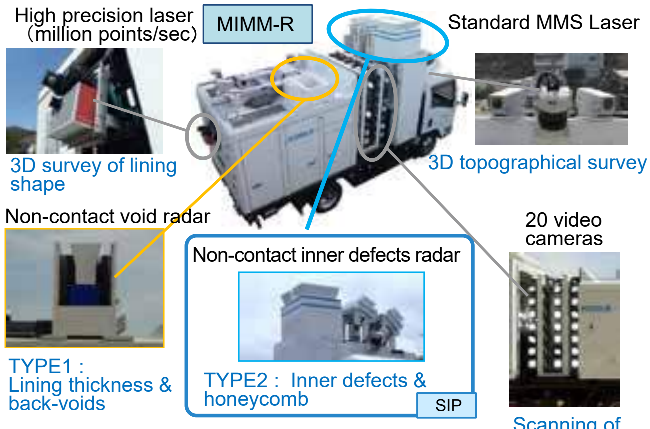
② The 2nd Objective is to develop a synthetic diagnosis system to comprehensively assess soundness, as well as a database compilation of various conditions of unsoundness, including inner defects, by 3D visualization technology.

Subjects



Inner Defects Detecting Radar Antenna

- Three non-contact antennas (Distance 3 m: world origin)
- Detecting speed: 50 km/h
- Screening of damage
- Assembled to MIMM-R



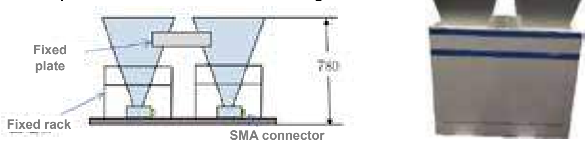
Inner defects radar assembled to MIMM-R system (camera, laser, void radar)

Current Accomplishments (1/2)

Radar for inner defects (New developed in SIP)

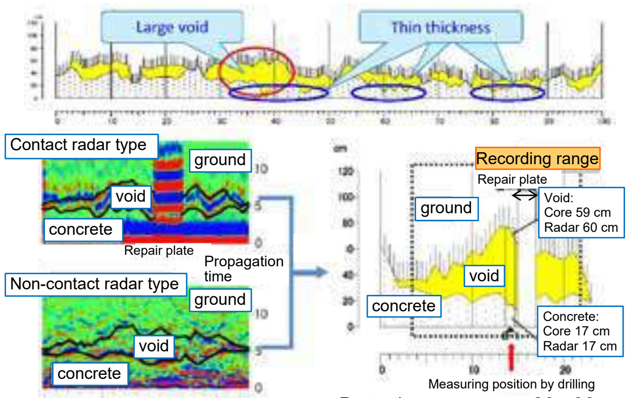
◆Targeting inner defects

◆Developed inner defects detecting radar



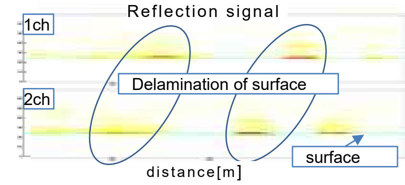
Items	Elements	Remarks
Rader type	FM-CW	Horn type
Detecting distance	4m	To lining 1m - 3m
Medium frequency	3GHz	Band (2GHz, 2 - 4GHz)
Antennas	3sets	Large 1, small 2

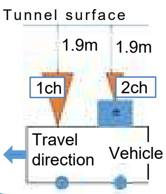
Radar for thickness & void (developed)



Detecting accuracy : 80 - 90%

Verification 1 Delamination

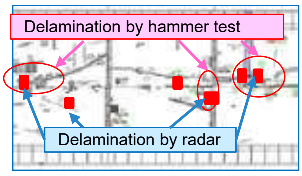




◆ Verification results; Install antenna in direction of traveling on the top of the vehicle

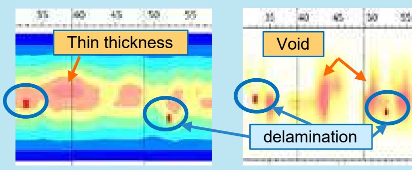
◆ Succeeded in detecting the same delamination while travelling

Verification 2 Actual tunnel



◆ After verification with inner defect radar in actual tunnel, confirm by hammering sound inspection

◆ Detects actual delamination Tendency to detect more



- ➢ No traffic regulation, screening of hammering test points before close inspection
- ➢ Screening problem position integrating thickness, voids, inner defects

Current Accomplishments (2/2)

3D visualization technology (synthetic soundness diagnosis system)

R&D contents in SIP

- ◆Point clouds analysis functions: Automatic definition of lining joint, extraction of sectional shapes and span axis with high accuracy
- ◆Radar results visualization functions: 3D visualization, contour indicator, longitudinal and cross section with synchronized position
- ◆3D visualization and database assembly Soundness diagnosis combining image, lasers and radar is the first of its kind in Japan.

Mobile measuring → Measuring & analysis results → 3D visualization → DB, diagnosis system

Mobile measuring

Camera system

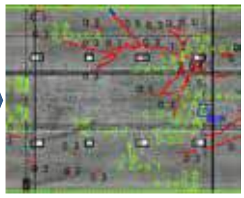
Laser system

Radar system

T1 : Thickness & voids
T2 : Inner defects

Measuring & analysis results

Image combination + Damage map

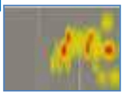


Position synchronization by point clouds

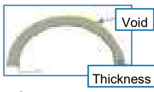
Laser point clouds

Position synchronization by point clouds

Contours, section thickness & voids

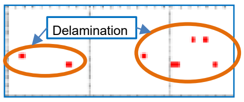


Void contours



Cross section

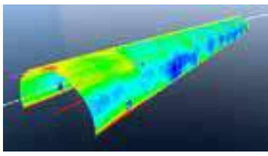
Inner defects



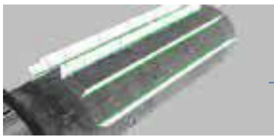
Detecting results of inner defects

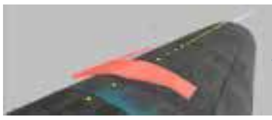
3D visualization

3D overlay display of wall lining image and damage map



3D display of deformation mode





3D display of voids and inner defects

DB, diagnosis system

3D visualization display is made by integrating information such as position synchronized images, damage maps, deformation mode contours, voids and inner defects by point clouds.

Scale of damage, causes, and soundness are comprehensively diagnosed while switching display modes.

Database system

Database assemble from measurement and analysis
↓
Asset management

Goals

Achieved goal and level

Items	Achieved goal	Achievement level
Radar system	System configuration ・Detection accuracy : 80% ・Longitudinal direction 5 cm Sectional direction 1 m ・Detection depth : 20 cm	・Radar system completed ・Successful reception of target inner defect signal ・Detecting depth : 20 cm over
3D visualization system	・Position & lining joint synchronization, ・Damage progressive evaluation S/W ・3D visualization VR S/W	・Position & lining joint synchronization completed ・Progressive S/W completed ・3D visualization completed ・DB iTAMS completed

Social Implementation Image

	Exit strategy	Target	Schedule, remarks
①	Application for inspection works of radar & S/W	Own works, lending to others	Expand quickly after SIP termination We aim to increase our share to about 20% in 5 years.
②	Support and supplement for close inspection and hammering test	Ministry of Land, Infra & Transport, etc.	Linking with trial of next generation social infrastructure robot promotion, standardization by reviewing the inspection revision procedure
③	Technical guidance, consultation in the field	Municipalities	Linking with SIP program of Gifu University, etc. Promotion of diagnosis system
④	Radar & S/W sales to domestic and overseas	Consultant, inspection companies	Radar system: Sales of about 5 units per year S/W : Sales of about 10 units per year
⑤	Overseas expansion of measurement works & technical assistance	ASEAN	Overseas business model using mobile measuring vehicle Radar measurement service Application using diagnostic software

Support for tunnel periodic inspection

Conventional inspection

Inspection planning → Cross visual inspection → Hammering test Drop hit → Diagnosis → Creating inspection form → Detail investigation → Repair design → Countermeasures

Mobile measuring inspection

Inspection planning → Mobile measuring inspection ・Image analysis ・Deformation mode analysis ・Lining thickness & void detection → Diagnosis → Creating inspection form → Repair design → Countermeasures

Mobile measuring inspection ・Camera system ・Laser system ・Radar system

Inner defects Screening support by SIP radar

Hammering test Drop hit

Detail investigation

We will combine cameras, lasers, radar, close visual inspection, and hammering sound tests, make appropriate judgments, support tunnel inspection, diagnose efficiency, implement work saving, and aim for low cost.

10 Remote sensing of concrete structure with the high-sensitive near-infrared spectroscopy

Principal Investigator Kazuhiro Tsuno (Shutoko Engineering Co., Ltd.)

Collaborative Research Groups Shutoko Engineering Co., Ltd., AIST, Tohoku University, Fuji Electric Co., Ltd., Sumitomo Electric Industries, Ltd.

R&D Objectives and Subjects

Objectives of this Study

Remote Observation of Deterioration Factors of Concrete
⇒ No need for approaching/contact/ scaffolding/traffic regulation

Prevention and early diagnosis of damage via primary screening
⇒ Long-life infrastructures, Cost savings in maintenance.

What we have Developed

- Remote spectroscopy
- Primary screening
- Detection of slight deterioration

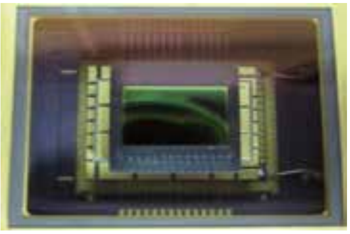
} Distribution of Deterioration Factor (concentration of moisture /chloride ions

For ① Detecting location for precise inspection
② Preventive maintenance/Repair

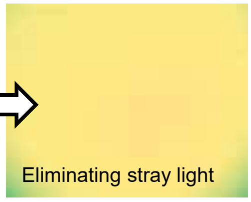
Current Accomplishments (1/2)

New technology implemented in our equipment

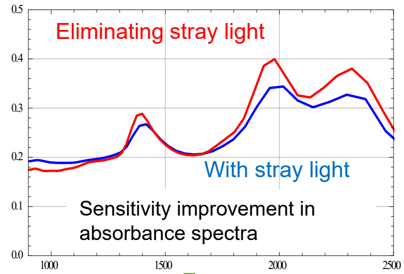
<Near Infra-Red Detector>



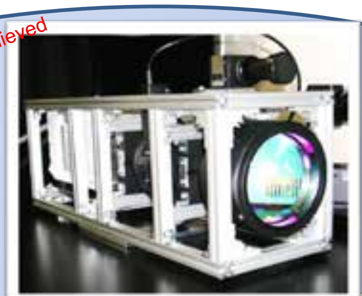
Wide band NIR sensor (wavelength =1.0～2.35μm)



Measures against stray light enabled extremely high accuracy and sensitivity in this project.

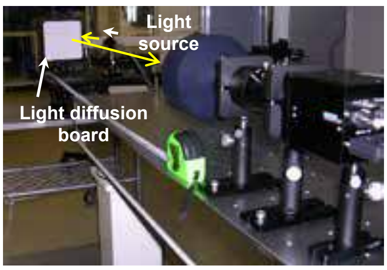


With the **interferometer** used in our original technique and Fourier transform spectroscopy we achieved **1000 times higher sensitivity** than conventional spectrometers



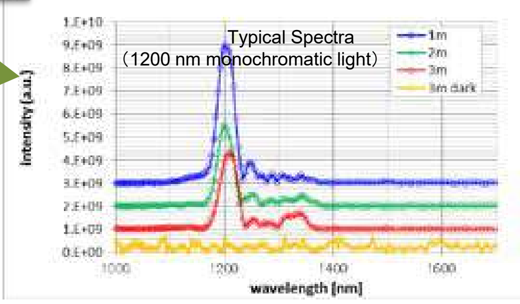
By obtaining accurate spectra, we attained **highly accurate chemical analysis**

<Remote Measurement System>



We developed spectroscopic system to be used from a remote location for this project.

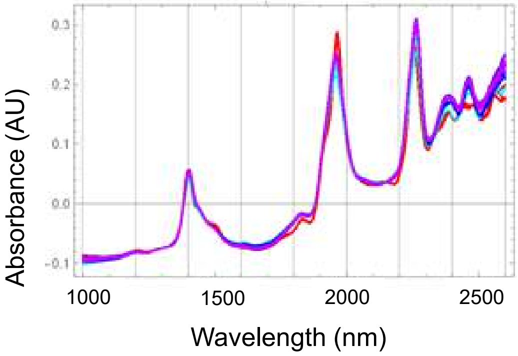
Instantaneous acquisition of NIR spectra 3 m apart



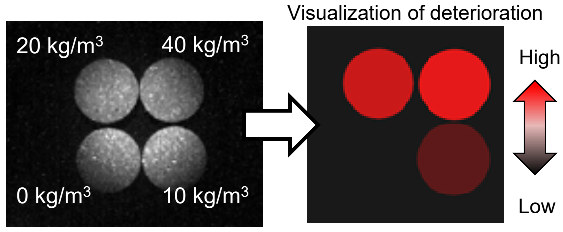
Current Accomplishments (2/2)

Analysis of concrete data

○Quantification of salt damage by Multi-component analysis



Visualization of deterioration



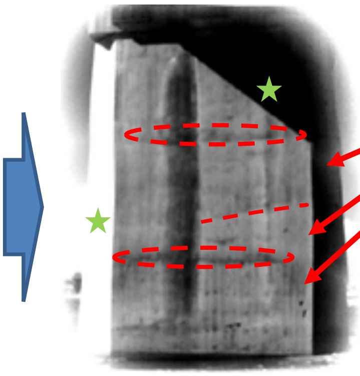
<visible camera image> <visualization of salt content>

Left : Test pieces with different amounts of water-soluble chloride. (Caption: Chloride concentration)

Right : Estimation of the amount of chloride by analysis

○Visualization of the amount of water distribution (bridge pier)

Visible camera image



Visualization of the deposits of water

Detection of water deposits
(Visualization dark and light regions)

Black shading : Large amounts of water at the surface

★This imaging measurement is not available under conditions where light saturation or light quantity are insufficient.

Near future: Implementation of a contour diagram scheme of salt damage on a bridge pier

Goals

Final Numerical Targets

1. Remote diagnosis of water and chloride content at the surface of concrete at 3 m intervals.
2. Measurement time: 10 sec per 1 m × 1 m area.
3. Equipment weight: under 5 kg

Concept Illustration of New Maintenance

Contour diagram of concrete deterioration distribution by remote diagnosis via primary screening. Labor-saving by extracting maintenance positions with high priority.

New Business Concept

1) Application in the primary screening of reinforced concrete structures
2) Evidence of a long-term maintenance plan against fatal deterioration

Inspection Service with Consulting Support

Tunnel inspection service

Annual inspection service

Bridge pier inspection service

(1) Chloride distribution of bridge pair
○○ yen

Recommended for washing !

(2) External force map by environmental factors
○○ yen

Long term maintenance planning!

(3) Water deposit distribution map
○○ yen

Reference data for core extraction!

11 R&D of learning-type hammering echo analysis technology

Principal Investigator: Masahiro Murakawa (Team Leader, AIST Artificial Intelligence RC)

Collaborative Research Groups: Shutoko Engineering Co., Ltd., East Nippon Expressway Co., Ltd. Tohoku branch, Nexco-Engineering Tohoku Co., Techny Co., Ltd.

R&D Objectives and Subjects

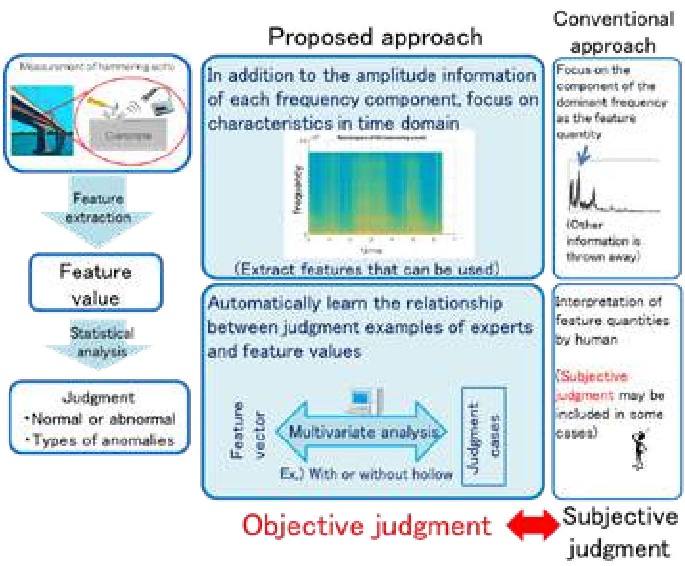
Objectives

- Improvement of hammering echo device as the first stage of inspection
  - —Easy and Reliable
  - —High precision (detection of damage in difficult areas even by experts)
  - —Reduction of total man-hours, including report preparation
- Realization of quantification and accumulation of hammering inspection results, and their visualization

Subjects

- Digitalization of hammering echo, and anomaly detection by its collection and analysis
- Using acoustic signal analysis based on machine learning, automatically distinguish hammering echo differences and detect damaged parts of structures
- Develop a device which is usable in combination with an ordinary inspection hammer, validate the proposed approach in an actual structure

Hammering echo signal analysis based on machine learning



Current Accomplishments (1/2)

Learning in two stages

- Even at the phase where data with supervised labels is not sufficiently gathered, the presence or absence of anomalies can be judged at the first stage
  - Corresponds to the differences of the hammering echoes triggered within various structure types
- Applicable toward any hammering equipment by **virtue of its versatility**

First stage: unsupervised learning method

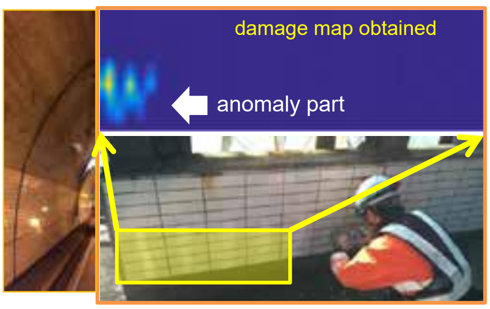
- Learn what is "normal" on site for each structure under examination
- Define the degree of anomaly as deviation from the learned "normal"
- Calculate the degree of anomaly for each hammering point

Second stage: supervised learning method

- Accumulate the judgment results in the first stage with **supervised labels**
- Decision learning based on accumulated results
- Improve decision accuracy of presence / absence of anomaly

Validity verification experiment on a tile-hitting echo test in a tunnel

Hitting echo test device using a probe rod



Even in a noisy tunnel it was possible to reliably find an area where some tiles are floating

Confirm that it is an extremely noise-resistant method of analysis

Current Accomplishments (2/2)

Development of a hammering device for difficult-to-inspect points

- For hammering of unreachable areas in abutments, piers, etc.
- Detection of internal defects in concrete, not only the exfoliated areas
- Reduction of man-hours for scaffold installation

- Uses a solenoid for hammering actuator
- Introduces a mechanism that allows the part hitting the surface lines up well with the target
- Used in conjunction with automatic trace acquisition system of hammering (under development)

Evaluating experiments for test pieces and actual bridges of local governments

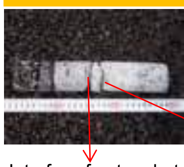
Development of handcart-type hammering device

- Grasping damage conditions of the floorboards before pavement excavation (non-destructive investigation)
- Detection of slab deterioration or cracks in the asphalt pavement surface
- Reduction of man-hours and excavation costs of hammering echo investigation

Current manual hammering echo inspection

Developed device (prototype ver. 2)

Evaluating experiments for actual bridges of the Tohoku expressway and test pieces

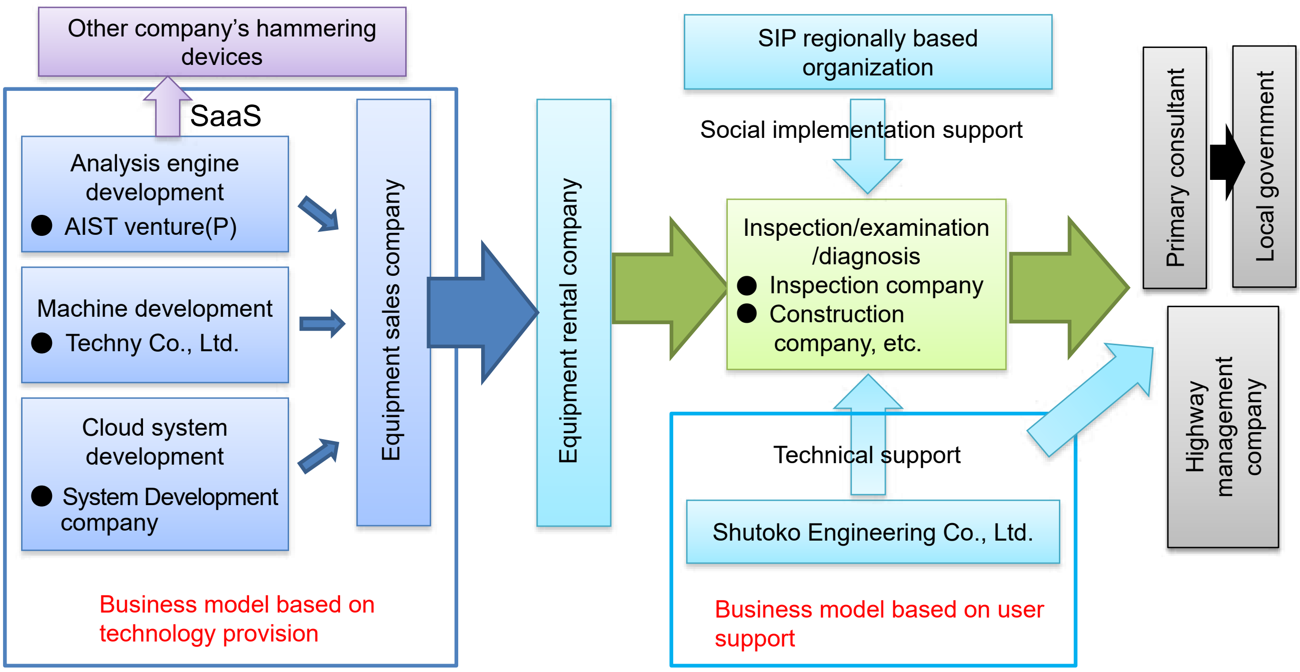


Validation of anomaly detection points by core removal in a floorboard just before replacement

Horizontal crack in an existing floorboard

Interface fracture between thickening part and floorboards

Goals



① Set up a development system that continually improves the technology

② Deploy the developed equipment with technical consulting / support from SIP regional bases

③ Provide an analysis engine as SaaS (Software as a Service)

- Intensive system administration and operation
- Stable supply of services and permanent upgrade

12 Inspection and diagnosis system of port structure using radio controlled boat

Principal Investigator Tetsuya Ogasawara (Penta-Ocean Construction Co., Ltd.)

Collaborative Research Groups Penta-Ocean Construction Co., Ltd.

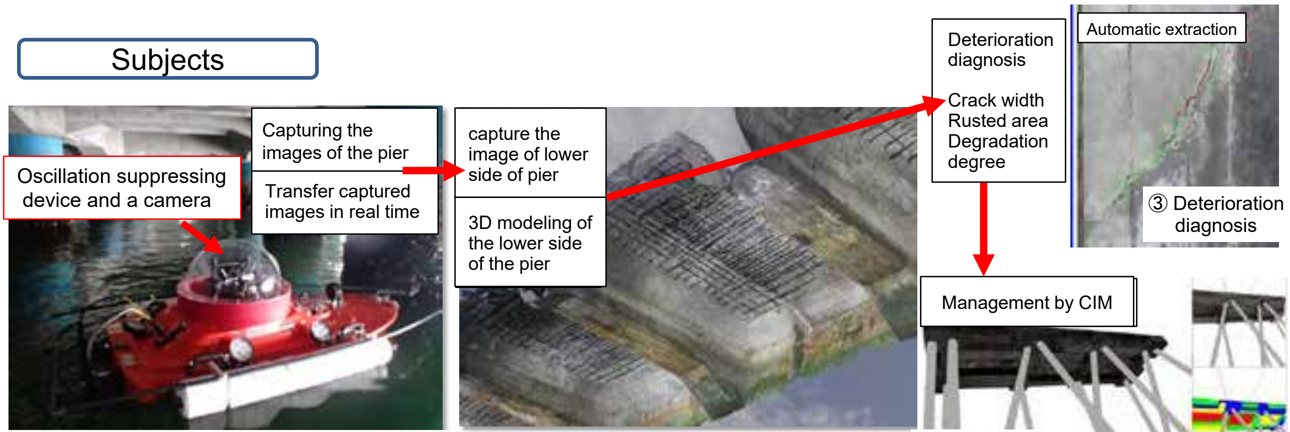
R&D Objectives and Subjects

Objectives

(1) To install a camera on a radio-controlled boat via a high-performance oscillation suppressing device in order to develop a system that should capture the images of the lower sides of piers efficiently while suppressing the effects of wave shaking.

(2) To diagnose and monitor deterioration by image analysis and to conduct experiments for the efficient maintenance and objective management of port facilities.

Subjects



① Capturing the image of the lower side of the pier with a radio-controlled boat
②Image analysis

Current Accomplishments (1/2)

Establishment of a comprehensive inspection and diagnosis system using a radio-controlled boat and designated software

- Using a radio-controlled boat and designated software developed in 2014 and 2015, we investigated the bottom of the pier and verified the importance of this system in 2016.
- After the creation of 3D models by SFM / MVS from the captured images, we extracted the orthochromatic images. Upon the comparison of the diagnosis results of the software with the results from humans, both were found to be in agreement. Thus we have confirmed the benefits of this technology.

Investigation conditions of the actual pier using a radio-controlled boat

Capturing images by the radio-controlled boat
↓
Create 3D models
↓
Extraction of orthochromatic images
↓
Register orthochromatic images in the software
↓
Extract damaged parts
↓
Determination of the degree of deterioration

Deterioration diagnosis flow of this technology

Advantages of this technology

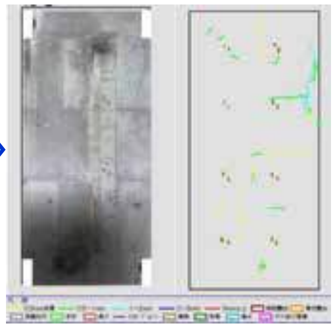
① A person without specialized knowledge can inspect and diagnose without going directly to the lower pier.
② Investigation speed is doubled → Increases efficiency of inspection.
③ Accumulation of objective data by images → Understanding the state of deterioration quantitatively, even upon the change of the person in charge.
④ From the 3D models, the state of deterioration can be understood with ease.
⑤ Reduces the burden on inspectors while surveying in narrow places and prolonged surveys.
⑥ Post-processing can be done efficiently using this software. It is possible to understand the state of deterioration quantitatively and compare the temporal changes in deterioration.

Current Accomplishments (2/2)

Establishment of a comprehensive inspection and diagnosis system using a radio-controlled boat and designated software

Captured images from the radio-controlled boat

3D models



Extraction of orthochromatic images (Slab)

Results of verification of deterioration diagnosis on the pier

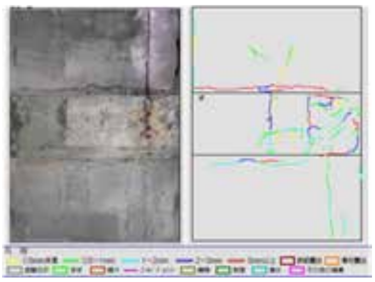
(Comparison of results of degradation diagnosis by this technology and a person)

①**Slab** →100% match

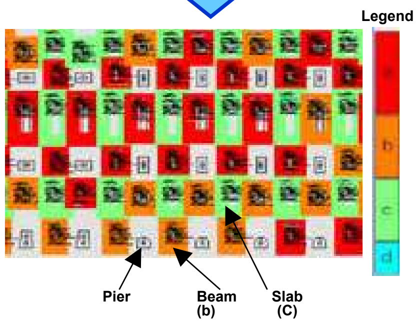
②**Beam** →90% match

During the investigation of the beam with this technology, the images were unclear due to rain and low illuminance, so we were not able to capture the cracks.

However, this can be improved (by using LED lighting and others).



Extraction of orthochromatic images (Beam)



Example of the results of degradation diagnosis by designated software

Goals

Goals: Contribute to the development and improve the efficiency of maintenance management of port facilities

- ○ Include post-processing time and cost, and compare with conventional visual inspection
- ○ Though the diagnostic results of this technology are in agreement with the results of humans, we set out to improve accuracy by investigating the cause of differences in results when done by person.
- ○ To shorten the preparation and clean up time and to increase the area inspected in one day
- ○ Promotion of this technology by posting articles and publishing them in magazines

Final goal in FY2016 (last year)

Improvement and completion of inspection and diagnosis system using a radio controlled boat and automatic deterioration determination

By advancing social implementation of this technology, we hope to accumulate inspection and diagnostic data, and improve the accuracy of inspection and diagnosis in the future

Social Implementation Image of this technology

Operating Organization ①

Penta ⇄ Orderer (Ordering)

- ○Deliverables
  - ・3D models
  - ・Deterioration diagnosis
  - ・Database construction
  - ・Cooperation with CIM
- ○Proposal for repairs
- ○Total support

Operating Organization ②

Machine rental

Penta → ・Port consultant ・Inspection company ⇄ Orderer (Ordering)

- ○Deliverables
  - ・3D models
  - ・Deterioration diagnosis
  - ・Database construction

Possibility of using the system more extensively

- ○ If the accuracy of such as the extraction of crack widths are improved, it may be available for initial inspection in new construction projects in Japan and overseas
- ○ This technology may be used in other fields because of its easy and wide-area monitoring

13 Development of the special GPR including a chirp radar in the survey of a cavity and a settlement of the back-fill material

Principal Investigator Shigeji Yamada (KAWASAKI Geological Engineering Co., Ltd. Business Division, Metropolitan Area Maintenance Director)

R&D Objectives and Subjects

Objectives

As a new technology, "Vehicle traction type GPR for deep cavities", where we develop a searching depth, and "Multichannel GPR for cavities under reinforced concrete", where we apply cavity detection under reinforced concrete that is hard to detect, are introduced. We provide better discovery precision of cavities and loosening areas around quay walls than conventional techniques and improve survey costs reduction and monitoring systems.

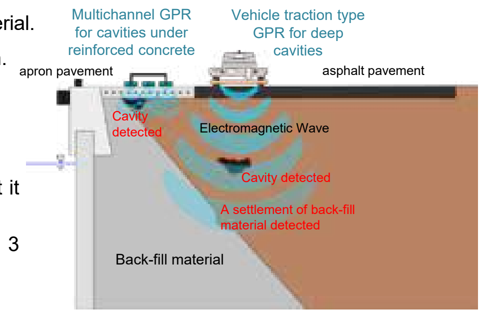
Subjects

<Vehicle traction type GPR for deep cavities>

We apply asphalt pavement to quay walls
- Ability to detect deeper than using conventional technology .
- Ability to detect cavities and settlements of back-fill material.
- Improvement of operational efficiency by vehicle traction.

<Multichannel GPR for cavities under reinforced concrete>

We apply apron pavement to the quay wall
- Ability to detect cavities under reinforced concrete that it is hard to detect with conventional technology.
- Improvement of operational efficiency by investigating 3 survey lines at the same time.

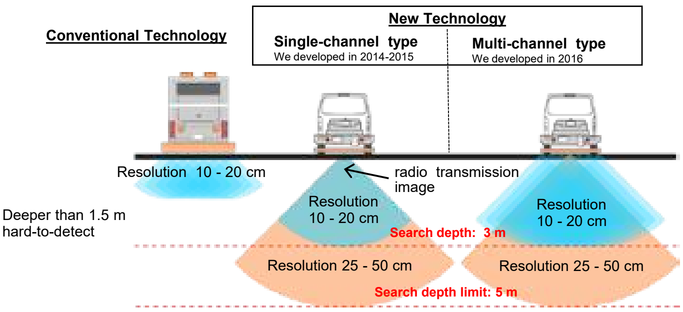


Current Accomplishments (1/2)

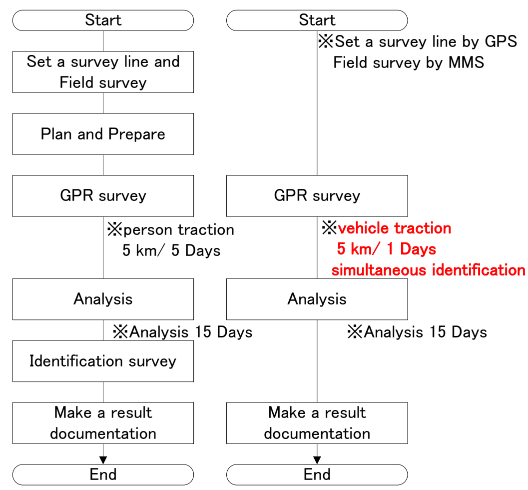
＜Vehicle traction type GPR for deep cavities＞

＜Results＞
- Resolution of cavity detection is less than 10 cm when monitoring
- Ability to detect back-fill material through the improvement of search depth.
- Improved operational efficiency by setting survey lines with GPS

◆ System improvements

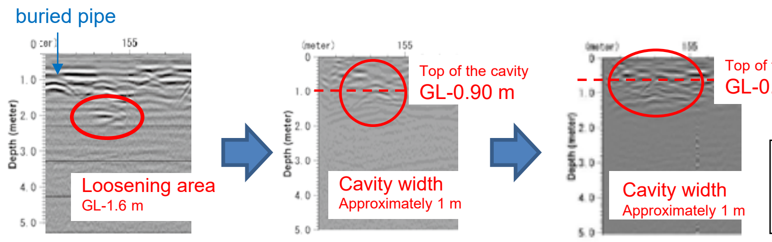


◆ Operation flow



◆ Monitoring of the cavity

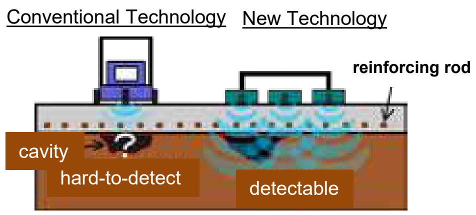
- 2013/9/25
No cavity
- 2015/9/29
Detect a cavity
- 2016/3/2
Change of cavity depth and width



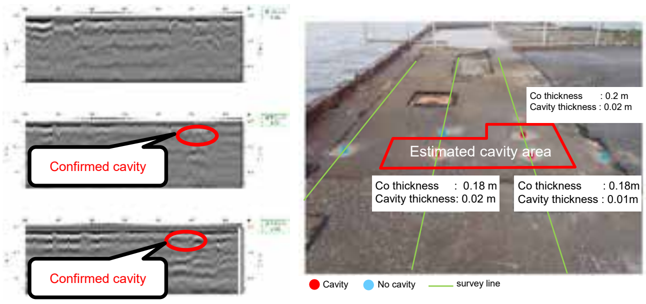
Vertical extension velocity of the cavity
- Before earthquake：15 cm/155 days 0.1 cm/day
- After earthquake: 35 cm/190 days 0.18 cm/day

Current Accomplishments (2/2)

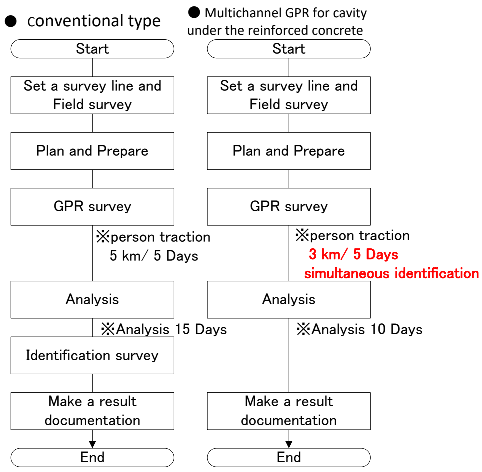
<Result>
- Ability to detect cavity less than a thickness of 5 cm
- Ability to detect cavity under reinforced concrete with a thickness of 38 cm
- Improved judgement of cavity area efficiency by measuring three survey lines simultaneously



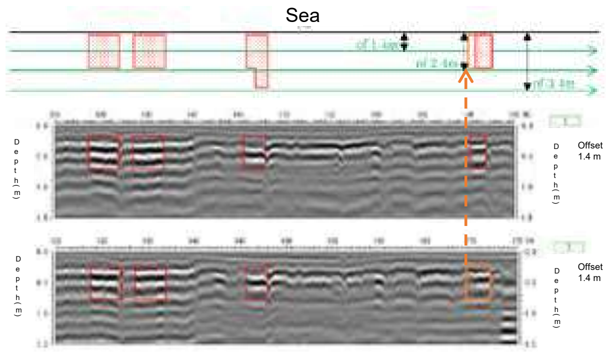
◆ Very small cavity detection



◆ Operation flow



◆ Monitoring of cavities



Orange broken line :
The cavity spread approximately 1 m over three months

Goals

◆ Final targets

thi	Targets	Degree of achievement	Further consideration
Vehicle traction type GPR for deep cavity	• Ability to detect cavities and back-fill material • Resolution:10 cm • Improvements of operational efficiency • Ability to detect deeper than conventional technology (from 1.5 m to 3 m)	• Resolution: less than 10 cm • Improved operation efficiency by the setting of a survey line by GPS • Ability to detect back-filling material under 3 m • Cost reduction by system improvement	• Examination of technology with objectivity • Examination of determination method by a third person
Multichannel GPR for cavities under reinforced concrete	• Ability to detect cavities • Resolution 10 cm • Ability to detect under reinforced concrete • Improve operational efficiency	• Ability to detect cavities of less than 5 cm in thickness • Ability to detect cavity under reinforced concrete with a thickness of 38 cm • Improved operation efficiency by multiple surveys	Monitoring (cavity range expansion) • Examination of determination method by a third person

◆ Advantage of new technology

実施項目	Rate of cost reduction	Labor-saving efforts
Vehicle traction type GPR for deep cavities	・15% decrease	・Field - work Days: 1/5
Multichannel GPR for cavities under reinforced concrete	・19% decrease	・Field - work Days: 3/5 ・Analysis Days: 2/3

14 Development of the Monitoring System for Port Facilities using Satellite and SONAR

Principal Investigator Takeshi Nishihata (Penta-Ocean Construction Co., Ltd.)

Collaborative Research Groups Japan Aerospace Exploration Agency (JAXA)

R&D Objectives and Subjects

Background

- Port facility's inspection is done by human's eye. It's largely depend on personal skill, and it takes large cost.
- It is necessary for developing monitoring method which can observe wide area to effectively maintain port facility.

Objectives

- Developing low cost, two stage monitoring system by using satellite and sonar for port facility maintenance

Subjects

- Developing satellite monitoring data analysis technique and measure system by using sonar

Periodic monitoring

First stage: Satellite monitoring (4 scenes per year by ALOS-2)

Detecting deformation and refinement — Detecting large deformation place

Second stage: Sonar monitoring, visualization and inspection of structures under sea.

Air

Synthetic Aperture Radar (SAR)

Water

Sonar System

At disaster

First stage: Satellite data observation (Data acquisition within 12 hour by ALOS-2)

Detecting deformation and refinement — Detecting critical deformation place

Second stage: Real time measure by sonar to search for obstacles under sea

Current Accomplishments (1/2)

1. Disaster Monitoring

The subsidence analysis from satellite-borne SAR has been demonstrated to be as accurate as the ground measurement.

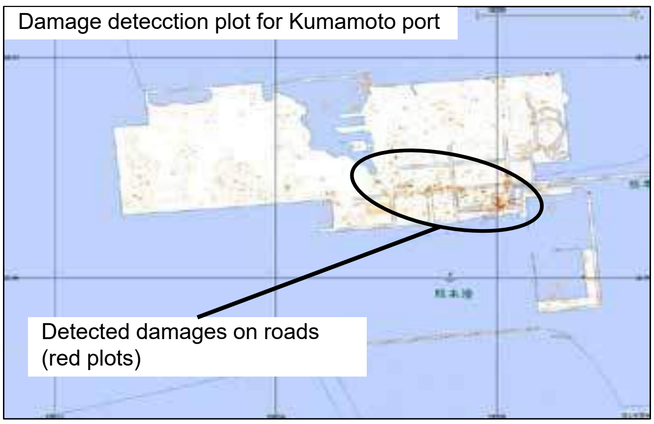
This enables visualization of surface ground motion and its trend in wider area.

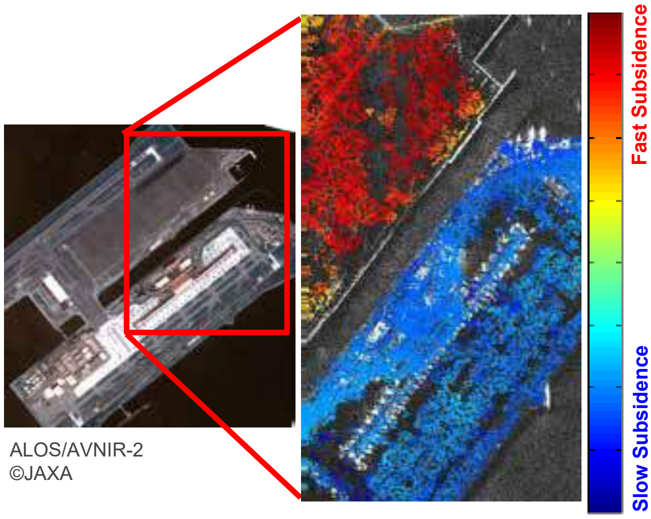
2. Periodic Monitoring

Produced prototype of damage detection plot for 2016 Kumamoto Earthquakes from ALOS-2 observation data.

Visualized damages of harbor facilities

Prototype of damage detection plot



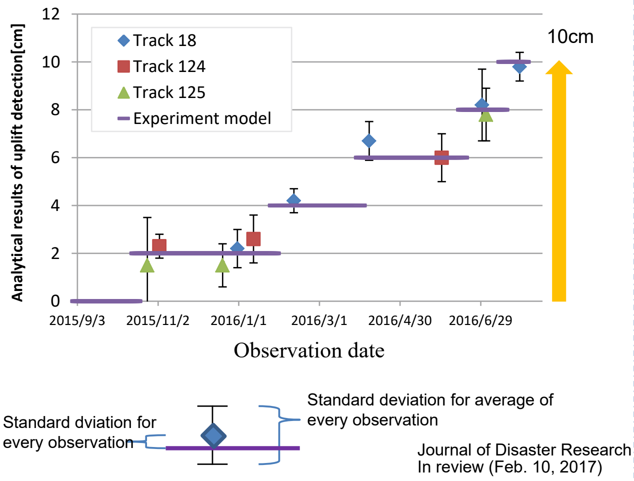


Validation and improvement for these application is planned to be continued.

Current Accomplishments (2/2)

3. Evalation using experiment model

Evaluated accuracy of ALOS-2 observation with experiment model. Marked 1.0cm std. for avarage of every observation and 0.4 cm std. for every observation



Journal of Disaster Research
In review (Feb. 10, 2017)

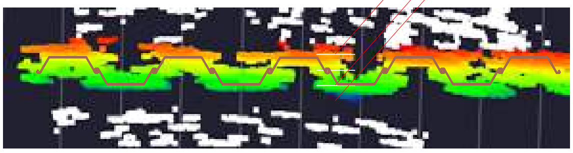
4. Port structure measurement by sonar

Sheet piles and blocks has been measured and measuring accuracy has been improved.

Observed Structures

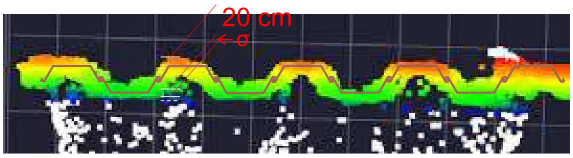
Sheet piles(planer image)

Before noise processing



Large noise(σ-15 cm)

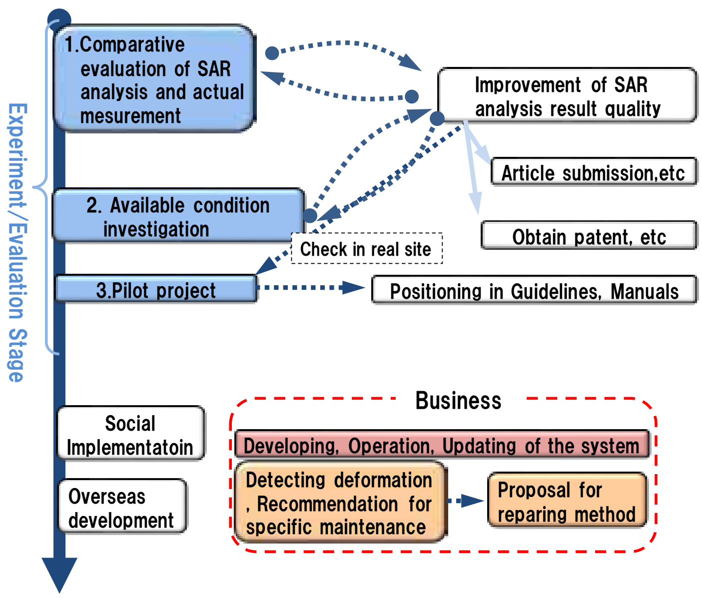
After noise processing



Small noise(σ<5 cm)

Goals

Time flow for practical use



Measurement method, feature and Goal

	Satellite	Sonar
Application scene	1. Port facility deformation monitoring at disaster 2. Periodic inspection of port facility	1. Grasp obstacles under sea on disaster 2. Periodic inspection of port facility under sea
Applicable condition	1. Emergency satellite observation at disaster within 12 hours in Japan 2.Differencial InSAR : cm order accuracy by using 2 scenes 3. Timeseries InSAR : mm order accuracy by using 15 or more scenes (data acquisition pace : 4scenes per year) - Range : 50 * 50 km square - Horizontal resolution : 3m	1. Rigging and initiallization requires 3 days for real time monitoring. 2. Detection of deformation by cm order of coastal facilities ・inspection area 50°×50°(beam resolution with 0.4 deg) ・maximum scope depth 150m ・significant wave height under 2m
Cost	- Satellite data's cost - Personnel expenses	・Leasing cost for sonar system ・Ship and labor expenses ・Personnel expenses for analysis

- Manualization about deformation monitoring at disaster and periodic monitoring by FY30.
- Obtain patent, article submission
- Domestic/Overseas practical use

15 Monitoring by using Ground-Base Synthetic Aperture Radar and Array-type Ground Penetrating Radar

Principal Investigator Motoyuki Sato (Professor, Tohoku University)

Collaborative Research Groups Tohoku University, NICT

R&D Objectives and Subjects

Objectives

- Quick and wide area monitoring of taxiways and runways
- Innovative technology combining Ground–Based Synthetic Aperture Radar (GB-SAR) and Ground Penetrating Radar (GPR)

Introduction of new methodologies using electromagnetic waves that replaced conventional sounding tests

Subjects

◆ Quick detection of surface anomalies by GB-SAR in large areas

- Repeat monitoring every 5 minutes.
- A 400 m x 400 m area can be observed within 10 seconds.
- Understanding of the surface conditions of pavement

◆ Precise inspection by GPR

- Up to 1 m depth in pavement
- 2 cm resolution
- Understanding the condition of the 2 cm thickness layer

GB-SAR

Current Accomplishments (1/2)

◆ GB-SAR Validation at Haneda airport

- Set a GB-SAR on the roof of a building for continuous monitoring of the ground surface of Runways and Taxiways
- Interval measurement (Minimum 1 min.) and displacement detection by Interferometry (Minimum 0.2 mm)
- 17 GHz(Ku band) frequency
- All weather, day and night, 24-hour monitoring
- Automatic early warning

GB-SAR system installed at Haneda airport

◆ Phenomena observed by GB-SAR

- Deformation of the pavement surface caused by blistering
- Deformation caused by the weight of airplanes
- Debris

◆ Advantages of the use of GB-SAR

- Full automatic measurements
- Automatic detection of anomalous displacement
- Detection of the fast rate change of displacement
- Continuous monitoring
- Five year continuous monitoring was conducted by our group at Miyagi prefecture for land slide monitoring
- Acoustic sounding inspection cannot be used for continuous measurement

Interferometric SAR image of the pavement surface obtained at Haneda airport

Current Accomplishments (2/2)

GPR

◆ GPR Validation at Taxiway at Haneda airport

- 8 Ch Multistatic GPR "Yakumo" was used for data acquisition
- 10% water content change can be detected by CMP signal processing in real time
- Validation by comparison with acoustic sounding inspection showed good agreements
- GPR can detect anomalies at a 20-50 cm depth, where the acoustic sounding test detected the anomaly.

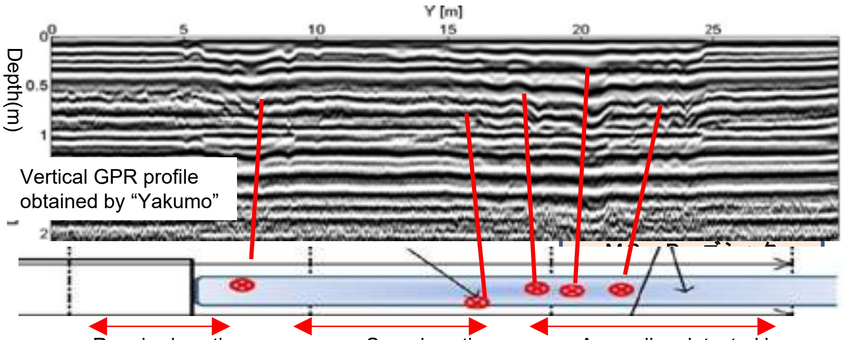
Validation at Haneda airport

Vehicle mounted GPR system

Hand pull type GPR can acquire data at 4 km/h with a 2 m width.

Vehicle mounted GPR can acquire data at 25 km/h with a 2 m width.

（Five h for a 3500 m runway measurement）



Move to the site (15 min)
Set up system (20 min)
Data acquisition (3 min)
4 km/h, 2 m width
2 m x 20 m area to be inspected
Analysis（5 min）
Cost Driver 1, Operator 2 for 4 hours
【Reference】Conventional method
（Observation and Acoustic sounding）
Operator : 8
Operation time : 23:30～03:00
（3h30m）
Inspection area : 2,620 m×80m

Goals

◆Final Goals

★ Cooperative operation of GB-SAR and GPR

- Wide area monitoring by GB-SAR (Continuous)
  400 m x 400 m in 3 minutes, detection resolution 1 mm
- Precise measurement by GPR (Anomaly points detected by GB-SAR)
  Measurement resolution 0.5 cm, Up to depth of 50 cm

★ Life Time

- GB-SAR 20 years
- GPR 20 years

Measurement area by GB-SAR

Expected Deployment

◆ Daily Monitoring

- Continuous monitoring by GB-SAR
- Automatic warning, if a surface anomaly is detected
- Automatic announcements for the operator
- GPR measurement of the spots where GB-SAR has detected an anomaly
- Alternatively, regular inspection by a vehicle mounted GPR is also possible

◆ Regular Inspection

- Regular inspection of planned areas by a vehicle mounted GPR

GB-SAR arrangements to cover all the area of Haneda airport

16 Monitoring system for a round of airport paved road inspection, utilizing a technique for detecting cracks automatically from high-resolution images.

Principal Investigator Toru Hara (Alpha Product INC.)

Collaborative Research Groups Alpha Product INC., Osaka Institute of Technology

R&D Objectives and Subjects

Objectives

- The objective of this research was to develop a system that could record the length and width of cracks on the surfaces of the runway of an airport and transcribe the obtained crack data on existing CAD plane views of the roads, to supplement the rounds of visual road inspections performed by an airport worker.

Subjects

<Automatic Extraction of Cracks>

- Images taken with two digital video cameras are processed automatically with dedicated software. Cracks extracted automatically from the images are displayed in different colors by width (in 0.5 mm increments). The length of the cracks is aggregated by width.

< Conversion and Transcription to CAD Data>

- The obtained data is converted into DXF format and transcribed correctly onto the existing plane views (CAD drawings) of the airport based on GPS coordinates and azimuth orientations measured at the start of shooting the video.

<Shooting System>

- The video is recorded by two persons using a handcart. Combined use of a laser pointer allows the operators to maintain linearity. The shooting system is capable of taking images of an area approximately 12 m × 3,000 min 5 hours. The system can also be moved with a tug vehicle.
- The shooting system can be disassembled to load on the work vehicle. The system is assembled by two persons. Assembly and disassembly time for the system is approximately 30 min and 15 min, respectively.
- All devices of the system use a rechargeable battery as power source. The estimated operating time of the system is approximately about 4 hours at a temperature of 0 ºC.
- Use of a Doppler laser range finder allows correct measurements of moved distances.

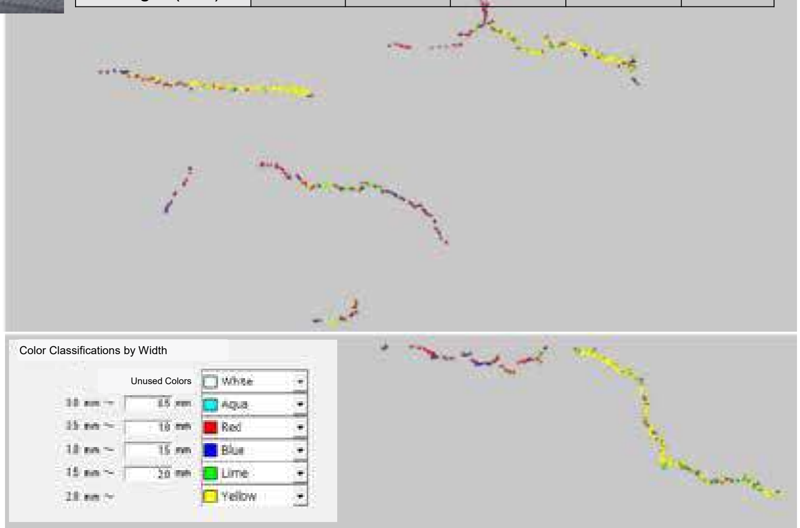
Current Accomplishments (1/2)

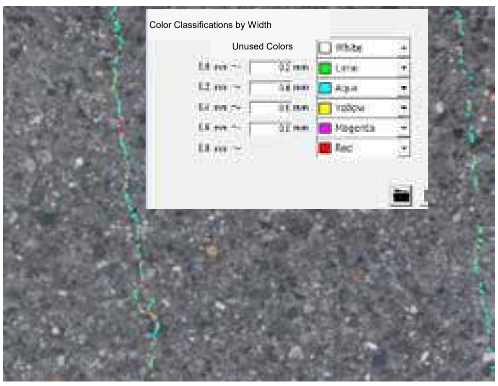
Measurement on the runway of Tokyo International Airport (Haneda Airport)

< Automatically Extracted Crack (No. 10) >

The figures below show Crack No. 10 and the aggregated lengths of the crack by width. The crack is indicated in different colors by width.

Width of Crack	0 - 0.5	0.5 - 1.0	1.0 - 1.5	1.5 - 2.0	2.0-
Length (mm)	0	702	1169	1039	4746



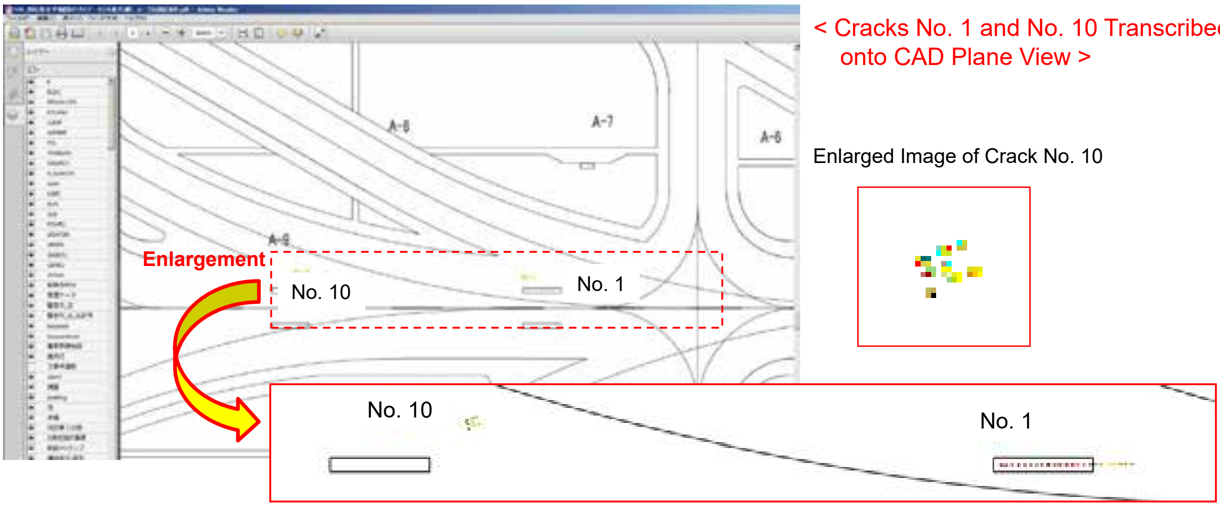


* Examples of an actual image and the extracted crack

A series of images are pieced together and stored separately. The stored images are available for viewing anytime.

Current Accomplishments (2/2)

< Cracks No. 1 and No. 10 Transcribed onto CAD Plane View >



Enlarged Image of Crack No. 10

< Confirmation of Changes in a Crack over Time (Data of Tunnel Segment Breaking Test) >

- Data of a tunnel segment pressure breaking test by elapsed time (in one-minute increments)

Photos (i)-(iii) show development of the crack over time.

< Real-time Image Display >

Images can be displayed on large monitors (2 pcs) in real time.

Goals

- Intellectual property rights acquisition and trademark registration

The automatic crack extraction technique has been registered in the New Technology Information System (NETIS) of the Ministry of Land, Infrastructure, Transport and Tourism (registration No.: NETIS KT-130046-V).

The shooting system, FOCUS-α, has been registered as a trademark.

- The following three business models are under consideration.

1. Sales of the entire system, including the analysis software
Estimated price: Approximately JPY 20 million to JPY 25 million

2. Sales of the shooting system alone. Data analyses will be performed by our company.
Estimated analysis charge (at this time):Approximately JPY 5,600/100 m^2*

3. Sales or rental of the automatic extraction software with a fixed extraction accuracy, and the image connection and CAD data conversion software
Estimated price : Approximately JPY 2 million to JPY 3 million

* Image connection (per 100 m) and crack data extraction.

CAD data conversion will be charged separately.

As of January 2017

Specifications of Shooting System

Item		Video camera cautious shooting
Shooting Method		Continuous shooting while moving
Shooting Area-hours		10,220 m^2/h
Extraction Accuracy		0.35 mm
Shot Image		8,800,000 pixels
Shooting Equipment		4K digital video camera
Focal Distance		37 mm
Number of Video Cameras		2 pcs
Lighting		LED lights (used always)
Power Source		Rechargeable battery (internal/external)
Ancillary Devices 1		Aluminum handcart
Ancillary Devices 2		Laser range finder/Red Laser
Shooting Operation		Continuous shooting speed: 5 km/h
Preparation for Shooting		Installation of the laser
Shooting System Transport Vehicle		1 (carrier)
Image Processing	Automatic Crack Extraction	Automatic continuous extraction
	Color Classification of Crack by Width	With
	Image Connection (per Shooting Direction)	Automatic connection
	Image Connection (Another Camera)	Automatic connection
Crack Date Conversion into DAD Data		Dedicated software is used

Data Processing Specification

Item	Automatic crack extraction from images
Extraction Accuracy	For runway: 0.35 mm (0.1 mm max.)
Processing Speed/Image	Approx. 4 seconds
Number of Processing Steps	5 steps
Adjustment of Processing Steps	Automatic adjustment (after making settings)
Applicable PC	Core-i7 3 GHz or more, RAM 32 GB or more

17 R&D of the crack detection system for runways with a 3D camera and all direction-moving robot

Principal Investigator Yasuo Kimura (NTT Advanced Technology Corporation, Network Service Innovation Business Unit)

R&D Objectives and Subjects

Objectives

Cracks appearing on the surface of runways bring degradation of asphalt and causes surface peeling. The large-scale surface peeling affects the operation of aircraft. The large parts of the actual crack detection are manual operation so that the detection performance depends on the human skill of inspectors.

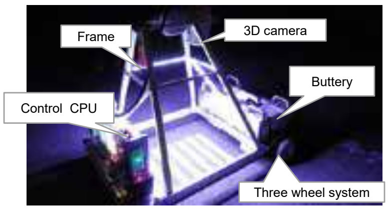
We must improve this situation in the ordinal routine work of crack detection. Our object is to develop a high-performance crack detection system by using 3D cameras mounted on an all direction-moving robot.

Source: MLIT “Variation of asphalt pavement and curren status of airport paving inspection technology”

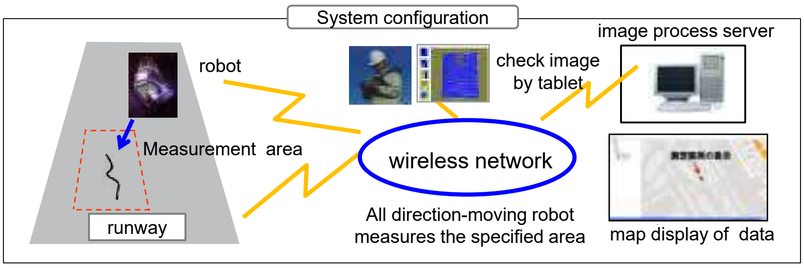
Subjects

The crack detection system for runways with a 3D camera and all direction-moving robot is able to quickly detect the many types of cracks on runways by analyzing 3D data automatically captured by 3D cameras mounted on an all direction-moving robot.

All direction-moving robot



System configuration

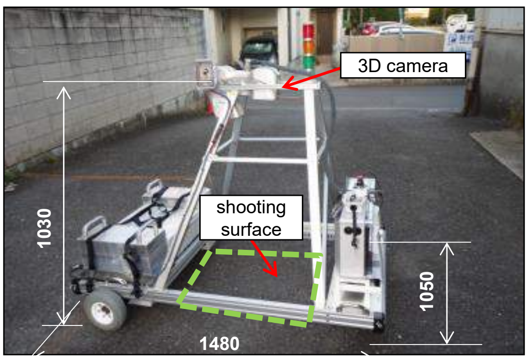


Current Accomplishments (1/2)

All direction-moving robot

We have developed the all direction-moving robot with a low-positioned center of gravity, three-wheel moving configuration, and spring dumper for suspension in order to suppress the affection for the 3D data due to unevenness of the road surface and due to wandering when moving and stopping. We have realized the automated crack detection system for runways by the fact that our system can capture 3D data automatically without moving conditions and send to the data server.

Specification of all direction-moving robot



All direction-moving robot（side view)

（front view)

Projection surface of the 3D camera projector

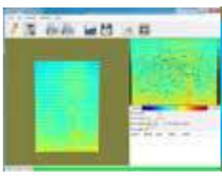
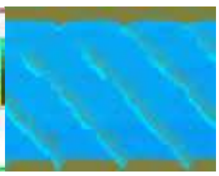


Image process (color mapping)



Zoomed in on grooving

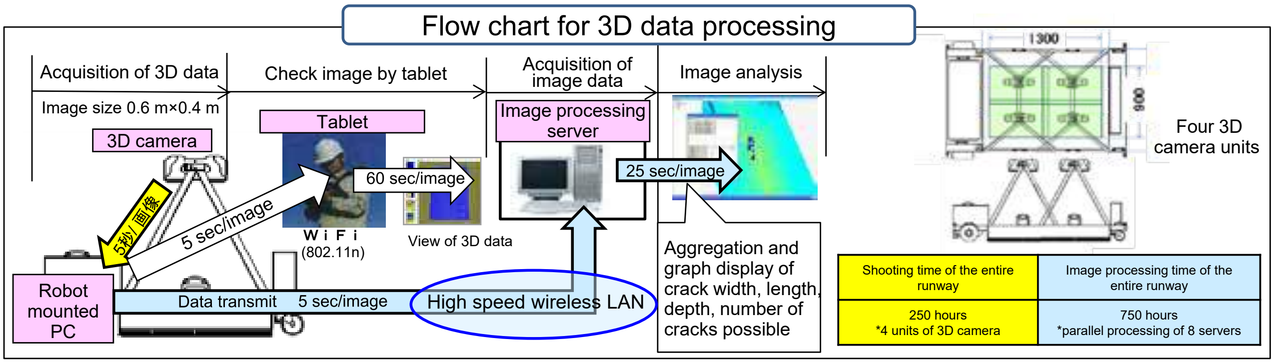
Specification

Item	Contents
Configuration	3-wheel configuration Drive wheel: 2, auxiliary wheel: 1
External dimensions	1050 W×1480 L×1030 H
Weight	total weight: 80 kg body: 60 kg battery:11.5 kg×2
On-board camera	Seiko Wave's 3D camera
Move control	Movement control by rotation control of two driving wheels
Control PC	Micro PC two configuration
Position accuracy	GPS: position accuracy ±1m
Movement control technology	・SLAM ・gyro ・Odometry
Power supply	Lithium, ferrite battery 24Ah×2 ・Detachable ・Continuous operation time: 2 hours or more
Camera control	Shooting control of dimensional camera
Vibration control	Spring damper for auxiliary wheel, ｅｔｃ.

Current Accomplishments (2/2)

Reduction of wasted time in analyzing data

Typical 3D data requires much processing time due to the shooting process, data transfer, and data analysis. We can obtain a total processing time of 30 seconds for 3D data corresponding to a 70 MB data file (70 cm x 50 cm square area) compared with our prototype processing system. With one 3D camera system, it takes one thousand hours to execute crack detection for the whole runway of a typical airport. To reduce the processing time, we can show the demonstration of our system in cases of operating four 3D cameras simultaneously, as below.

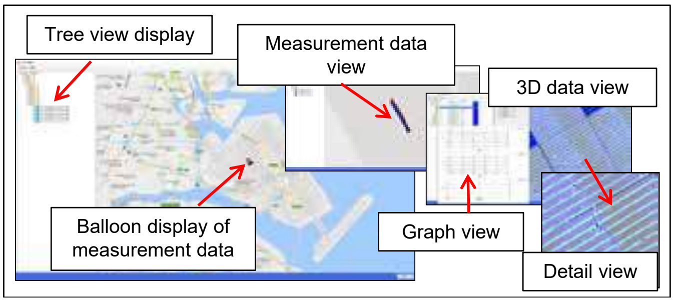


Data mapping

We can manage the measuring 3D data and show the resulting cracks on the map. The main features of our system are as follows:

(1) Tree view display and data storing
(2) Balloon display of data
(3) Measuring data display in detail
(4) Graphically display the measured data

It is easy to identify the cracks with collaboration in the mapping system, which can improve the performance of crack inspection in the field.

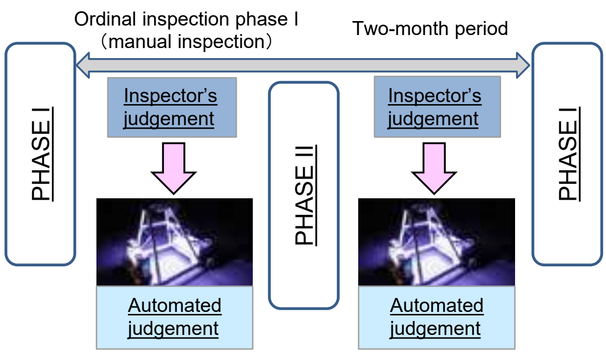


Goals

Achievement of Goals

Items	Achievement of items
3D data capturing	・250 hours sweeping time for runway area (Width 60 m × Distance 3,000m) with a four camera configuration. ・750 hours aata analyzing time with 8 server multi-operation system
Detection of cracks	・ linear cracks with more than 1 mm width can be detected automatically ・alligator cracks can be detected with a manual assistance.
Visualization of monitoring data	・ monitoring data can be projected onto the map ・ 3D graphical representation

Support for ordinal inspection



・ High precision and effective inspection can be performed by using 3D data analyzing with our programed robots.

Concrete product concepts

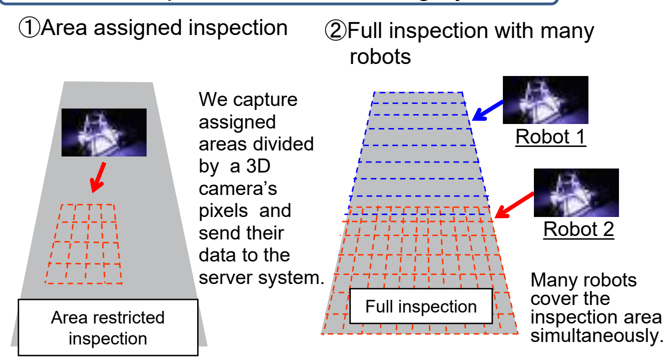
① Alternative inspection method for ordinal inspection operation
・ support and assistance of ordinal inspection work for runways

② Crack detection system business for promotion
・ automated crack detection system
・ 3D surface analyzing system

③ Technical consulting
・ system support and consulting for different fields

④ New Business
・ New Monitoring services for building and other structures

New concept of crack monitoring system

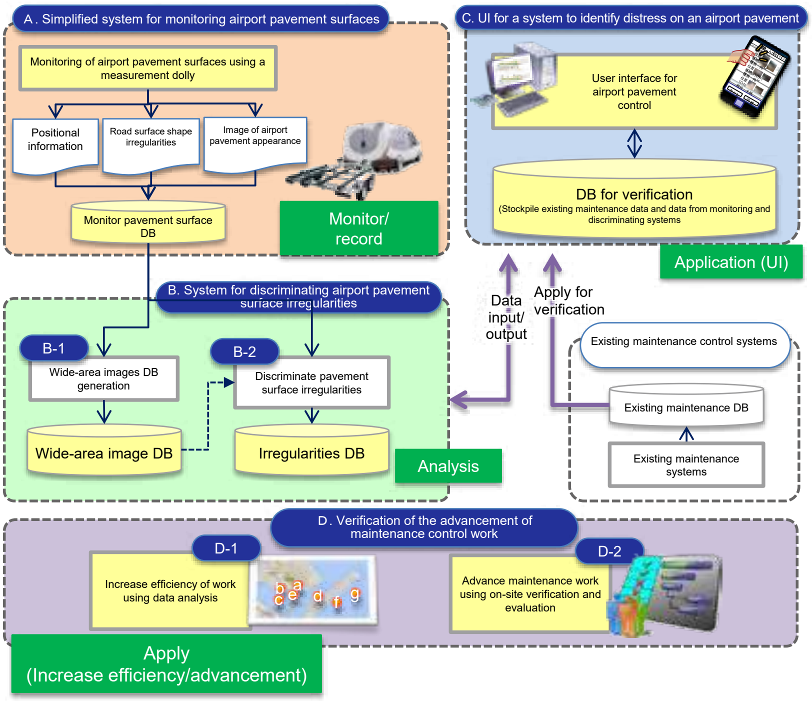


18 R&D of a Simplified System for Monitoring the Airport Pavement Surfaces Using Maintenance Vehicles

Principal Investigator Yusho Ishikawa (Professor, The University of Tokyo)

Collaborative Research Groups The University of Tokyo, Pacific Consultants Co., LTD., Social Capital Design, Inc.

R&D Objectives and Subjects



Objectives

- Easily visualize, record, and monitor damage, such as the cracking of pavement, during pavement inspections by airport administrators
- Understand trends in irregularities through continuous monitoring and use as a method of efficient maintenance control

Subjects

This simple pavement maintenance system comprises the following four items:

- A : Simple monitoring and recording of road surfaces
- B : Discrimination of irregularities using monitoring data
- C : Provision of on-site support through visualization of maintenance data
- D : Data analysis to achieve high efficiency and more advanced work

Current Accomplishments (1/2)

A. Simplified system for monitoring airport pavement surfaces

◆Technical challenges

- Develop easily operable system that can be operated by airport administrators
- Monitoring system that can acquire large amounts of detailed data over a short duration of maintenance

◆Current system conditions

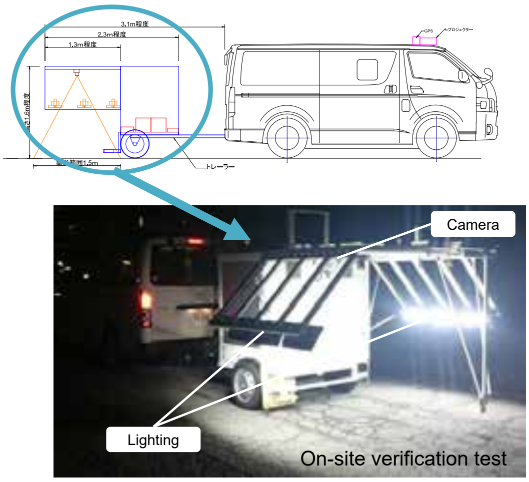
- Develop a measuring dolly that is equipped with an optical camera, infrared sensor, and GPS device and then mount this on a vehicle owned by the airport administrators so that it can be used during pavement inspections
- Must be able to acquire and accumulate data and take pictures at vehicle speeds of 30 km/h

◆Ultimate goal

- Accurately determine surface cracks that are 1 mm or wider and deformations at vertical and horizontal resolutions of 5mm and 3cm, respectively

Understand the run position using a GPS device with an error of 10 cm.

Simplified system
for monitoring airport pavement surfaces



On-site verification test

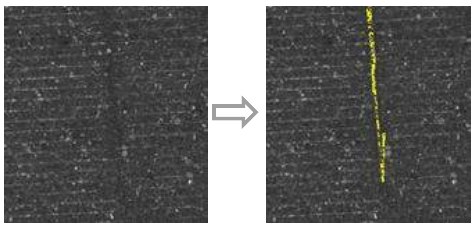
B. System for discriminating airport pavement surface irregularities

◆Technical challenges

- Generate wide-area images that cover the entire airstrip surface
- Discriminate road surface deformation to a high degree of accuracy

◆ Current system conditions

- Be able to integrate images from video camera to generate wide-area images that cover the entire airstrip surface
- Detect alligator cracks and linear cracks that are 1mm or greater from these integrated images and then record them in a database (DB) with the position they were detected in
- Detect and record deformations with a depth of 1cm based on the irregularity information obtained by an infrared sensor



Discriminate deformations while excluding grooves

Current Accomplishments (2/2)

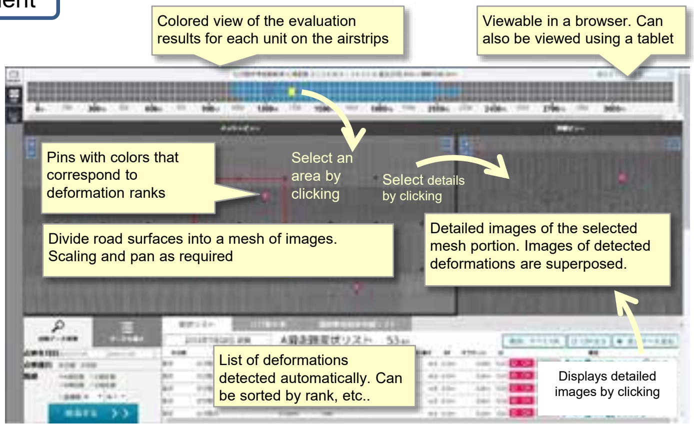
C. UI for a system to identify distress on airport pavement

◆Technical challenges

- Accumulate deformation data through several on-site verification tests and determine if there have been changes over time
- Find connections with previous data

◆Current system conditions

- Visualize deformations and past conditions using functions such as deformation lists, evaluation level distribution, wide-area overhead pictures, and deformation stacked viewing
- Administrator can refer to the same information using an office PC or an on-site tablet terminal



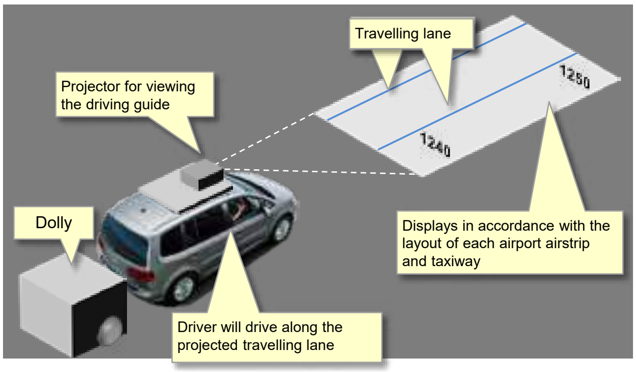
D. Verification of the advancement of maintenance control work

◆Improving work efficiency using data analysis

- Use data obtained from the system to not only understand daily pavement deformation but also apply data analysis to extract deformation trends and regularity

◆Improve maintenance control work using verification data

- Understand on-site needs to verify efficacy of various systems
- Verify results from verification tests to achieve higher efficiency for procedures based on system implementation and current pavement inspections
- Advance on-site work by developing a guide application function that can improve the driving accuracy during monitoring



Goals

Objectives

Application Items	Objectives
A : Simple monitoring system	Detect 1mm wide surface cracks and view deformations at horizontal and vertical resolutions of 5mm and 1cm, respectively
B : Deformation discrimination system	Create linking images of airstrips, display high-speed images that correspond to positions, discriminate linear/alligator cracks, and record damage type/rank/size
C : UI development	Create user information that can distribute deformation trends for an entire airstrip, showing fluctuation in damage rank, and understand changes in damage units
D : Advance maintenance control	Analyze trends such as temporal changes and spatial distributions using a deformation database. Establish work procedures with improved efficiency for pavement inspections

Anticipated mechanism for providing services

◆ When used to perform daily pavement inspections

- Sell a simple pavement inspection system (with maintenance) and have the administrators use it during inspection. Provide services that advance work based on data acquired from this system

◆ When used to perform periodic inspections

- Have service providers investigate pavement road surface characteristics during periodic inspections and then interpret, evaluate, and analyze the data and provide the results

・Service Provider

【System lease/maintenance and inspection】

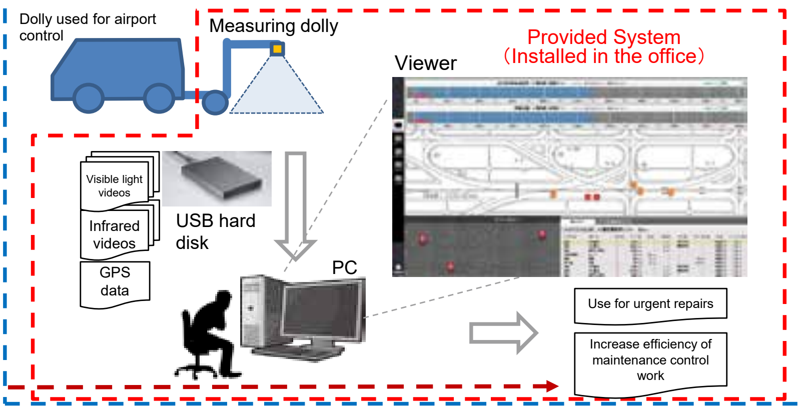
- Sales, maintenance, and inspection for a simple pavement inspection system
- Perform repairs when a system malfunctions
- Improve and modify the system

【Provide services that relate to advanced maintenance control work】

- Confirm and analyze degradation trends by analyzing information collected during inspections, repair status, and usage status
- Provide proposal that will lead to improved efficiency for maintenance control work

・Airport Manager

Used by administrators themselves during inspections and data is used for maintenance control



Providing services for daily pavement inspections

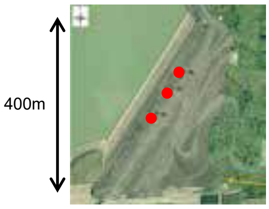
19 Development of wide area displacement monitoring for early detection of deformation or damage of civil engineering structures using satellite SAR

Principal Investigator Masafumi Kondo (National Institute for Land and Infrastructure Management)

R&D Objectives and Subjects

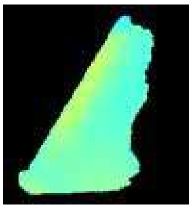
Objectives

Monitoring displacement of many civil engineering structures both in normal times and after natural disasters by utilizing satellite SAR data covering a wide area without sensors on the ground surface

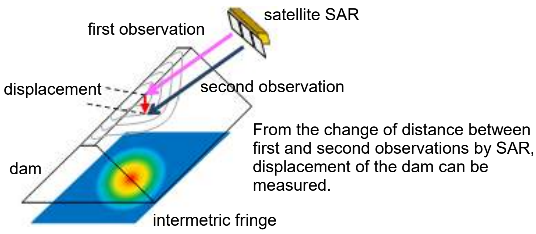


Current survey points on a rock fill dam (red circles)

From survey at limited points to whole area measurements



Satellite SAR image



Schematic drawing of displace monitoring by satellite SAR

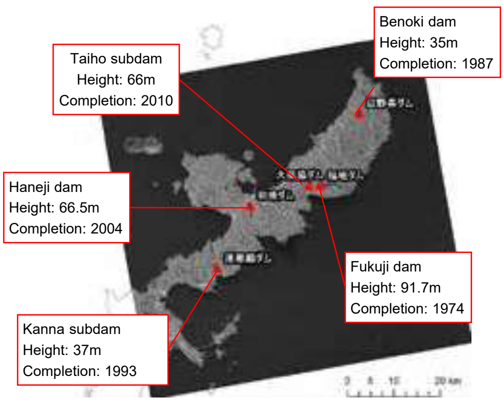
Subjects

We are conducting the following studies to develop a new displacement monitoring method using satellite SAR as a core technology

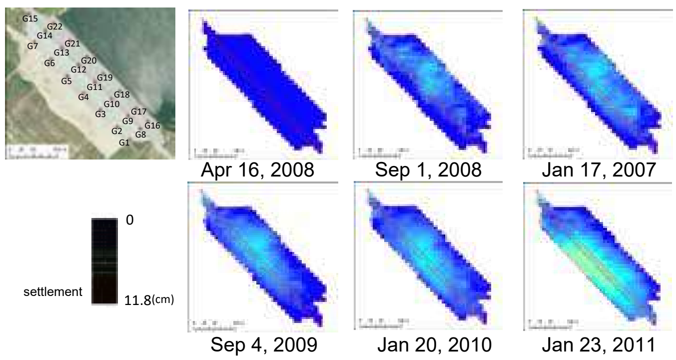
①Development of a monitoring method for practical application for rockfill dams
②Research on applicability for concrete dams or other structures
③Development of a reliable monitoring method combining SAR, conventional survey, GPS, etc.

Current Accomplishments (1/2)

(1) Trial of displacement monitoring for five rockfill dams in one scene using ALOS/PALSAR data
Target dams : Five rockfill dams
Data used : ALOS/PALSAR (2006-2011) (Spatial resolution:10m, wavelength: 23.6cm (L-band))



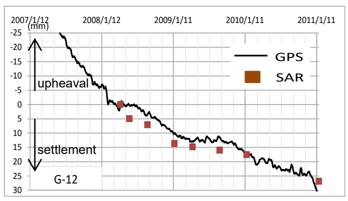
SAR data and location of five rockfill dams



Example of displacements of Taiho subdam after several years from completion using ALOS/PALSAR

Difference between SAR and conventional survey / GPS

	Current surveying method	Average error (RMSE) (unit: mm)
Taiho subdam	GPS	6.0
Haneji dam	conventional survey, partially GPS	4.4
Fukuji dam	conventional survey, partially GPS	4.3
Kanna subdam	conventional survey	5.5
Benoki dam	conventional survey	6.7



Comparison of displacement between SAR and GPS

Displacement obtained by satellite SAR was in good agreement with GPS (average error: 5 mm).

We have confirmed that displacement monitoring by satellite SAR is practical for rockfill dams, showing good accuracy.

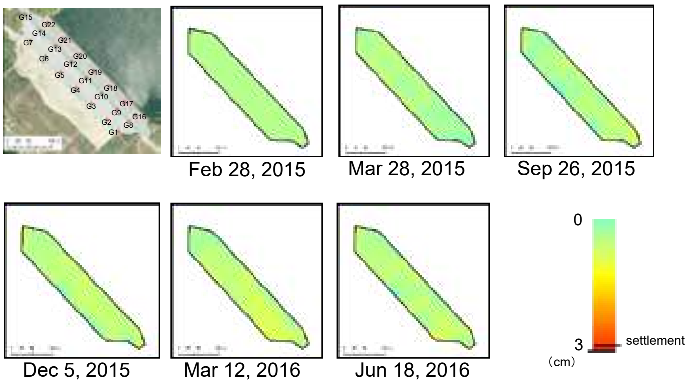
Sato et al. : Interferometric SAR time series analysis for external deformation monitoring of five rockfill dams using ALOS/PALSAR data, Journal of JSCE, F3, Vol.73, Jan 2017.

Current Accomplishments (2/2)

(2) Trial of displacement monitoring for various rockfill dams across Japan using ALOS-2 data

Target dams : Nineteen rockfill dams
Data used : ALOS-2 (2014-) (Spatial resolution 10m, wavelength 23.6 cm (L-band))

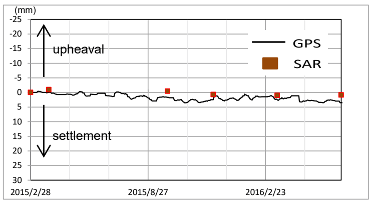
Locations of dams



Example of displacements of Taiho subdam dam after about ten years from completion using ALOS-2

Target dams were selected across Japan for future practical use in many dams

Applicability for concrete dams is under study



Comparison of displacement between SAR and GPS

Displacement obtained by satellite SAR was in good agreement with GPS (average error: 2 mm).

We are continuing further studies toward practical use for rockfill dams.

Goals

【Current progress for final goals】

①For practical use of satellite SAR for deformation monitoring of rockfill dams

- Accurate displacement measurement in normal times
- Wide and early displacement measurement after earthquakes

→ Preparation of technical manual for satellite SAR based displacement monitoring of rockfill dams

②Research on applicability for deformation monitoring of concrete dams or other structures

- Trial measurement for concrete dams (under study)

③Development of a reliable monitoring method combining SAR, survey, GPS, etc.

- Accurate displacement monitoring by satellite SAR at places without displacement data (under study)
- Reliable monitoring technology combining satellite SAR and other methods (conventional survey, GPS, etc.) (under study)

【Final Goals】

- Realization of efficient and effective displacement monitoring by combining satellite SAR and other methods
- Contributing to improvement of monitoring technology for life expansion of civil engineering structures, including dams, by complementary use with conventional methods

Concept of monitoring and maintenance of dams using satellite SAR

Combination with other methods
survey | GPS | Optical satellite
Efficiency improvement of displacement monitoring in normal times
Reliable displacement monitoring of entire surface

satellite SAR

Utilization in normal times
Daily visual inspection | Periodic inspection every 3 years
Comprehensive inspection after 30 years | Measurement data
Early detection of local deformation
Long-term monitoring by satellite SAR

Utilization after earthquakes
Special inspection (after earthquake)
Early detection of structural damage immediately after earthquake
Continuous monitoring of structures with deformation

Social implementation
- Practical application to dams managed by MLIT
- Technical manual also useful for other structures

Realization of life expansion of civil engineering structures by utilizing satellite SAR for sophistication and efficiency improvement of monitoring technology

20 Understanding the scouring situation by ALB (Airborne Laser Bathymetry)

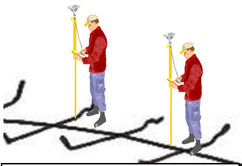
Principal Investigator Hiroaki Sakashita (PASCO CORPORATION)

R&D Objectives and Subjects

Objectives

- To establish a monitoring methodology to quantitatively evaluate the scour of pier foundations under the water surface by utilizing ALB (Airborne Laser Bathymetry) measurement

Conventional scour survey



Performing measurements and visual inspection at bridges and distance target positions

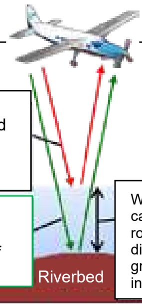
- Dangerous to conduct visual inspection at high water flow speed
- Difficulties in grasping the scouring under the water surface
- It is possible to grasp only the cross section of the survey line position

Scour survey by ALB

- Water depth can be measured from aircraft
- Measure a wide range of riverbed topography in a short period of time
- Grasping of arbitrary cross section by 3D measurement

Measurement by utilizing near-infrared laser pulse land portion reflection on water surface

Green laser pulse penetrates through water and reflects off the bottom



Water depth is calculated from the round trip time difference between green laser and near infrared laser pulses

R&D Contents (2014 – 2015)

- Comparison and analysis with conventional method (shallow survey), evaluation of ability to understand the scouring situation → Ensuring the same accuracy as in the past and implementing safe and efficient measurement of wide riverbed topography.
- Development of efficient and effective scouring monitoring methodology using ALB
Effective scouring monitoring by efficiently understanding the amount of surface river bed variation in 3D shape of scouring, which was difficult previously.

1. ALB survey, bathymetry
2. ALB data accuracy verification | 3. Bathymetry survey accuracy verification
4. Data comparison and analysis
5. Monitoring methodology

Current Accomplishments (1/2)

(2014-2015)

1. 3D wide range measurement

3D data of riverbed topography acquisition by ALB (aerial laser sounder) measurement.

Simultaneous data acquisition with aerial photos.

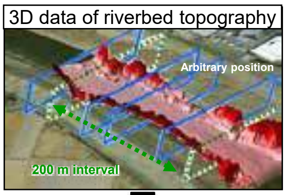
Gradation map	Aerial photo
3D data displaying altitude by color variation	Orthorectified images from continuous photography

- Realization for the 3D measurement of riverbed topography.
- No need for persons to conduct surveys (safety).
- Local equipment installation is unnecessary (efficient)

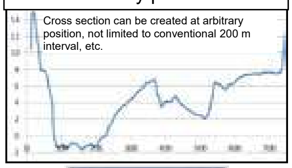
2. Cross section creation of arbitrary position

Creation of sectional view of an arbitrary position by acquiring the riverbed topography previously grasped at 200 m intervals etc. as three-dimensional data.

3D data of riverbed topography



Cross-sectional view of arbitrary position



- It is possible to grasp the cross-sectional shape at an arbitrary position with a single measurement.
- Contributing to predict scouring risk sites.

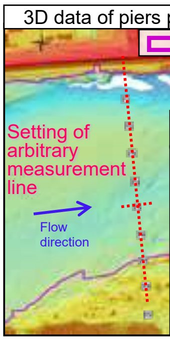
3. To grasp scouring situation of the piers

Obtaining 3D data of riverbed topography at pier locations.

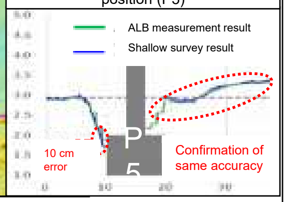
Comparison of cross section of the piers surroundings with bathymetry survey and accuracy verification.

3D data of piers position

The outline part is missing data (deeper than about 6 m)
※ Measured in good water quality condition <transparency 100 cm or more>



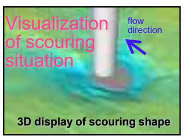
Longitudinal section of bridge pier position (P5)



- Accuracy confirmation equivalent to bathymetry survey.
- In present verification, it was possible to measure up to about 6 m in depth (dependent on water quality), the scouring depth error was about 10 cm.
- Study of effective countermeasures from the scouring situation.

Utilization example

"Visualization" of scouring Situation by superimposing grasped scouring (3D data) and general drawing of the bridge.



- Efficient measurement of a wide range of riverbed topography and understanding the scour of the pier with high accuracy.
- Contribution towards efficient and effective facility management.

Current Accomplishments (2/2)

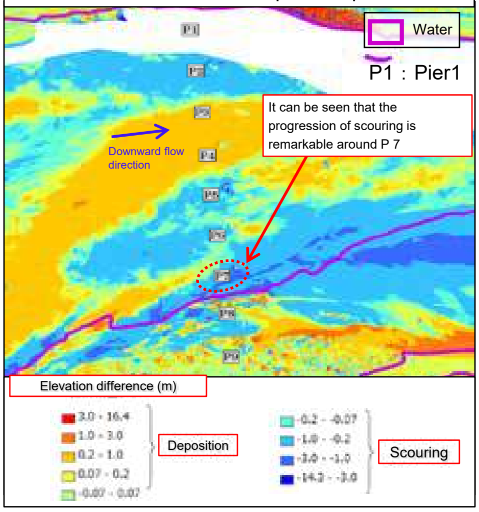
(2014-2015)

4. Calculation of variation amount for two periods

Visualization of differences in river bed variation by calculating elevation difference of two periods of data.

Understanding of the scouring by the amount of riverbed variation around the piers.

Elevation Difference Map of two periods

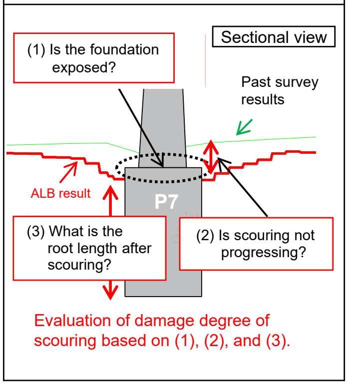


- Selectable piers with prominent scour progression (scouring progresses around P7 in the above figure).
- Study the timing of countermeasures from the progress of scouring.

5. Evaluation for extent of damage

Judging the degree of damage evaluation based on the grasped scoured condition and bridge periodical inspection procedure.

Evaluation logic for degree of damage



- Determining the necessity of detailed investigation and emergency measures by judging the degree of damage.
- Utilization for judging the countermeasure classification.

Utilization flow of the results

1. Wide range 3D measurement
2. Creation of cross-section at arbitrary position
3. Grasping scouring situation of the piers
4. Calculation of variation amount for two periods
5. Determining degree of damage evaluation

Decision by bridge manager for countermeasure classification

- Advanced bridge management by utilization for scouring monitoring

Goals

Numerical target

Cost reduction by 10% in comparison with conventional scouring survey.

Users

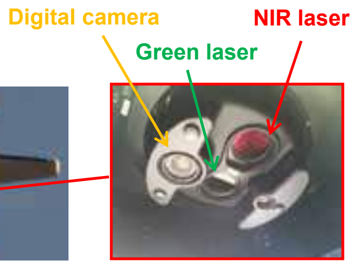
River manager, bridge manager, harbor / beach manager, etc.

Wishing to investigate bottom topography.
Wishing to understand the scouring situation.

How to use/places of use

Scope of coverage from aerial measurement by installing laser and digital camera equipment on the aircraft.

ALB measurement



Equipment with ALB

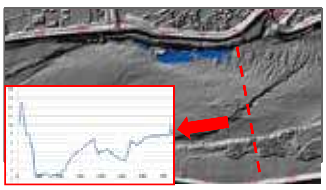
Sales method

Implementation of proposal activities for ALB measurement technology targeting users. → Service ordering by manager for surveying, scouring investigation. → Provision of services such as ALB measurement technology and analysis and evaluation of measurement results, and profit creation.

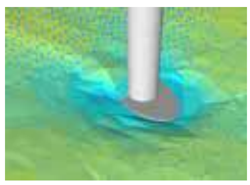
Services to Offer

Acquiring 3D topography data for monitoring scour situation around the piers.

Acquisition of high-definition 3D topography data



Creation of cross-section at arbitrary position



Monitoring scouring situation

Efficient comprehension of wide riverbed topography by aircraft

→ Utilization of scouring monitoring for the improvement of river management and bridge management

21 R&D of monitoring system for bridge performance assessment based on vibration mode analysis

Principal Investigator Tadao Kawai (Professor, Osaka City University)

Collaborative Research Groups IMV Coporation

R&D Objectives and Subjects

Objectives

・ Development of monitoring system for aged deterioration or damage of bridge based on vibration mode analysis.

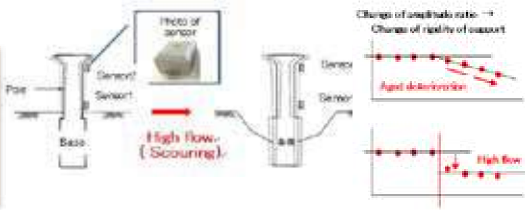
Conventional inspection

Inspection by diver

・Difficulty in high flow or muddy stream
・Requires preparation for diving

Proposed inspection

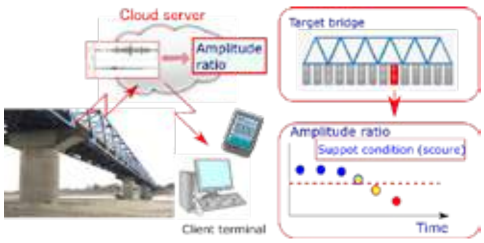
・Acquisition in high flow or muddy stream
・Quick estimation upon request



Subjects (2014-2017)

・ Implementation of vibration monitoring system for bridge.
→ **Remote system to monitor amplitude ratio of pole.**

・ Development of estimation method for support performance of pole.
→ **Detection of a scoured or deteriorated pole.**



Current Accomplishments (1/2)

(2014-2016)

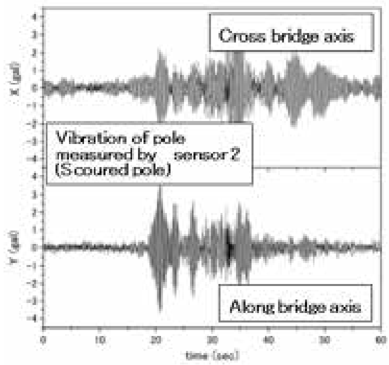
1. Measuring system

Attachment of two sensors on upper and lower part of a scoured pole and a nonscoured pole for measurement.
Attachment of radio gateway on upper side of pole for data transmission.

・Remote acquisition of vibration data at office via Internet connection.

2. Vibration of pole

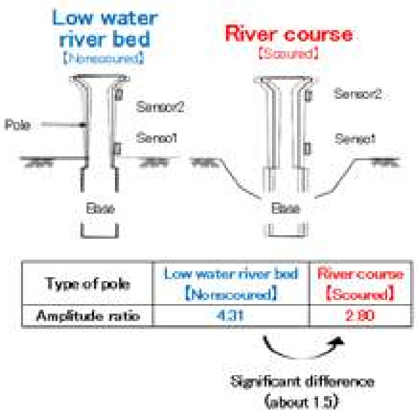
Measurement of low frequency vibration of pole with low noise using a special sensor for infrastructure.



・Estimation of amplitude ratio with low noise.
・Estimation of support rigidity of pole

3. Amplitude ratio

Verification of significant difference of 1.5 in amplitude ratio between a scoured pole and a nonscoured pole.



・Detection of scoured pole by estimating amplitude ratio.

Utilization example

① Estimation of support rigidity of pole under the condition of high flow or muddy stream.
② Management of efficient inspection schedule.

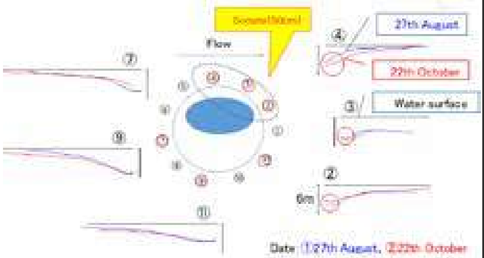
① Quick correspondence in emergency
② Efficient management of bridge inspection

Current Accomplishments (2/2)

(2014-2016)

4. Scanning of river bed

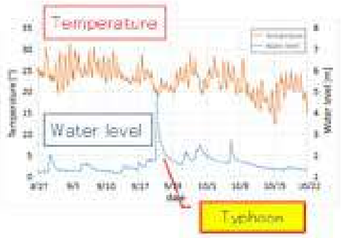
Detection of progress of scour by scanning around a pole with ultrasonic sonar before and after typhoon.



・Verification of correlation between scour and amplitude ratio for better estimation.

5. Change by high flow

Close correlation between amplitude ratio of a pole and scanning data of river bed.



Average (Error)	Bridge axis	
	Nonscoure	Scoure
30th August	3.90 (0.384)	3.06 (0.223)
29th September	3.67 (0.374)	2.82 (0.213)
27th October	3.84 (0.352)	2.87 (0.259)

High flow

Reduction by 10%

・ Detection of scour or its progress of pole by estimating amplitude ratio.

Flow of utilization

1. Measuring system
2. Vibration of pole
3. Amplitude ratio
4.Scanning of river bed
5.Change by high flow

Quick correspondence
Efficient management of bridge

Goals

Numerical target

Management cost cut of 50% by remote monitoring and efficient inspection .

Users

Railway companies, highway companies, local governments, etc.

How to use/Places of use

Attach sensors and radio gateway on pole of bridge to monitor amplitude ratio of pole through Internet connection.

Sales method

Sale or rental of monitoring unit. ▶ Rent WEB base cloud service for inspection and management of bridge. ▶ Reduction of traffic obstacles in emergency. Reduction of inspection cost.

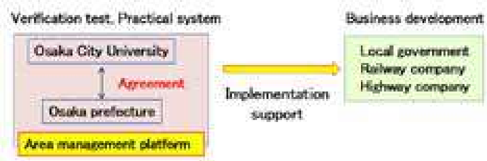
Services to Offer

Offer useful services for quick correspondance in emergency and efficient management of bridge inspection.

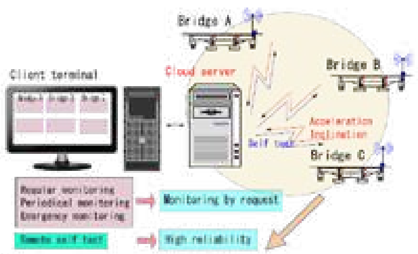
Cost of typical system (20 poles)

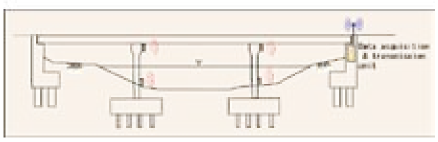
Initial: 800,000x20=16,000,000 yen
Management (year) :
20,000x20+600,000=1,000,000 yen

Detection of scoured pole and efficient inspection
→ Quick correspondance in emergency and efficient management



Pilot service in Osaka Prefecture





22 Creation of Monitoring System using Equipment with Robotic Camera and etc. for Bridge Inspection

Principal Investigator Yasuhisa Fujiwara (Sumitomo Mitsui Construction Co., Ltd.)

Collaborative Research Groups Hiatchi Industry & Control Solutions, Ltd.

R&D Objectives and Subjects

Objectives

This research aims to develop a regular monitoring system to determine the information of a bridge deteriorated due to aging at locations that cannot be inspected at close range, such as girder ends and bearings.

Conventional system

General regular inspection

- Difficult to inspect locations which cannot be approached
- Difficult to ensure a place for equipment installation
- Difficult to refer to past data on site

Regular monitoring using equipment with robotic camera, etc.

- Locations at close range can be inspected.
- The same location as with the previous inspection can be inspected by linking with GPS.
- The data on site can be accessed by connecting with the Internet

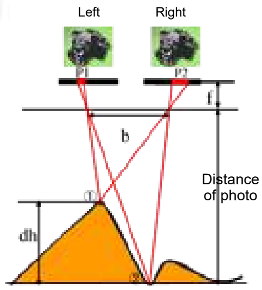
Suspending Type

Subjects (2014-2018)

- The inspection equipment includes a robotic camera※, digital camera, and laser scanner.
- Development of the linkage and practical use of each device by considering the advantages of each.
- Verification of the system on an actual bridge.

⇨ A monitoring system which uses the advantages of each device can be realized.

※Robotic camera with laser range finder and light for bridge inspection



Stereo photography using digital camera

Current Accomplishments (1/2)

(2014-2018)

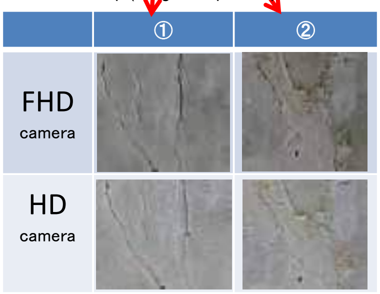
1. Resolution improvement

To improve the image resolution, the prototype model, which uses a Full High-Definition (FHD) camera, was modified from the original model, which had a High-Definition (HD) camera.

HD camera: 1280 x 720 pixels

FHD camera: 1920 x 1080 pixels

Zoomed-up (image comparison)



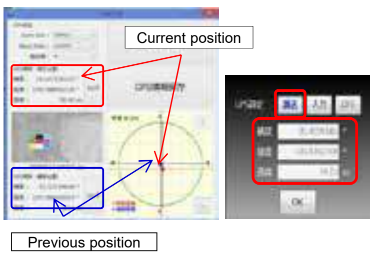
The modification from HD camera to FHD camera:

- Improves the damage detection performance.
- Improves the clarity of cracka.

2. GPS capability

By linking the camera with GPS, it is possible to inspect the same location of the bridge at any time.

Linkage of the camera with GPS



Camera position shown on the display

With GPS capability:

- Linkage of camera with GPS can be realized.
- The position of the camera can be determined, enabling inspection the same location.

3. Color tone correction

The damage due to aging deterioration from the image is difficult to detect when affected by environmental influences such as changes in weather and brightness of the day.

Two correction techniques were investigated to remove the environmental influences.

(1) Using standard color palette technique

The color tone correction of the image can be carried out by taking an image of the structure with the standard color palette.

(2) Using laser pointer beam technique

In case the palette is not available for use, a laser pointer can be used to correct the color tone of the image.

The use of standard color palette and laser pointer beam:

- Can exclude the environmental influences.
- Can correct the color tone image of a location that cannot be inspected at a close range.

Current Accomplishments (2/2)

(2014-2018)

4. Capture reference distance using stereo photography

3D configuration of the structures can be recognized by using stereo photography of 2 digital cameras. However, a reference distance on the structure's surface is required.

Therefore, an L-shaped scale of the robotic camera Which responds to inclined surfaces was developed to improve the accuracy of this noncontact measurement system.

L-shaped scale on an inclined surface

Stereo photography using digital camera

- An L-shaped scale which can be used with the inclined surface was developed.
- The accuracy of stereo photography in the case where the camera is not in front of the structure's surface was improved.

5. Visualize the change in time-series images

Superimposed images captured from different times at the same location can be obtained by extracting some distinguishable features of the image and converting their coordinates to the same direction to match the others.

➡ From the superimposed images, the locations where changes are found are displayed in different colors.

- Images which convert to the same direction were used.
- Visualization of the location that changes due to aging damage can be realized.

Display in different color the location with change in time-series

Flow of utilization

Robotic camera

1. Resolution improvement
2. GPS capability
3. Color tone correction

Auto-repeat image capture

Connecting with Internet

Digital camera and laser scanner

4. Capture reference distance using stereo photography

5. Visualize the change in time-series images

A monitoring system with high data access accuracy and ease of usability

Goals

Numerical targets

- Improve the resolution of the robotic camera by 150%
- Decrease the error of the L-shaped scale display of the incline surface to less than 10%

Monitoring of girder end using robotic camera (Elevating Type)

users

Bridge administrators, construction consultants, etc.

How to use/Places of use

Regular monitoring of concrete bridges

Sales method

Robotic camera for bridge inspection has been sold by Hiatchi Industry & Control Solutions, Ltd. and SMC Civil Technology, Ltd., and distributed for bridge inspection. Moreover, it is not only for sale but also for rental.

GPS, digital camera, and laser scanner should be prepared by the user by purchasing or renting from the market.

Cloud service for storage system is provided by Hiatchi Industry & Control Solutions, Ltd. and other service companies.

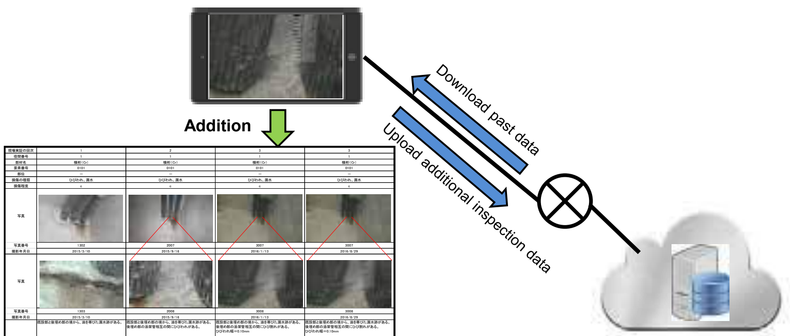
Services to Offer

- The instrument for monitoring, consisting of robotic camera, digital camera, and laser scanner, is provided.

➡ A proper inspection technique to monitor girder end and bearing can be selected.

- An Internet database system is set up which can store the deterioration data due to aging.

➡ The data can be referenced and edited by login to the system from the inspection site.



Inspection sheet (database)

Inspection database

Monitoring which is useful for detecting the indication and change of damage becomes possible.

➡ Realize a monitoring system with high data access accuracy and ease of usability

23 R&D of quantitative evaluation system of cracks on distant slabs by digital image analysis technology

Principal Investigator Kenichi Horiguchi (Taisei Corporation)

R&D Objectives and Subjects

Objectives

・Development of a system that can quantitatively evaluate the deterioration stage of road bridge slabs by image analysis

Conventional inspection of slabs

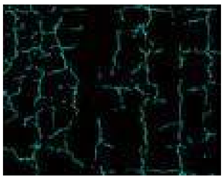

Conventional visual inspection

・Creating crack drawings by freehand
・Difficulty in quantitative evaluation of cracks
・Difficulty in inspecting distant and narrow spaces

Inspection of slabs by image analysis

・Automatic creation of accurate crack drawings
・Quantify the length for each crack width
・More efficient inspection of distant and narrow spaces


Photographing by UAV


Result of crack image analysis

Subjects (2014-2018)

・Development of digital imaging technology by UAV and pole
→ Realization of high-definition image shooting eliminating the influence of vibration

・Development of image analysis technology capable of extracting and quantitatively evaluating planar damage
→ Estimation of area of free lime and hidden crack width

・Image technology that can obtain analysis results quickly on site
→ Realization of faster processing using tablet PC


Image analysis by tablet PC

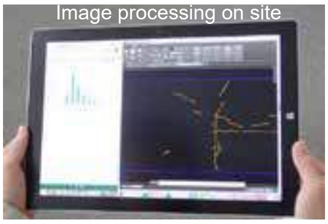


Image processing on site

Current Accomplishments (1/2)

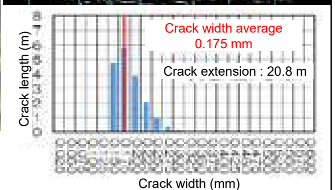
(2014-2016)

1. Shooting technique of distant and narrow spaces

Conventional inspection of bridge slabs is implemented by visual inspection and freehand drawing by inspectors. In this developed technology, it is possible to quantitatively calculate the width and length of cracks by creating a crack drawing from images taken with a digital camera mounted on a UAV or a pole.


Photographing by UAV


Result of crack image analysis

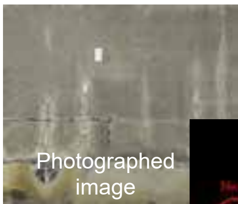


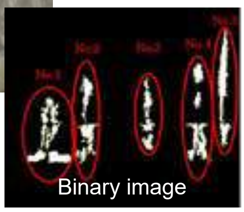
Crack length per width

・Possible to shoot distant and narrow spaces of slabs
・Accurate drawing of cracks from digital images
・Accurate calculation of crack width, length, and density
・Eliminate errors by inspector

2. Quantitative evaluation technique of planar damage

When free lime is generated in bridge slabs and covers cracks, cracks inside the free lime cannot be quantitatively evaluated. In this developed technology, the area of free lime can be quantitatively calculated from image analysis and the width of hidden cracks can be estimated.


Photographed image


Binary image

Free lime area

Group	Area (mm^2)
1	46579
2	34542
3	21731
4	36671
5	37659

・Free lime areas can be calculated by image analysis
・The width of cracks hidden by free lime can be estimated
・From the image analysis results of cracks, accurately evaluate the degradation stage of slabs

Utilization examples

・Investigation of places using areas under the high bridges as stores
・Investigation of places where installation of scaffolds is extremely difficult with remote island bridges


Urban Road (Store)

・Possible to free up investigation site in a short time
・Enables efficient shooting at sea

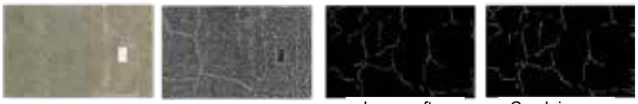
Current Accomplishments (2/2)

(2014-2016)

3. Rapid technology for image analysis processing

In the conventional inspection conducted by an inspector, it takes time to collect inspection data and draw freehand, and it was difficult to immediately obtain inspection results at the site.This developed technology can simplify image processing and can also be processed on a tablet PC, so that results can be obtained quickly on site.

Conventional method



Imput image — Wavelet transformation → Binary image — Noise removal → Image after crack discrimination — Crack image

Rapid method

Imput image (1.0 × 0.6m) — Trace image — Wavelet transformation → Crack image

	Conventional	Rapid
Noise removal Trace	52:20	06:30
Analysis time	02:46	01:37
Total	55:06	08:07

- Significantly improved speed of image analysis processing
- Possible to show inspection results at the site

Flow of utilization

1. Shooting of distant and narrow spaces
2. Quantitative evaluation of cracks
3. Quantitative evaluation of free lime
4. Summarize quantitative evaluation results
5. Evaluation of relationship with damage level of slabs

Realization of quantitative evaluation of damage level of bridge slabs

Goals

Numerical target

Among inspections of 500,000 small and medium-sized bridges, realize more than 1% share

Users

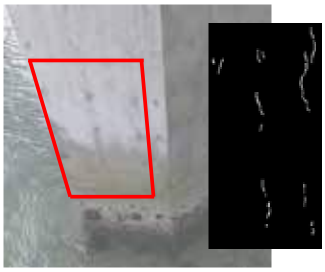
Inspection company of structure, local government, especially municipalities

How to use/Places of use

1) Selling system packages to inspection companies
2) Analysis agency businesses utilizing cloud function

【Efforts toward practical application 】

Usability evaluation by structure inspection company



A trial example of detection of cracks in video provided by University of the Ryukyus

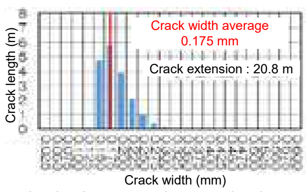
Sales method

System change to an easy-to-use interface → Technical support to inspectors, analysis agency businesses utilizing cloud function → Management of inspection data agency business

Services to Offer

Provide data that quantitatively evaluate damage stage of road bridge slabs

Choose the appropriate shooting method



Quantitatively grasp the cracked quantity

Damage Level	Criteria of crack width	Image analysis result
a	0.05mm	・Crack width, length, density ・Calculation of crack width from free lime area
b	0.10mm	
c	0.20mm	

Accurately grasp the damage level of the bridge slab

Possible to quantitatively evaluate the degree of damage of bridge slabs which was difficult in the past

→ Provide information for checking and prioritizing countermeasures and maintenance

(1) Inspection, Monitoring and Diagnostics
(2) Structural Materials,Deterioration Mechanisms, Repairs, and Reinforcement
(3) Information and Communications
(4) Robotics
(5) Asset Management

24 Field Validation of the Continuous Remote Monitoring System with Power saving Wireless Sensor

Principal Investigator Hideshi Nishida (Omron Social Solutions Co., Ltd.)

Collaborative Research Groups Tokyo Institute of Technology

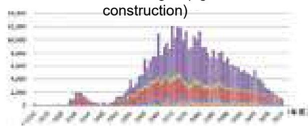
R&D Objectives and Subjects

Objectives

To realize an advanced maintenance and management system with easy installation and acquisition of objective information.

Problem-solving in inspection

Number of Bridges (age of construction) ※



- Visual inspection every five years
- Number of bridges (690,000)
- Deterioration of bridges (mean age 35 years)

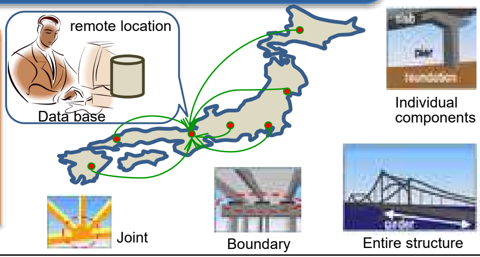
- Engineer shortage
- Difficulty with access
- Prioritization at disaster

⇩

- Omissions
- Drop of the maintenance level

Remote Monitoring System

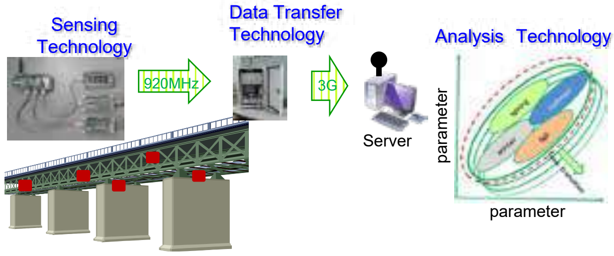
- Easy installation
- Remote monitoring
- Capture of slight change
- Offer simple information



※Source: Home page of "Ministry of Land, Infrastructure, Transport and Tourism, Kinki Regional Development Bureau"

Subjects (2014-2018)

- Sensing technology for outdoor installation with low power
  →Long-term reliability. (Battery life over 5 years)
- Data transfer technology (Wireless)
  → Easy installation and efficient remote monitoring.
- Data analysis technology
  → Indexing of the various types of deterioration damage.
  (Creation of Characteristic Chart for target bridge)



Current Accomplishments (1/2)

(2014-2016)

1. Built a Monitoring System on Real Site

Sensing Technology

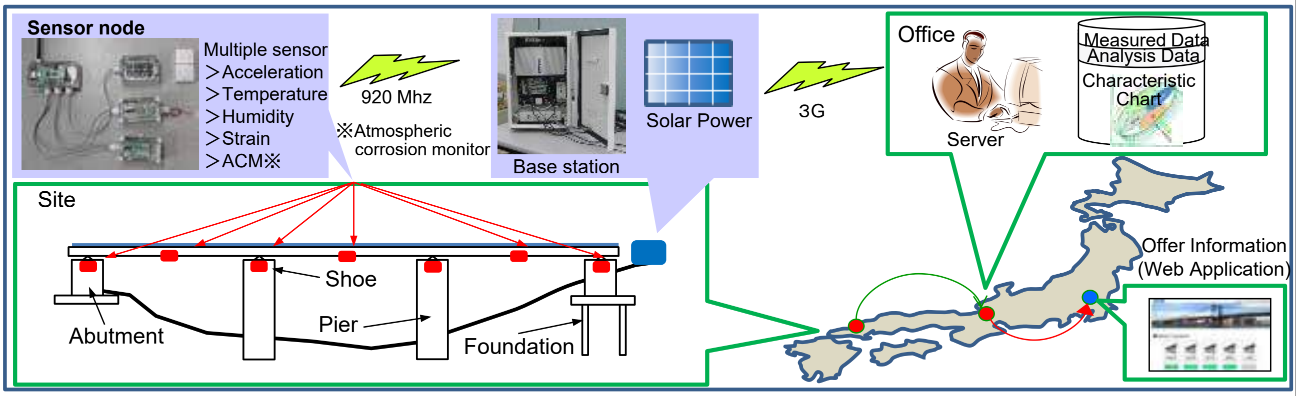
- Implement 31 sensor nodes on real site. (Power-saving wireless)
- Good prospect for long operation over 5 years with Li battery. (5 minutes x 3 times / day)

Data Transfer Technology

- Implement a Base Station on real site.
- Operational experience with only solar power. (continuous working result : over 1 year)
- Good quality of 920 MHz Wireless (230m length)
- Time synchronization under 1 msec (GPS)

Analysis Technology

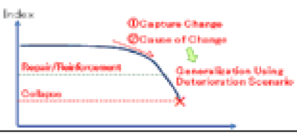
- Implement a Server at remote location.
- Data storage over 1 year
- Start offering Characteristic Chart



- Realize a remote monitoring system with Easy installation and Long-term usage without power distribution work.
- Realize sensor data indexing enabling understanding of the state of the bridge without professional knowledge.

Utilization example

Remote monitoring of damage and deterioration of the bridge



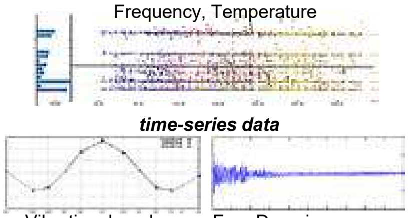
Enable proactive maintenance of the bridge by monitoring slight changes in evaluation indexes.

Current Accomplishments (2/2)

(2014-2016)

2. Acceleration Data

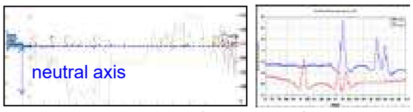
Practical use of Frequency, Damping Ratio, Shape of vibrational mode as health index.



Capture the behavior of entire structure or individual components quantitatively.

3. Strain Data

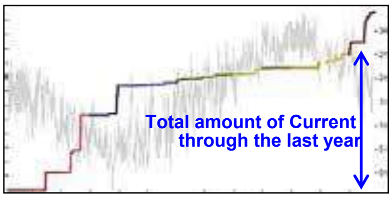
- Practical use of self-power generation piezoelectric strain sensor.
- The validity evaluation of index:
  ①Calculation of neutral axis
  ②Calculation of live load (input for the bridge)



Capture the deteriorations related to crack or stiffness reduction quantitatively.

4. Corrosion Data

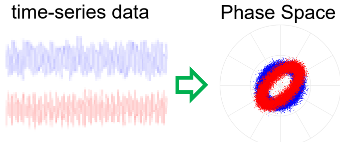
Trend of corrosive environment index
＝Investigation result of real site
(Board Thickness Decrement)



Presume the position and the time of corrosion degradation quantitatively.

5. Analysis Technology

Time-series data are analyzed to evaluate structural characteristics and condition changes in target bridge. One of the applied damage evaluation methods is phase space topology.
Time-series data are converted to phase space and changes in phase space are monitored.



Detect the time, position, and level of the damage when it happens.

Flow of utilization

Presume the deterioration scenario of the target bridge, by site investigation and structure analysis.

Determination of needed sensors and indexes
- 2. Acceleration Data
- 3. Strain Data
- 4. Corrosion Data
- 5. Analysis Technology

1.Built a Monitoring System on Real Site

Realize optimum monitoring system for the target bridge

Goals

Numerical targets

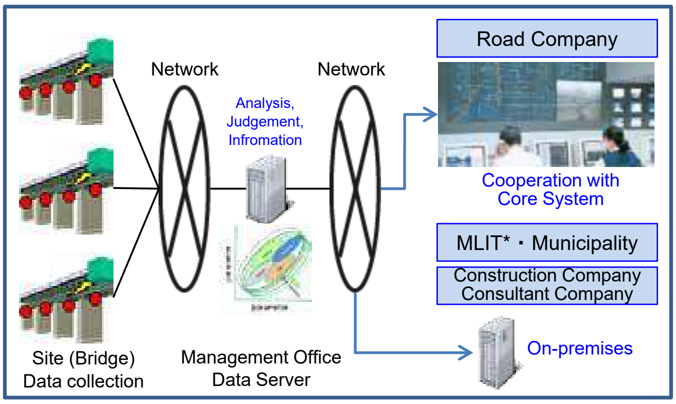
To implement sensor system that can be operated over 5 years with battery.
To implement Monitoring menu that is easy to understand and use.

users

Road Companies (Highway, MLIT*, Municipality) etc

how to use/Places of use

- Install sensors in the local bridge needs monitoring.
- Store the sensor data at management office.
- Monitor the analysis information at maintenance office.



Sales method

Omron Social Solutions Co., Ltd.
Monitoring Proposal, System Offering
→ Construction Company: Monitoring before and after construction.
Consultant Company: Assistance of operation and maintenance
→ Road Manager (Road Company / MLIT, Municipality)

* Ministry of Land, Infrastructure and Transport

Services to Offer

Consultant Assist			System Offer	Consulting
Realization of Customer Problem →	Monitoring Proposal →	Operation Proposal →	System Sales ⇔	Management Support

Value provided → Enable to
- Optimize LCC.
- Speedup recovery operation at the time of disaster.
- Judge repair method Quantitatively by visual control.
- Monitoring between inspection cycles.

Realize
- Reduction of economic losses.
- Proactive safety plan.
- Gain in social confidence.

25 R&D of the technology which monitors the displacement rate of a manmade structure with high accuracy and efficiency

Principal Investigator Minoru Murata (NEC Corporation)

Collaborative Research Groups Obayashi Corporation

R&D Objectives and Subjects

Objectives

・Development of technology which monitors the displacement rate of infrastructures in a wide area (manmade structures such as bridges) with high accuracy and efficiency

Conventional Infrastructure Inspection

- Grasp the degradation by close visual inspection.
- Grasp the degradation by hammering test.
- Measure the distortion by sensors.

Requires a lot of time and costs (problem).

Infrastructure Monitoring by Satellite SAR

- Can extract a point for inspecting infrastructures in a wide area.
- Higher density measurement than the point leveling.
- High accuracy measurement (mm/year).
- Can measure ground deformation around the area.

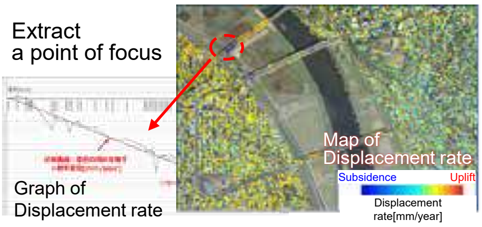
Synthetic Aperture Radar (SAR)

Can identify an inspection object with high priority (screening).

Subjects (2014-2015)

・Analyze satellite image data of target bridge.
→ Check the displacement rate (mm/year) at multiple points on a bridge.
→ Check the ground displacement (subsidence/uplift) around a bridge.

・Confirm measurement accuracy by verification experiments.
→ Measure and verify the displacement by placing a reflector at a test site (error: Approx. 0.5 - 1 mm).



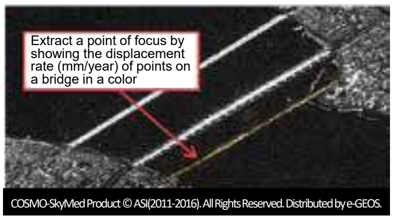
Current Accomplishments (1/2)

(2014-2015)

1. Displacement rate of Bridge

Analyze SAR image of a wide area to measure the displacement rate of a bridge within the area at once.

Overlay analysis results to show the displacement rate in a color.



Wide Area/High Density Monitoring

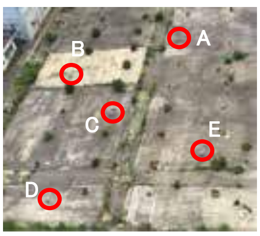
・Extract an abnormal part of manmade structures such as bridges.
・Extract a point of focus for close visual inspection.

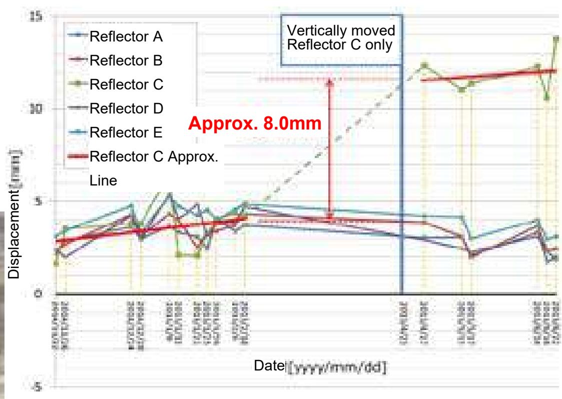
2. Accuracy Verification

Conducted accuracy verification of this method at NEC test site.
・According to the calculation result of Reflector C movement (approx. 8.0 mm), the accuracy of this method is 0.5 to 1.0 mm.

Artificial Reflector

Reflectors (A – E) placed at NEC test site





High Accuracy Monitoring

・Measure artificial structures such as a bridge to an accuracy of millimeters.

Utilization Example

Earthquake-resistant land promotion project
(Large-scale filled development land screening)

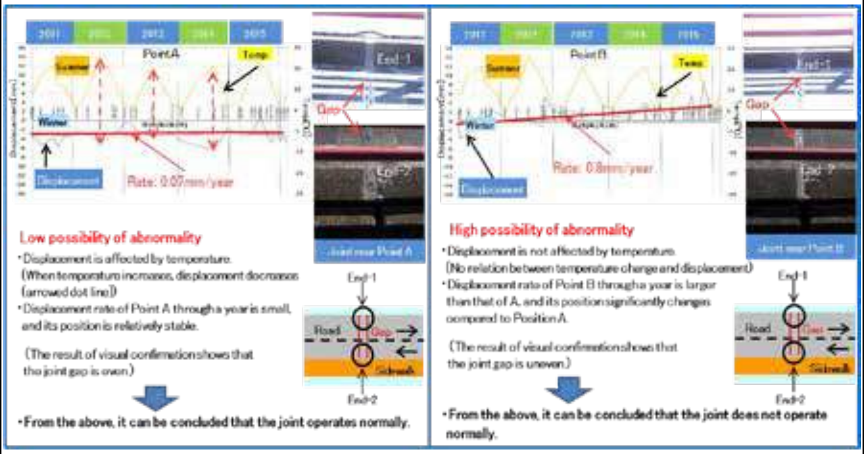
Provide a quantitative criteria for specifying a dangerous location (secondary screening). (Substantially reduce the burden at a site.)

Current Accomplishments (2/2)

(2014-2015)

3. Detailed Analysis of Measurement Point on Bridge

Analyzed the relation between displacement and temperature of a measurement point on a bridge. (Period: April 2011 to February 2016)



Monitoring which reduces the burden at a site

- NEC's own image analysis technology allows the detection of possible defect on a bridge. (Since it is unnecessary to set up a measuring device at a site, approval for use of road and traffic control are not required.)
- Measure the surrounding area of a target structure at one time at high density (including private land).

Flow of utilization
(Periodic inspection of bridge)

Inspection Plan

Utilize this achievement

Screening (Achievement 1, 2, 3)
(Minimize life cycle cost by prioritization)

Close Visual Inspection

Grasp damage situation

Record periodic inspection result

Maintenance and Repair Plan
(Minimize a life cycle cost)

Achieve screening of multiple bridges in a wide area, prioritization, and selecting of point of focus.

Goals

Numeric Target

Achieve 30% of application rate to subsidence screening.

Users

Local governments, Highway companies, Railway companies, General contractors, etc.

How to use/Places of use

Analyze SAR images of an area which contains various infrastructures specified by a user and provide information of the displacement rate of the infrastructure.

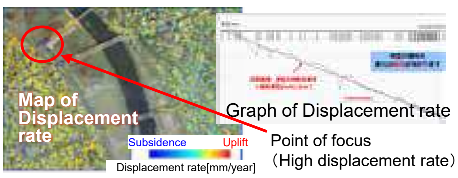
No	Scene	Application
1	Bridge Inspection	Screening (priority of close visual inspection)
		Displacement with age monitoring (fixed point monitoring, forecast)
2	Large-scale filled developed land monitoring	Screening of filled developed land (Specify dangerous area)
3	Slope monitoring	Security for highway, etc.
4	Subsidence monitoring	Effect of tunnel construction (shield work)
		Uneven settling of buildings
		Uneven settling of airport/port
		Subsidence of commercial facilities (filled ground)
		Uneven settling of plant/outdoor tank
5	Monitoring of facilities, buildings, houses	Select facilities, etc. which are in danger of collapsing at the time of disaster. -> Preventive maintenance
6	Deterrence to improper construction	Monitor the health of construction (piling, etc.)
7	Monitoring of effect of strengthening work	Monitor the health after construction.

Sales Method

A target user specifies infrastructures to be measured and measurement period. ▶ Analyze SAR images which contain the infrastructure and measure the displacement rate. ▶ Provide a report or GIS data to the user.

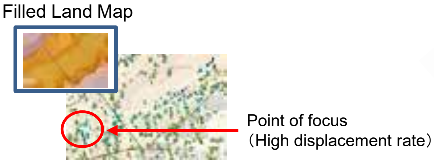
Services to Offer

Provide data of displacement rate of infrastructures (bridge, large-scale filled development land, ground over shield work, etc.)



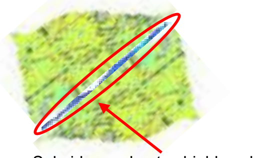
Bridge inspection service

Filled Land Map



Overlay displacement rate data on a map.

Large-scale filled development land monitoring service



Subsidence monitoring service

Can provide highly accurate and efficient infrastructure monitoring which has not been obtained by various sensors, close visual inspection, or leveling.

→ Achieve advanced preventive maintenance of infrastructure.

26 R&D of Monitoring System for Detecting Surface Failure by pore pressure sensor with inclinometer

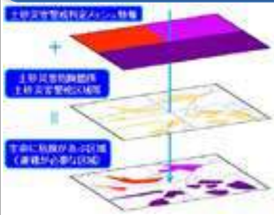
Principal Investigator Yasunori Shoji (OYO Corporation)

R&D Objectives and Subjects

Objectives

・Development of a monitoring system for detecting surface failure in-situ and transferring the data and alert to governments and residents.

Current technologies

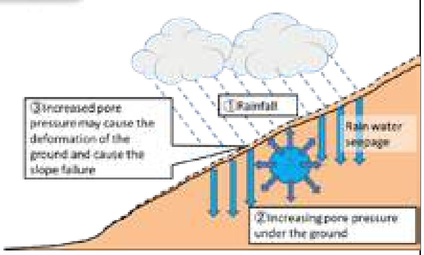


(Referred from JMA's web page)

- Monitoring rainfall only.
- Hard to detect surface failure locally.

Newly developed technology

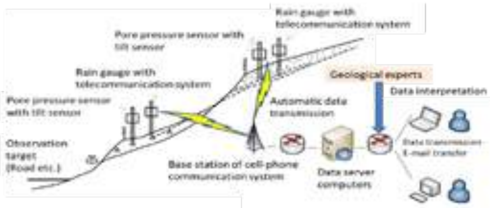
- Monitoring
  1) Rainfall,
  2) Pore pressure and
  3) Tilt of the slopes simultaneously.
- Suitable for detecting surface failure locally.



Subjects (2014-2016)

- System for monitoring ①Rainfall, ②Pore pressure, and ③Tilt of the slope simultaneously and transferring the data and alerts automatically to any place.

→ Providing one-stop service of determining suitable monitoring locations, designing the system, installation, and achieving data transfer .



Current Accomplishments (1/2)

(2014-2016)

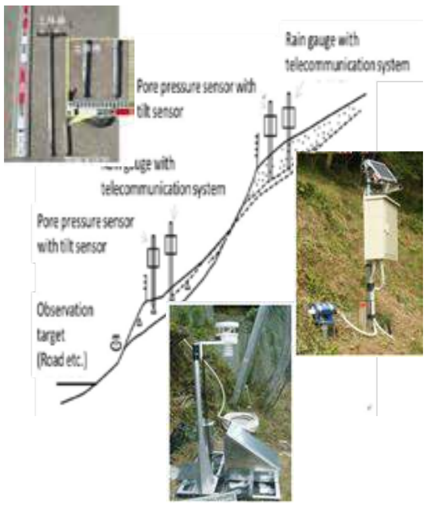
1. Determining monitoring locations

- The thickness and geology of the surface layer is investigated by using the Soil Layer Strength Rod developed by PWRI. Then suitable measurement locations are selected.

・Suitable monitoring location can be selected according to geological condition.

2. Packaged system

- Composed of
  ①Rain gauge,
  ②Pore pressure sensor,
  ③Tilt sensor,
  wireless communication system, and power unit.
- Verification test on a slope near a national road is ongoing from October, 2015.
- We confirmed the verification test is operating normally as of December, 2016.
- At the moment, there is no evidence of slope failure at the observation point.



・The monitoring system was established.
・A monitoring system using an external power supply is not required.

Utilization example

Early warning data of slope failure will be transferred to public administrators and residents.

Early evacuation can be carried out and slope failure hazards can be mitigated.

Current Accomplishments (2/2)

(2014-2016)

3. Easy data acquisition, transfer, and display

The process of acquiring data, transferring the data, and issuing alert to public administrators and residents is automated.

Data center (image)

- Alert message is transferred by e-mail according to data.
- Message can be sent to cellular phone and PC by internet.
- Threshold level can be set at three levels at maximum.
- Message can be sent to 20 users at maximum simultaneously.

＊The message is subject to change.

- Easy to investigate the status of the slope at the monitoring point
- Can be customized to combine the data with a digital map to visualize the data for easy understanding.

Flow of utilization

1. Determining the monitoring location
2. Packaged system
3. Easy data acquisition, transfer, and display

The system, which can detect the status of the slope at an early stage of the failure, is established.

The system can contribute to conduct early evacuation and mitigate the slope failure hazards.

Goals

Numerical targets

- Reduce cost by 20% compared to the current system
- One-stop service that reduces time by 30% from installation to data acquisition.

Users

Public administrators of local governments, road administrators, residents, etc.

How to use/Places of use

Places of use are slopes along roads and resident areas.

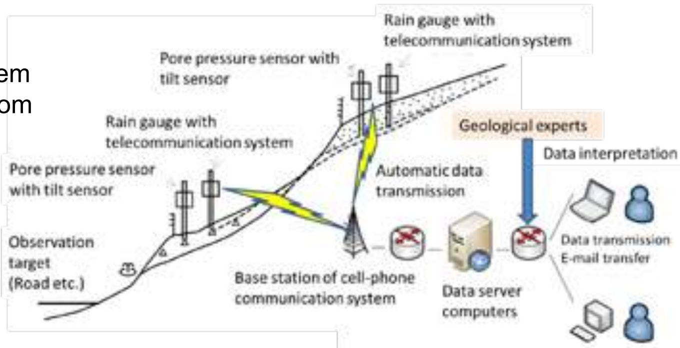


Image of the operation of monitoring system after implemented.

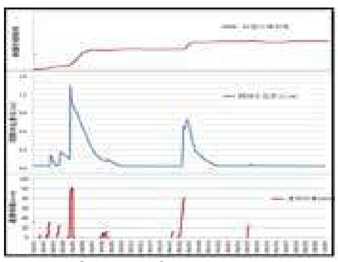
Sales method

Subcontract to consultants. → Prime consultant, who conducts Geological investigation experiments, enables one-stop service planning. → Providing one-stop service of determining suitable monitoring locations, designing the system, installation, acquiring the data, transferring

Services to Offer

Providing one-stop service of determining suitable monitoring locations, designing the system, installation, acquisition and transfer of data.

Location of the alerted slopes



Status of the slopes

The system can give status information of the slopes in real time in an easily understandable way.

→ Early evacuation reduces slope failure hazards.

27 R&D of Early Warning Monitoring System of Slope Failure using Multi-point Tilt Change and Volumetric Water Content

Principal Investigator Lin Wang (Chuo Kaihatsu Corporation)

R&D Objectives and Subjects

Objectives

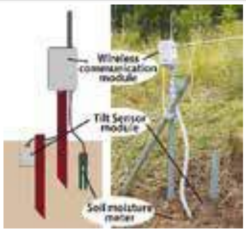
Research and develop a highly accurate, multi-point early-warning system for slope failure using low-cost tilt sensors.

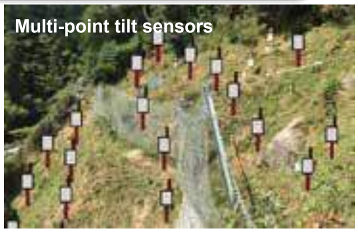
Extensometer

- Difficult to install.
- Expensive to set up numerous units on a single slope.
- Sensitive only to regional movement.

Multi-point Monitoring System using Tilt Sensor

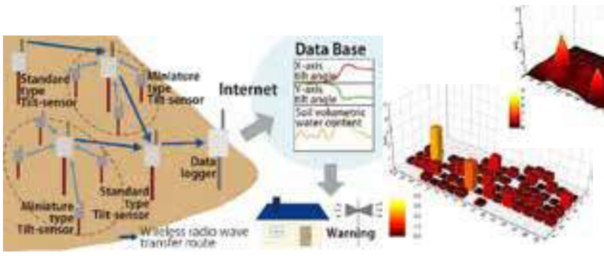
- Easy to install.
- Low cost of equipment and installation.
- Sensitive to movement of whole area.





Subjects (2014-2016)

- Low-cost, easily-installed tilt sensors.
  ⇒ Realized low cost multi-point measurement.
- Prediction of slope deformation by multi-point measurements.
  ⇒ Realized high-precision, stable, early warning slope failure system.



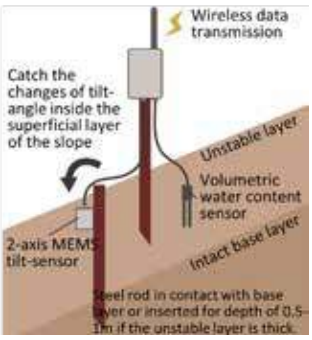
3D analysis of slope movement

Current Accomplishments (1/2)

(2014-2016)

1. Easy installation

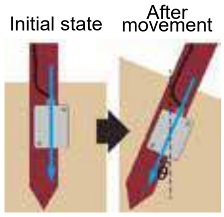
Effective, rapid, and convenient installation of sensors by inserting a steel pole into the slope and affixing the sensor module.

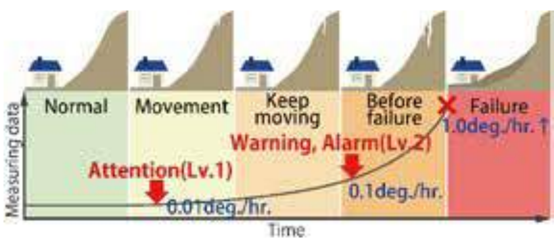


In-field efficiency

2. Established method of evaluating risk and warnings for a dangerous slope

Based on detected behavior and by adopting a conservative approach, it is proposed that a precaution for slope failure be issued when the tilt rate reaches 0.01° per hour and a warning of slope failure be issued at a tilt rate of 0.1° per hour.

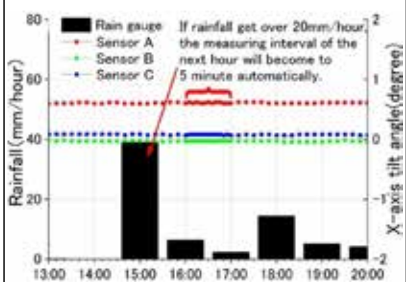




Real-time quantification of slope risk

3. Risk-based automation of measurement interval

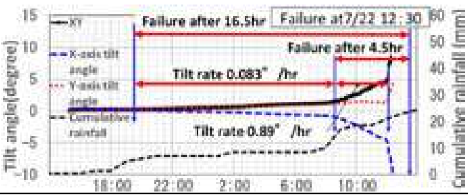
The risk of slope failure increases during heavy rainfall, and thus the system is set up to automatically shorten the time interval (an optional setting) of measurement when rainfall exceeds 20 mm per hour.



Improved accuracy

Utilization example

At other field sites, the tilt rate increased toward failure within a relatively short time before slope failure. Tilt rate is thus inversely proportional to the remaining time until failure.



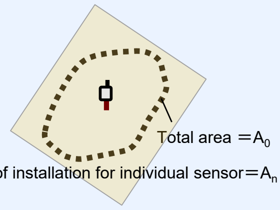
Early warning can be issued based on the relationship between tilt rate and remaining time to failure.

Current Accomplishments (2/2)

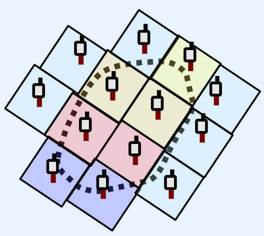
(2014-2016)

4. Construction of a stable early warning system using multi-point measurements

1 Single sensor ⇒ False warning issue can easily be caused by local movement, animal contact, etc.:



Suitable sensor intervals for multi-point measurement reduces the coverage of each sensor, thus improving system accuracy :

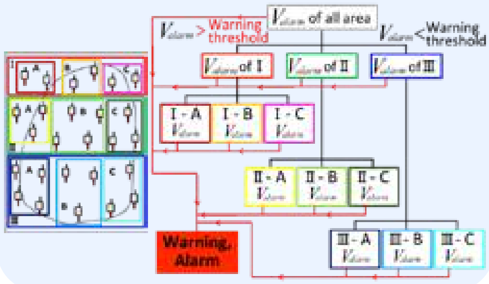


2 Warning threshold based on behavior of multiple sensors:

$$V_{alarm} = \sum_{n=1}^{N}\left(\left|V_n\right| \times \frac{A_n}{A_0} \times \partial_n\right)$$

V_n = Tilt rate (X-axis) of each sensor (deg./hr.), If >1.0, V_n=1.0.
A_n = Area of installation for individual sensor.
A_0 = Total area of installed sensor array.
∂_n = Coefficient to be decided by the geological, soil, and vegetation conditions at installation point.

3 Reliable management of warning issuance based on numerous monitoring zones and multi-point measurements :



Realized high-precision and stable early-warning system for slope failure

Flow of utilization

1. Easy installation
2. Established method of evaluating risk and warnings for a dangerous slope
3. Risk-based automation of measurement interval
4. Construction of a stable early warning system using multi-point measurements

Realized early-warning system based on spatial and temporal analysis of entire slope behavior

Goals

Slope Failure Early-Warning Monitoring System Based on Multi-point Tilt Measurement and Water Content

Technical Service

- Early warning of slope failure
- Prevention of secondary disaster
- Assess pre-failure phenomena of slopes
- Dynamic monitoring of landslides in mountainous areas
- Application to Internet of Things and trends in Big data

Numerical targets

- Installation time reduction of about 60%.
- Economic improvement of about 40% by reducing equipment and installation costs.

Users

Local autonomies, Regional Bureaus of MLIT, Private businesses, International supporting organizations, etc.

Places of use

To fulfill a role of early warning for disaster prevention by using the results of research and develop for natural slope, road works, cutting slope works, and rock fall.

High-precision and stable early-warning system for slope failure.

→Realized early-warning system based on spatial and temporal analysis of entire slope behavior.

28 Mole (Small Animals) Hole Detection System Attached to Large Weeding Machine

Principal Investigator Kiyoshi Suzuki (Aero Asahi Corporation)

R&D Objectives and Subjects

Objectives

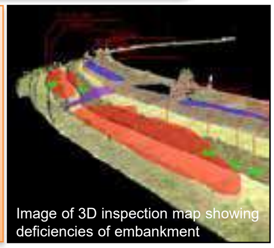
Development of a monitoring system for the advancement on inspection of embankment utilizing the measuring system attached to a large weeding machine .

Conventional Inspection

- Inspections on foot consume time and labor, despite shortage of field workers.
- Inspection accuracy depends on inspector's experience.
- Unable to conduct accurate and detailed survey, obstructed by vegetation on surface.

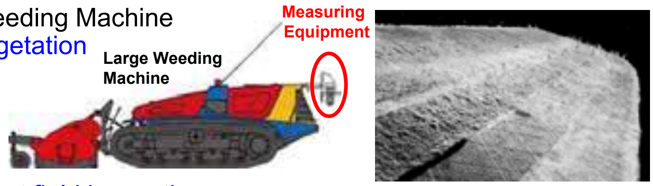
Inspection by the New Monitoring System

- Conduct more efficient inspection and save time and effort.
- Inspect embankment more objectively and quantitatively due to detailed terrain data.
- Detailed survey of embankment will be conducted continuously at low cost.



Subjects (2014-2016)

- ●Measuring Equipment easily attachable to Large Weeding Machine
  →Conduct accurate measurement unaffected by vegetation
- ●Automatic Detection System
  →Detect deficiencies automatically and provide the information quickly.
- ●Embankment Monitoring System
  → Provide the results of deficiency analysis to support field inspection

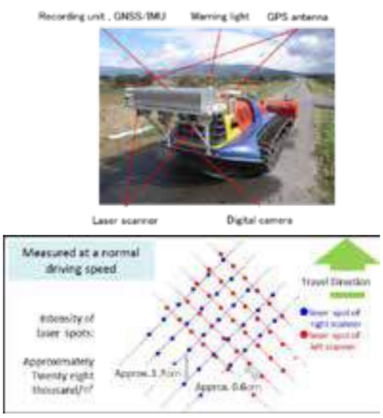


Current Accomplishments (1/2)

(2014-2016)

1. Measuring Equipment

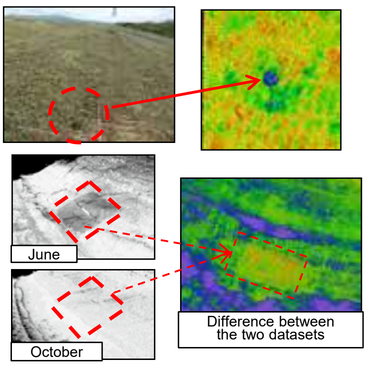
- Developed measuring equipment that can be easily attached to the rear of a large weeding machine.



- Acquire high-resolution terrain data simultaneously with weeding.
- Accurate and detailed measurement of embankment unaffected by vegetation

2. Detection Accuracy

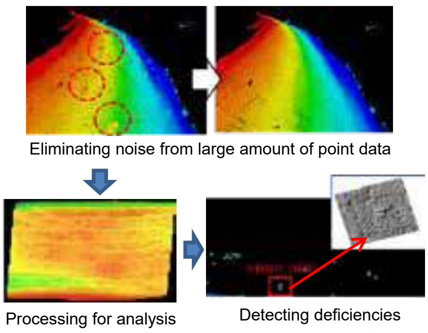
- Able to detect from small- to large-scale deficiencies ,such as mole hole to depression of slope.
- Detection accuracy is superior to conventional visual inspection.



- Small- to large-scale deficiencies are detectable.

3. Automatic Detection System

- Developed automatic detection system of deficiencies of embankment utilizing detailed terrain data.
- Processing time was reduced to 20 hours per km of embankment by a newly developed algorithm.

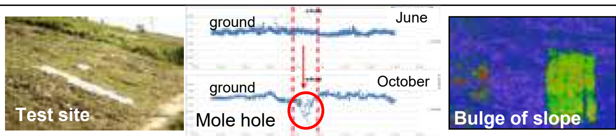


※image of simplified process of analysis

- Time- and effort-consuming detection was automated.
- Results of analysis can be provided quickly.

Utilization Example

The system detected deficiencies in a test field site.



The detection system is effective in actual field.

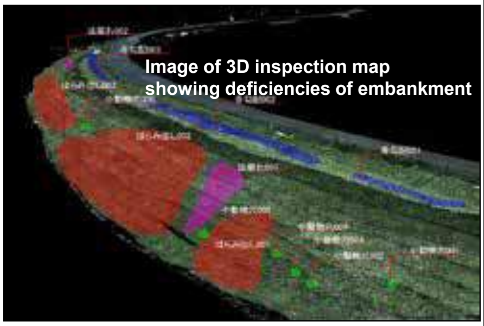
Current Accomplishments (2/2)

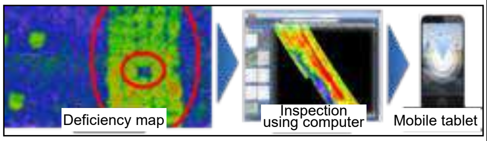
(2014-2016)

4. Field Inspection Support System

・Developed field inspection support system which provide information on deficiencies.

・Mobile tablet with AR function.
・Cloud-based computerized inspection system

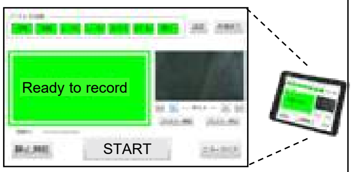




- Easier and more efficient field inspection
- More objective inspection not relying on inspector's experience.
- Upgrading future monitoring system of river embankment by a database of detailed terrain data and inspection results .

5. User -Friendly Operation

- Neither expert knowledge nor skill is necessary for the measurement.
- Weeding operation is not hindered, as minimum operator interaction is necessary for measurement.



・touch panel operating device (tablet or smartphone)
・user-friendly operation.
・easy-to-understand operating manual

・no operation necessary during weeding
・can be used in light rain

・Easy to introduce to the field

Flow of utilization

1. Measuring Equipment
2. Detection Accuracy
3. Automatic Detection System
4. Field Inspection Support System
5. User -Friendly Operation

○Accurate and detailed measurement of embankment will be continued at low cost.

○ICT introduction to the field inspection will upgrade the future monitoring system of embankment.

Goals

Numerical target

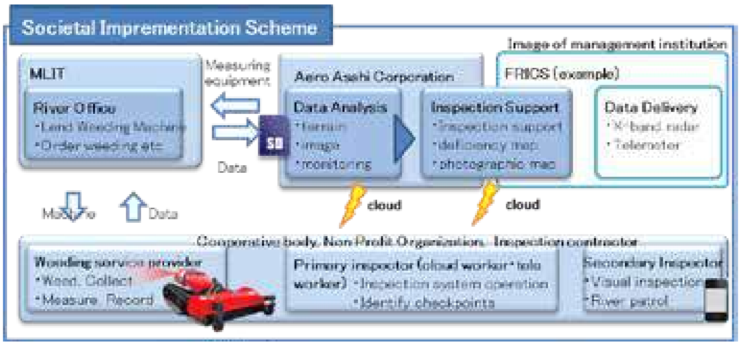
・Detection rate of deficiencies: 90%
・Lead time of measurement and analysis: 24 hour/km
・Installation of the measuring equipment to Large Weeding Machine: 100%

Users

River administrators, Weeding-service providers, etc.

How to use/Places of use

Measurements are carried out nationwide every year. Information of detailed terrain data and inspection results of the embankment will be stored in a database and provided to users.



Sales method

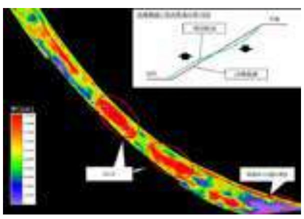
Measurements are conducted nationwide. Measurement

・Sale or rental of the equipment
・Provide analysis services
・Inspection system royalty, etc. Profit Creation

Inspection system operation through the Internet ,etc.
・cloud workers
・senior citizens etc. Job Creation

Services to Offer

Sale or rental of the equipment



Data analysis service

Field inspection support service

Upgrading the maintenance system of embankment

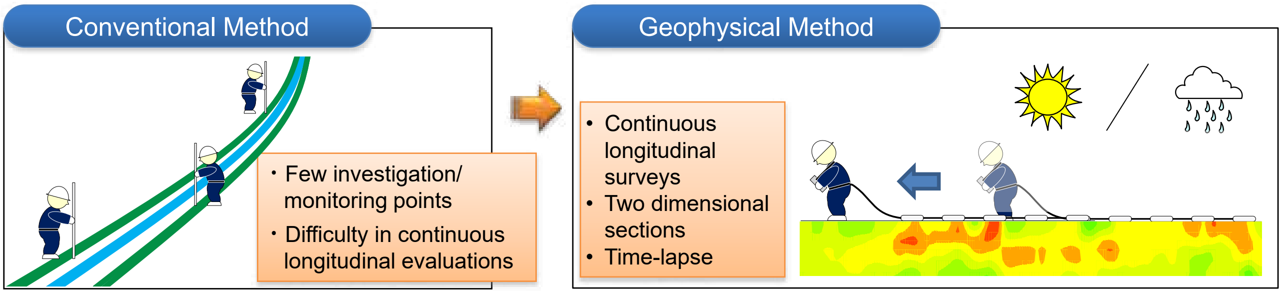
29•32 R&D of "Electric resistivity monitoring system for the state of water contents in river levee" and "Monitoring system for internal state of river levee utilizing geophysical exploration and ground water observation"

Principal Investigator Hideki Saito and Akira Shinsei (Oyo Corporation)

R&D Objectives and Subjects

Objectives

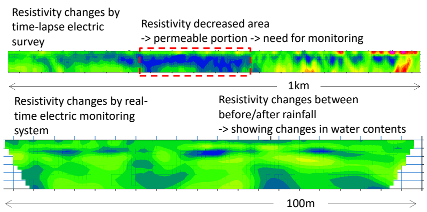
・Development of a screening method to determine priority observation location in case of flooding and a monitoring method for status changes in river levee.



Subjects (2014-2016)

・Development of an interpretation technique for time-lapse geophysical data..
→ Concentration on priority areas for observation in case of flooding.

・Development of an observation method for internal state changes by flooding.
→ Monitoring changes of water content in the levee in case of flooding.

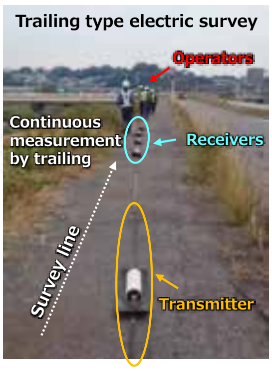


Current Accomplishments (1/2) (2014-2016)

1. Time-lapse electric surveys

Trailing type electric survey is used because of its efficiency for long lines.

Flexibly responding survey can be conducted after rainfall or small flooding.

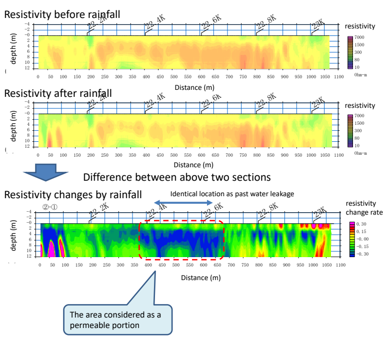


・quick and low-cost surveys
・continuous longitudinal evaluation

2. Priority observation area

Creating a resistivity change section from before/after electric surveys.

Resistivity decreased area is considered to be a permeable portion.

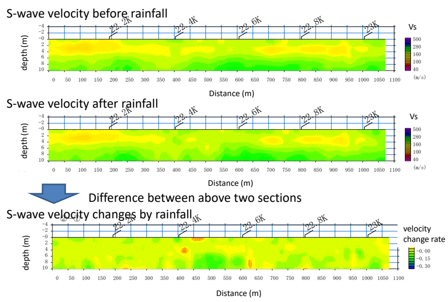


・resistivity decreased area detected
・the area should be monitored in case of flooding

3. Time-lapse MASW

Land-streamer type system is used because of its efficiency for long lines.

Decreased S-wave velocity area is considered to be a loosened portion.



・2D section of Vs changes by rainfall
・Vs must be decreased by loosening of levee body suffered from flooding

Utilization example

350m area out of 1 km was pointed out as the location to be monitored during flooding

It is possible to point out the area that should be monitored in case of flooding by time-lapse electric survey

Current Accomplishments (2/2)

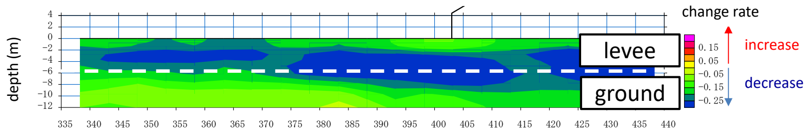
(2014-2016)

4. Clarify the internal state of levee

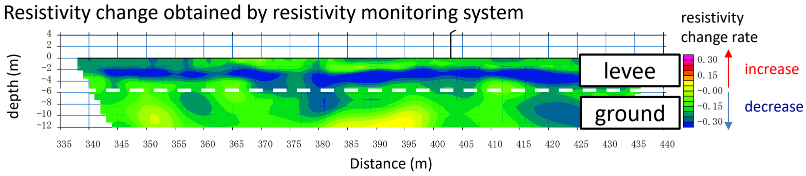
Resistivity changes show water contents inside the levee body
* Trailing system was confirmed to be useful compared with monitoring system

S-wave velocity changes show the existence of loosening portion in the levee
*The loosening of levee was not observed during this R&D period.

Resistivity change obtained by trailing type electric survey



Resistivity change obtained by resistivity monitoring system



Applicability of trailing type electric survey was confirmed by comparison with high resolution resistivity monitoring system

- Change of water content in a levee body due to flooding can be clarified.
- Loosening of a river levee due to flooding can be clarified.

Flow of utilization

1. Time-lapse electric survey
2. Priority observation area

Priority observation during flooding

3. Geophysical survey after flooding
4. Clarify the internal states

Efficiency in flood prevention and maintenance

Goals

Numerical target

Efficiency in monitoring locations determined by the method.
Goal to reduce costs for patrol by 10%.

Users

River administrators

How to use/Places for use

Conducting geophysical surveys in the same line of river levee before and after rainfall or small flooding.

Land streamer type surface wave survey

Trailing type electric survey

Sales method

Electric and seismic surface wave surveys conducted by geophysicists. → Interpretation and consultation by river engineers → Flood prevention and maintenance by river administrators

Services to offer

Geophysical surveys in a longitudinal direction

Time–lapse geophysical surveys before/after rainfall or flooding

Determine the location to be monitored

Clarify the changes of internal states of levee body due to flooding

Utilize in flood prevention and maintenance

Determining the monitoring location in case of flooding and providing changes in the states of levee after flooding

→ It can be applicable to other fields, including slopes, reclaimed land, etc.

30 R&D of monitoring system including a detection of river levee deformation

Principal Investigator Shunsuke Sako (Japan Institute of Country-ology and Engineering, General Incorporated Foundation)

Collaborative Research Groups Consisted of three Japanese bodies; PHOTONIC SENSING CONSORTIUM for Safety and Security, SAKATA DENKI Co., Ltd., KITAC CORPORATION

R&D Objectives and Subjects

Objectives

Conventional levee inspection

- **Identify deformation by visual inspection on foot.**

<Issues>

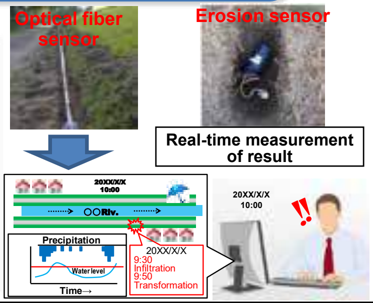
- Difficulty in detecting deformation depending on the frequency of weeding or weather conditions.
- Securing personnel for inspection, which is likely to become more challenging from now on

Development of new inspection technology

- **Identify levee deformation with optical sensor or erosion sensor**

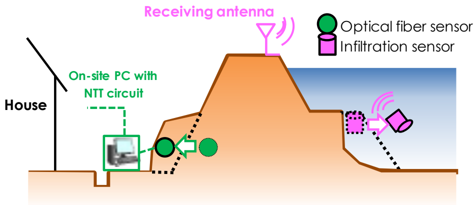
<Merits>

- Available to identify minute deformation of a levee body quantitatively
- Available to measure the result in real time with a monitoring system



Subjects (2014-2018)

- If part of of levee transfers or transforms at a position where an optical fiber sensor is installed, the sensor follows the movement and measures the location having the deformation and the damage level of the levee in real time.
- Detect erosion and corrosion by a posture change of an erosion sensor, and notify it from underground/water in real time by a low-frequency electromagnetic wave. Conduct measurement of the location of erosion in real time.



→ While not requiring visual inspection, realize a monitoring system that allows measurement of levee deformation due to infiltration or erosion.

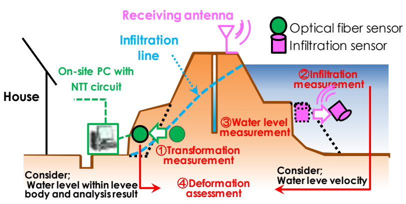
Current Accomplishments (1/2)

(2014-2016)

1. Developing Monitoring System for Levee Deformation with Sensor Devices

Operations undertaken at a levee along the Shonai-River;

① Measurement/organization with an optical fiber sensor
② Measurement/organization with an erosion sensor
③ Measurement of water level within levee body
④ Evaluation of deformation identified with sensor devices
⑤ Development of system

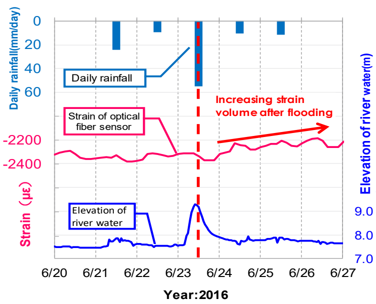


- Realized the monitoring of levee deformation with an optical fiber sensor and an erosion sensor

2. Measuring Levee Deformation with Optical Fiber Sensor

Conducted measurement of levee deformation (strain) with the optical fiber sensor.

The strain grew in a compressed direction accompanying an increase in precipitation or water level.

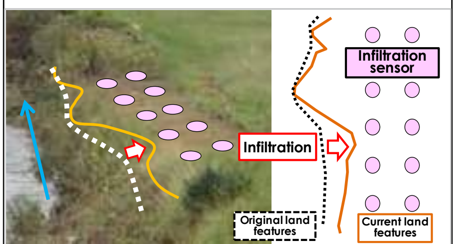


- Realized identification of the transformation of levee body (transfer of the levee body) accompanying flooding with the optical fiber sensor

3. Measuring Levee Deformation with Erosion Sensor

Conducted measurement of the levee deformation (the presence of erosion) with the erosion sensor.

Accompanying flooding, the water level increased by exceeding the height of the erosion sensor installed. The erosion extended to a length of approx. 50 cm around the sensor. (Stopped just in front of the sensor location)



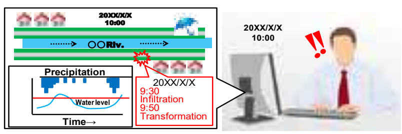
- Realized detection of erosion that occurred underwater with a wireless signal from the sensor device

Utilization example

1) Formerly: Patroller detects the deformation due to infiltration by visual inspection.

2) Formerly: Impossible for patroller to detect the erosion because it occurs under water.

Utilize to improve a certainty of river management and save work in terms of the following operations.



1) Quantitatively identify the deformation due to infiltration with the optical fiber sensor.
2) Identify the erosion phenomena caused under water with the erosion sensor.
3) Possible for administrator to identify the above deformation in real

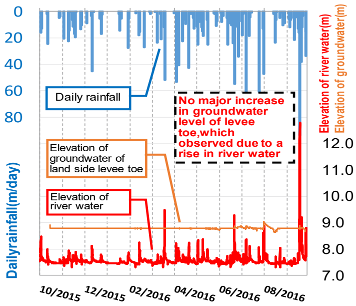
Current Accomplishments (2/2)

(2014-2016)

4. Measuring Water Level within Levee Body

Conducted the measurement of water level within the levee body.

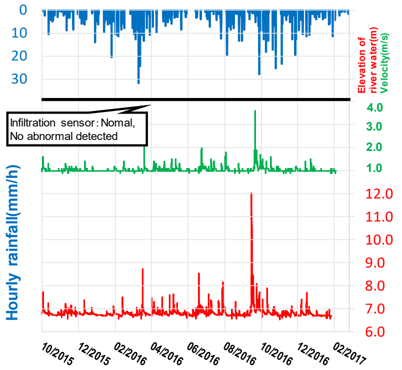
Focused on the phenomenon that levee deformation grows according to the water level within the levee body.



● No escalation of water level up to a saturated extent of levee as far as the flooding of this scale type

5. Evaluating Deformation Identified by Analysis Model

●Assessment of deformation due to erosion



●In Sep 2016, the velocity was around 3.6 m/s and the erosion caused at that time was approx. 50 cm. While the erosion sensor was running properly, nothing was detected.

●Assessment of deformation due to infiltration

With seepage analysis, trace a time history of growth of the infiltration line within the levee body by taking the precipitation and the river level when flooding as external forces.

Analsys item	Max value of local hydraulic grade		Heaving
	Vertical direction	Holizontal direction	
	iv	ih	G/W
Review criterion value	<0.5	<0.5	>1.0
Result	0.300	0.447	-
Judgment	**O.K.**	**O.K.**	

Compare with the measurement result of deformation/water level by optical fiber sensor and the analysis result.

●By developing the correlation diagram between the volume of strain measured with the optical fiber sensor as well as the water level within the levee body, we can identify the moisture condition inside of the levee body, which affects the levee deformation.

Practical Process Flow of Outcomes

1. Developing Monitoring System for Levee deformation with Sensor Devices
2. Measuring Levee Deformation with Optical Fiber Sensor
3. Measuring Levee Deformation with Erosion Sensor
4. Measuring Water Level within Levee Body
5. Comparative Verification of Measurement Results Derived from Analysis Model

Realize real-time and quantitative monitoring of levee deformation with an optical fiber sensor and an erosion sensor.

Goals

Numerical targets

Realize a cost reduction by 60% compared to that of the conventional visual inspection for the following flood fighting points;

- Critical flood fighting point A (38.6 km) against infiltration
- Critical flood fighting point A (84.0 km) against erosion

(For the case of LCC 10 years later)

Cost comparison list

	Visual inspection	Optical fiber sensor		Erosion sensor
Position installed	---	Three units	Single unit	Sensor: 10 m inerval Receiver: 100 m interval
Installment cost	---	¥112 mill	¥38 mill	¥60 mill
Maintenance cost(yr)	¥16 mill	¥3 mill	¥3 mill	¥1.12 mill
LCC of 5 yrs later	¥82 mill/5yrs	¥126 mill/5yrs	¥53 mill/5yrs	¥66 mill/5yrs
LCC of 10 yrs later	¥164 mill/10yrs	¥141 mill /10 yrs	¥68 mill /10 yrs	¥72 mill /10 yrs
Cost items	Labor cost	Materials + Construction + Labor cost		Materials + Construction + Labor cost
Availabilty of measurement	Impossible: At night or when covered with flourish vegitation	24 hrs, 365 days avaiable		24 hrs, 365 days avaiable

users

- ●Administrators of rivers under Ministry of Land, Infrastructure, Transport and Tourism
- ●Administrators of Class B rivers under prefectures
- ●Embankment administrators of railways or roads, etc.
- ●Observers of slope deformation, etc.

how to use/Places of use

●In order to monitor the deformation due to infiltration/erosion at rivers under direct control and Class B rivers under prefectures, install sensors at estimated critical flood fighting points.

Sales method

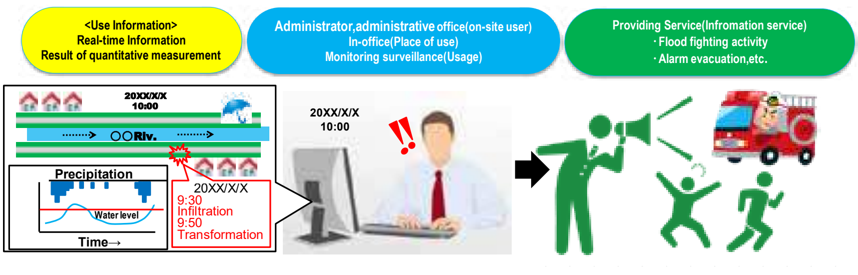
On the basis of the new technology developed, the administrator provides the information to citizens. By providing high quality information, the administrator earns the citizens' trust, and furthermore, the system is manufactured/procured. This enables generation of profits.

Services to Offer

Instead of the conventional qualitative levee management by visual inspection, obtain quantitative real-time information at site office

By utilizing the real-time information and promptly providing information to protect people's lives and property,

contribute to "No failure to escape" and "Minimization of damage on socio-economy."



(1) Inspection, Monitoring and Diagnostics
(2) Structural Materials, Deterioration Mechanisms, Repairs, and Reinforcement
(3) Information and Communications
(4) Robotics
(5) Asset Management

31 Effective Use of Satellite SAR Observation for River Embankment

Principal Investigator: Takeshi Katayama (Infrastructure Development Institute)

Collaborative Research Groups: Japan Aerospace Exploration Agency, Pacific Consultants CO., LTD.

R&D Objectives and Subjects

Objectives

Utilize satellite observation to collectively monitor a wide range of embankments at a frequency of several times a year, and improve embankment monitoring efficiently.

Conventional Monitoring

Regular Cross Section Surveying

■ Visual Check
- Difficult to check wide area in short time
- Difficult to detect changes such as gentle subsidence

■ Regular Cross Section Surveying
- Difficult to confirm displacement of embankment between measurement points
- Difficult to monitor at high frequency

Satellite Observation

■ Features of Satellite Observation
- Covering wide area in short time
- Continuous monitoring along river embankment
- Monitoring several times a year

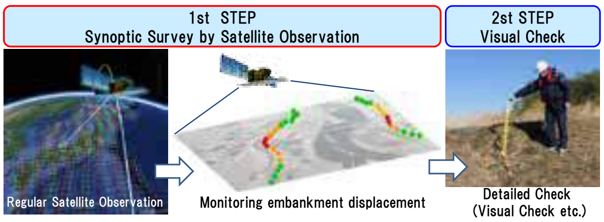
→Extracting of priority area for detailed visual check, etc.

L-Band Synthetic-aperture radar (PALSAR-2)

Subjects (2014-2017)

- Developing methods to calculate long-term displacement of river embankment
- Accuracy verification of calculated displacement
- Considering how to display the result of calculation

→ Conventionally, it was necessary to visually inspect all managed sections. However, it becomes possible to extract points for which detailed check is to be conducted.

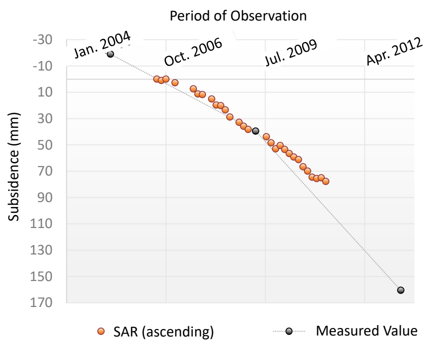


Current Accomplishments (1/2)

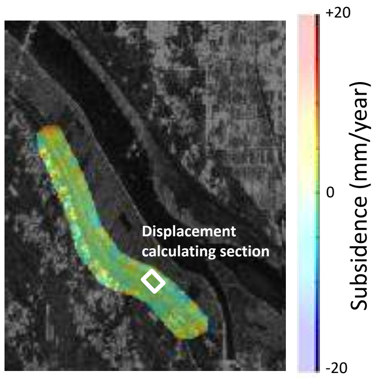
(2014-2015)

1. Establishment of displacement analysis model about ground level by using ALOS observation data

- Comparing analysis results by ALOS satellite observation with actual survey results
- We confirmed that we could obtain the displacement of average ground level in the certain section (displacement calculating section) inside the embankment.
- Based on this comparison verification, we examined a method of analyzing satellite images.
- This method can be applied to analysis using observation data by ALOS-2 (Operation period: from May 2014 to the present)



Orange points indicate the relative displacement of the mean ground level in the section including the crest of embankment (approximately 10 pixels. The pixel size is about 10m x 10m.) The straight line links the 3 survey results.



This diagram indicates subsidence amount of the embankment. The white rectangular frame indicates the section (displacement calculation section) in which the relative displacement of the average ground level was calculated.

- Accomplishment of grasping displacement of average ground level such as height of embankment crest by satellite image analysis
- It is possible to grasp long-term tendency of deformation of the height of embankment crest

Current Accomplishments (2/2)

(2014-2015)

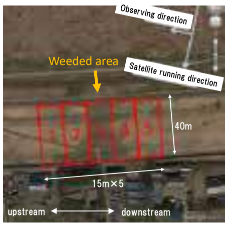
2. Evaluating Influence of Vegetation

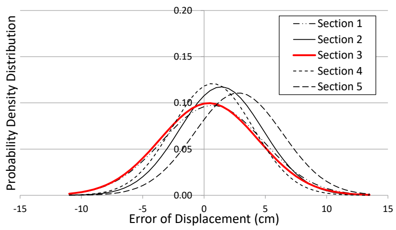
The electronic wave used in our satellite monitoring is L-band with long wavelength, so the influence of vegetation is considered to be small. We conducted on-site verification as follows;

・We compared results of satellite image analysis in a constantly weeded area with those in un-weeded areas

・Compared analytical errors of displacement of ground level in Section 3 (constantly weeded) and Sections 1, 2, 4, and 5 (with plants of about 50 cm in height) in embankment slope (in the picture left below); no significant difference was shown (in the graph right below).

→ Confirmed that there is no significant influence of vegetation on displacement of ground level calculated by satellite image analysis.





【Detailed Description】We calculated the difference between the satellite image analysis and survey results for each displacement of a plurality of ground level analysis points in Sections 1 to 5, then determined probability density distribution. By comparing the red curve, which shows the distribution of errors in Section 3 (the weeded area), with the other distribution curves of errors in the other 4 sections (un-weeded areas), we confirmed that whether or not an embankment is weededdoes not cause any significant difference in the distribution of errors.

Even for ground with vegetation, it is possible to grasp displacement

Flow of utilization

1. Establishment of displacement analysis model about ground level by using ALOS observation data

2. Evaluating Influence of Vegetation

Verification of satellite image analysis using ALOS-2 observation data (under consideration)

Preparing satellite image processing tool (under consideration)

Monitoring by embankment manager using satellite image processing tool

Improve efficiency of river embankment monitoring by extracting priority inspection sections

Goals

Numerical target

Accuracy of several hundred square meters as a minimum area unit to grasp displacement amount of average ground height.

Users

River Offices（Ministry of Land, Infrastructure, Transport and Tourism, Prefectures)

How to use/Places of use

Obtaining displacement of crest height of embankments by using SIPT in River Offices.

Sales method

・Work on manualization of our technology and tools.

・Delivering the SIPT to river offices.

・Utilizing SIPT in the projects ordered by River Offices

Services to Offer

Providing the processing tool which can process satellite observed images and display image processing results. Monitoring long-term displacement of crest height of embankments through displayed images.

Satellite observation data

Processing tool 1 (Image analysis tool)

Displacement of embankment

Processing tool 2 (Display tool)

Display useful for embank management

Satellite Image Processing

Threshold Setting for ground level displacement amount

Obtaining long-term displacement of crest height of embankment by SIPT (sample image)

It is possible to grasp long-term displacement of crest height of embankment continuously along rivers several times a year.

→Improve efficiency of river embankment monitoring by extracting priority inspection sections

33 Improvement for More Advanced and Efficient Road Structure Maintenance using Monitoring Technology

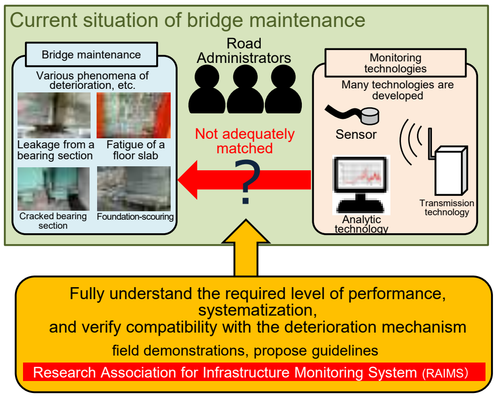
Principal Investigator Atsushi Homma (Research Association for Infrastructure Monitoring System)

R&D Objectives and Subjects

R&D Objectives

Current situation: Although a lot of monitoring technologies and products for bridges are developed, the road administrators cannot choose technologies and how it should be applied since the practical specifications are not standardized.

To make the maintenance cycle more sophisticated and more efficient, propose guidelines to introduce the most advanced monitoring systems to bridge management based on experiments, analysis, and field demonstrations in accordance with the needs of the actual road administrators.



R&D Subjects (FY2014 to FY2018)

- Classify and analyze road administrators' needs for monitoring technologies
- Examine the relationship between measurement data, which are obtained from monitoring technologies, and damage to structures by conducting laboratory experiments and field demonstration experiments
- Develop scenarios for introducing monitoring technologies to bridge maintenance works, and make guidelines for monitoring systems

Achieve more advanced and more efficient bridge maintenance works through facilitating the introduction of monitoring technologies by guidelines for road administrators.

Current Accomplishments (1/2)

(2014-2016)

1.Study the needs of road administrators and the required performance of roads and bridges

Collect and classify information about monitoring technologies based on road administrators' request.

(1) Classify road administrators' needs (documentary survey, discussion with experts, etc.)
(2) Classify the adaptation status of monitoring for bridge maintenance (conduct interviews with road administrators of local public bodies)
(3) Examine the required monitoring performance

Classification	Objectives of administrators	Needs of maintenance	Objectives of monitoring
Monitoring to support inspection	Reduce the number of failures to notice deformations during routine inspections (screening)	Improved efficiency	Understand the section where some kind of abnormality occurred (it does not matter whether the phenomenon is identified or not)
	Reduce inspection time and cost by narrowing the range of regular inspection	Improved efficiency	Understand the range where soundness has been confirmed (inspection is considered unnecessary)
Monitoring to support diagnosis	Prevent aggravation of deterioration and damage by taking preventive maintenance measures	Sophistication	Understand when it has reached the point where preventive maintenance measures should be taken.
	Prioritize actions	Improved efficiency	Obtain quantitative data to conduct an objective evaluation
	Maintain the service status	Improved efficiency	Check if it has reached the point where traffic restrictions or road closures should be carried out
Monitoring to confirm the effects of repairs and reinforcement	Confirm appropriateness of the measures	Sophistication	Confirm the effectiveness and durability of the measures
Monitoring to support measures during an emergency	Shorten the time until traffic restrictions are removed (express highway)	Improved efficiency	Understand the section where the risk of bridge collapse is predicted
	Shorten the time that dangerous spots for traffic are left unaddressed (ordinary roads)		

Particularly important needs of road administrators

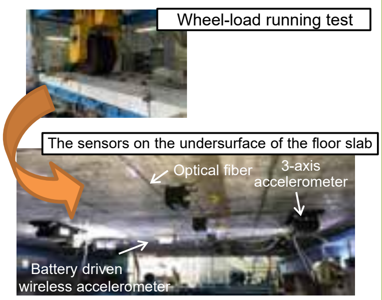
- Deal with the growing burden caused by mandatory close visual inspections
- Support the inspection of areas which are difficult to approach, such as an overpass
- Monitor bridges that need measures but they cannot be taken for a while
- Monitor important regional bridges at low cost

- Matching the applicable situation with the applicable monitoring technology required by road administrators

2. Floor slab monitoring experiments / RC girder monitoring experiments

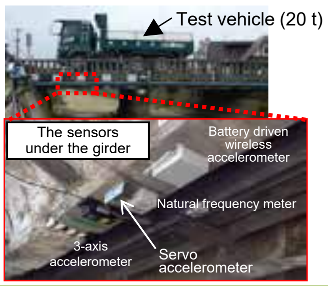
Laboratory experiments (2015)

To confirm the applicability of the sensors, deflection and cracks were monitored while replicating fatigue failures of the floor slab with a wheel-load running test using a specimen. The applicability of the sensors for each phase of deterioration was confirmed.

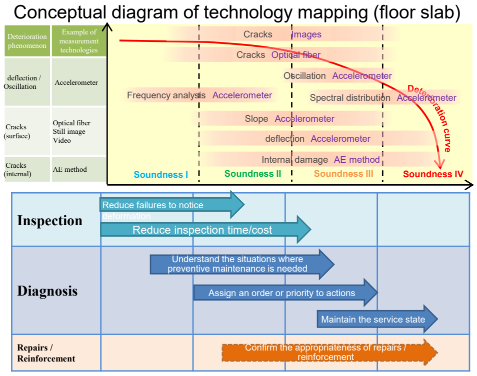


Field demonstration experiments (2016)

Deflection and cracks were monitored at actual bridges mainly using the sensors whose usability was confirmed during the laboratory experiments. The applicability of the sensors in an outdoor environment was confirmed. (Some Measurements will continue until 2017)



Conceptual diagram of technology mapping (floor slab)



Performed mapping of deterioration phenomenon that should be noticed and monitoring technologies that can catch the phenomenon in accordance with the soundness of the bridge.

- Develop guidelines for practicable and effective monitoring methods based on the soundness of the floor slab and girder.

Current Accomplishments (2/2)

(2014-2016)

3. Monitoring system for concrete structures under chloride attack

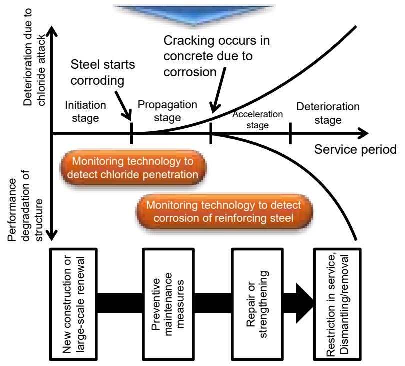
Accelerating tests on RC beam specimens (2015)

Performed accelerating tests by salt water immersion And electrolytic corrosion using RC beam specimens, in which 6 sensors were installed for monitoring re-bar corrosion and chloride penetration. Performance of the sensors was evaluated focusing on applicability for existing bridges.

+

Verification tests on existing bridges(2016)

Installed sensors to monitor the progress of Deterioration due to chloride attack to existing bridges and verify their applicability in on-site environment. (Measurements will continue until 2017)



Mapped applicable monitoring technologies based on the progress of deterioration.

- Develop guidelines for practicable and effective monitoring methods based on the state of deterioration due to chloride attack.

4. Evaluate wireless communication methods

Field experiment of wireless method assuming collection of monitoring data.

(1) Fixed-point collection type monitoring
To confirm the possibility of multi-hop wireless communication among sensor installation points, the range of communication at various locations of the bridge were measured.

A gateway is placed in neighboring emergency telephone or utility pole etc.

An image of fixed point collection type monitoring system

(2) Patrol collection type monitoring
Focused on a technology that wirelessly collects sensor data using vehicles running at 80 km/h, we confirmed that a routine inspection patrol vehicle doing other work is able to collect the data.

- Develop guidelines for specific methods to collect monitoring data using wireless communication.

Utilization Flow of Results

1. Examine road administrators' needs and required performance

Demonstrate bridge monitoring systems

2. Floor slab monitoring RC girder monitoring

3. Monitoring for chloride attack

4. Evaluate wireless communication methods

Other monitoring Data storage, etc.

Make guidelines to introduce monitoring systems

Bridge maintenance works are able to become more sophisticated and more efficient as the monitoring system becomes easier to use.

Goals

Final target value

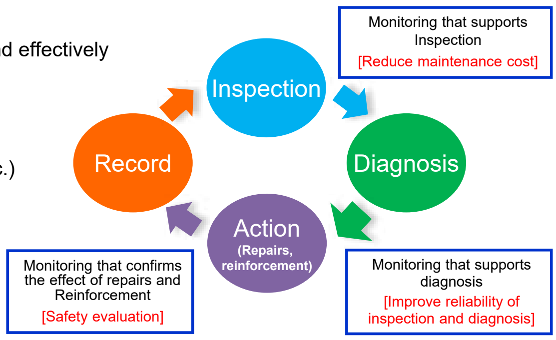
Aim to achieve a service life of 100 years by maintaining bridges appropriately and effectively through the facilitation of the use of monitoring in accordance with the guidelines.

Target users

All road administrators (the state, local public bodies, expressway companies, etc.)

Usage method, locations to use, etc.

Introduce monitoring systems in accordance with the objectives, target bridges, management systems, etc. to the inspection guides etc. for each road administrator based on the guidelines.



Flow of spreading the guidelines

Share the results at lectures, technology exhibitions, etc.
Cooperation with local public bodies

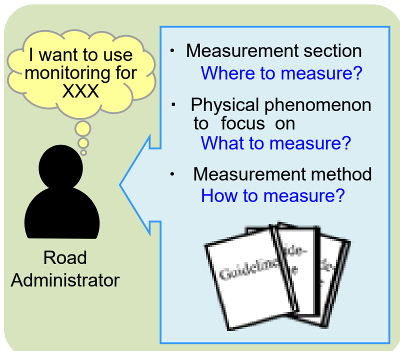
Promote the use of monitoring for national roads, expressways
Send information/give advice to local public bodies

Outline the service provided

Propose utilization methods of monitoring systems for bridge maintenance using guidelines

[Examples of expected use]

- Improve the efficiency of inspection works by making more effective inspection plans based on regular monitoring data.
- Improve the accuracy of inspections and reduce the number of failures to notice damage by carrying out monitoring to help to inspect spots that are difficult to access.
- Improve safety by introducing monitoring to damaged structures.
- Devise reasonable repair and reinforcement methods by confirming the effects after any repairs and reinforcement through monitoring



It's possible to introduce a monitoring system that matches the objectives of road administrators
→ Achieve more advanced and more efficient bridge maintenance works

35 Clarification of Deterioration Mechanism of Infrastructures and Development of Technology for Efficient Maintenance and Management through COE for Infrastructure Materials Research

Principal Investigator Koichi Tsuchiya (Director of RCSM, NIMS)

Collaborative Research Groups Kyoto University, Tokyo Institute of Technology

R&D Objectives and Subjects

Objectives

【Social Backgrounds】

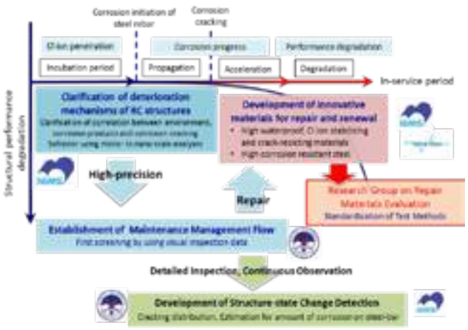
- It is necessary to develop an efficient maintenance and management flow to deal with a large stock of social infrastructures with a limited budgets and human resources in Japan .
- It is necessary to establish a feasible and highly accurate degradation diagnosis method as well as innovative repair technology.

【Purpose of Research &Development】

- Development of diagnostic technology with reduced labor, reduced cost and well-planned maintenance suitable for maintenance in local authorities.
- Fostering multi-disciplinary researchers/engineers who have a birds-eye view over materials and structures for the future.

Subjects

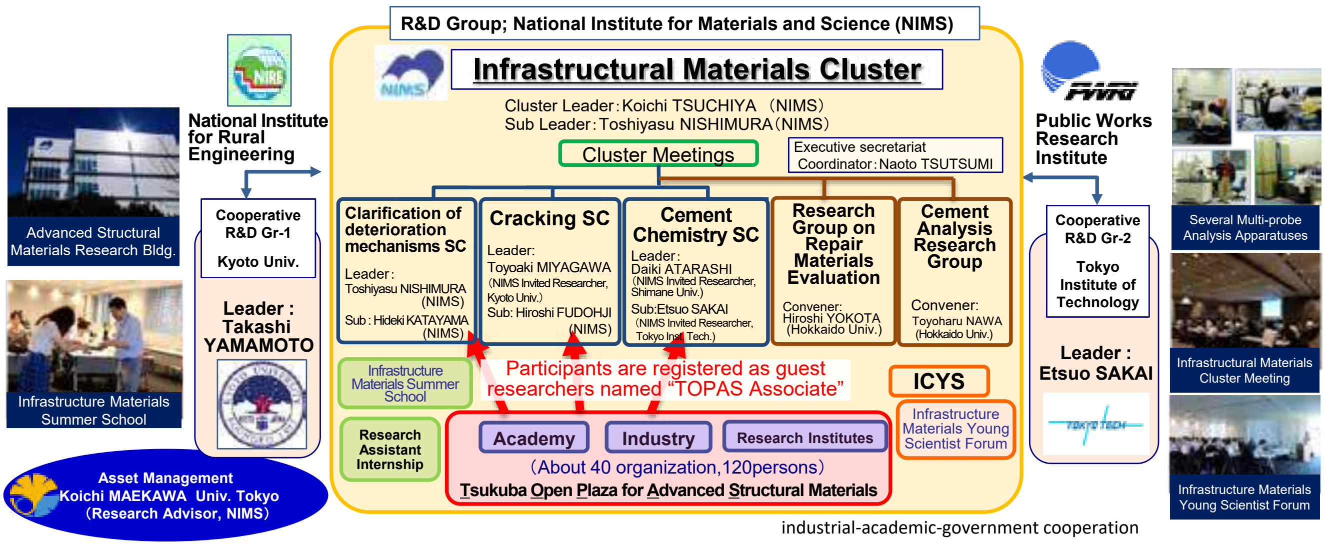
- Establishment of COE for infrastructural materials R&D to promote interdisciplinary collaboration, industrial - academic - government cooperation and human resource development.
- Clarification of deteriorating mechanisms in RC infrastructures.
- Improvement of remaining life assessment for infrastructures by clarification of the correlation between 1) environment in service, corrosion products and cracking and 2) concrete cracking and load capacity, using advanced inspection technologies, such as non-destructive evaluation and corrosion environment sensors, which have been cultivated in NIMS.
- Development of efficient repair materials and long-life materials as well as evaluation methods.



Current Accomplishments (1/4)

Consolidation to COE for infrastructural Materials R&D with industrial - academic - government cooperation

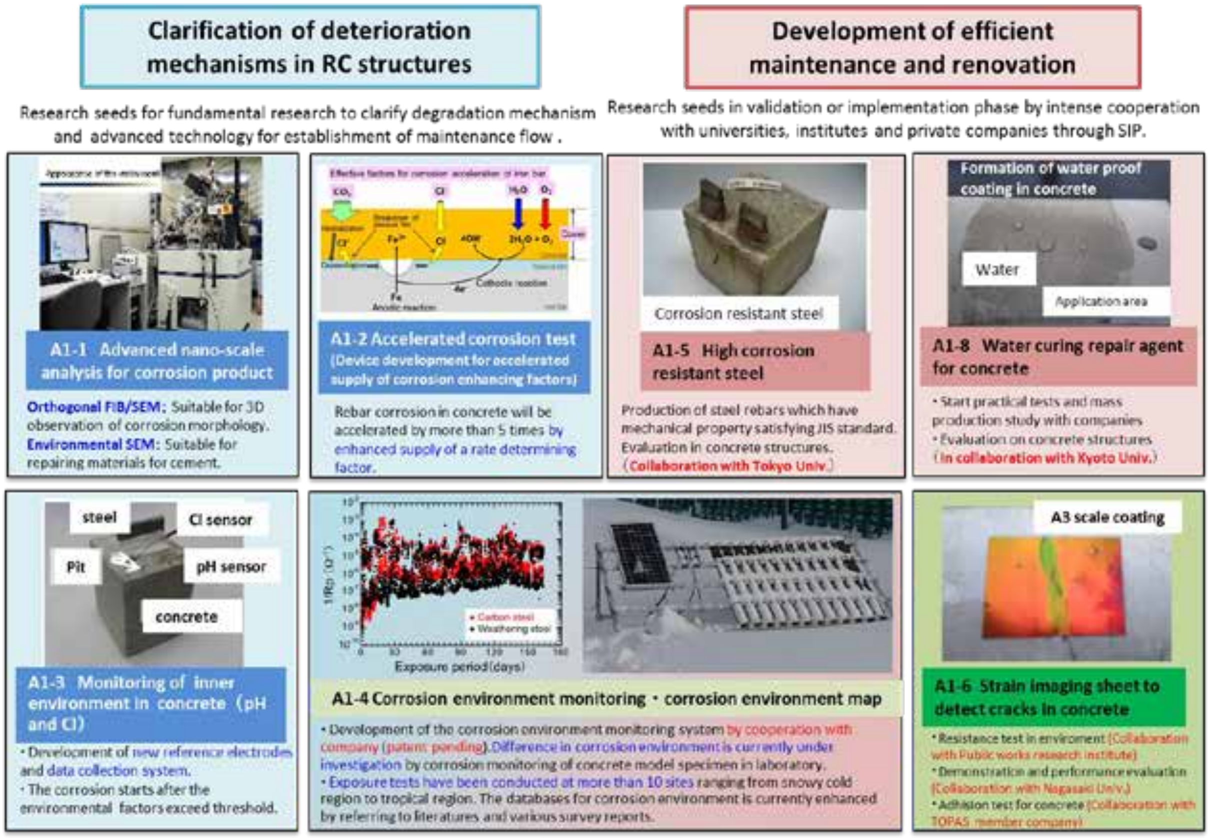
- About 30 researchers and engineers who belong to the "SIP-Social Infrastructure Materials Lab" and various analytical apparatus for infrastructural materials R&D are located in the Advanced Structural Materials Research Bldg.



- New industrial - academic - government cooperative group named "TOPAS" has been established to promote Infrastructural Materials R&D.
- "Infrastructural Material Cluster" (31 industries, 8 academic institutes or public labs, and 120 persons) plays an important role in the project, such as 1) information exchange, 2) several educational programs [young scientist forum, summer school, cluster seminars] and 3) discussion and investigation of cooperative R&D for social infrastructural implementation.

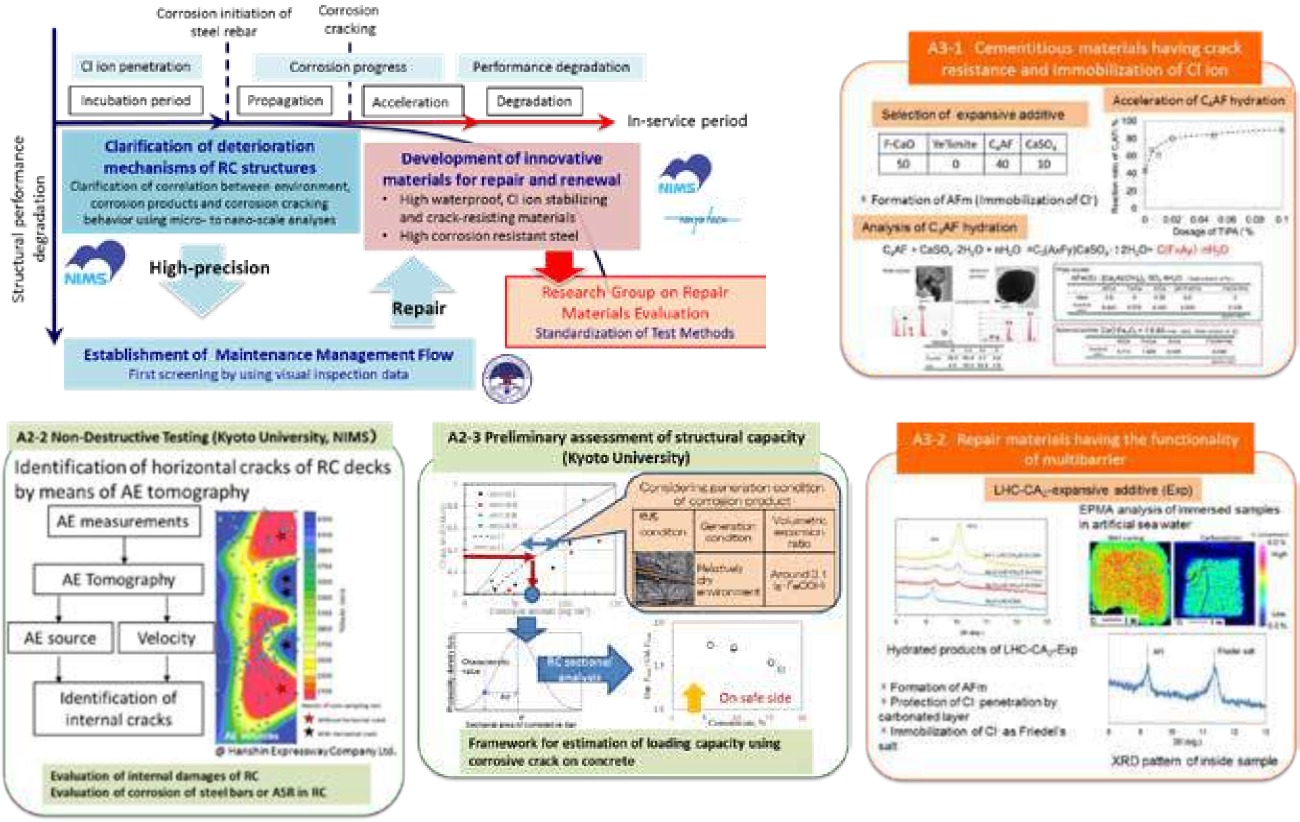
Current Accomplishments (2/4)

Clarification mechanisms & Application of NIMS seeds for Infrastructure Maintenance



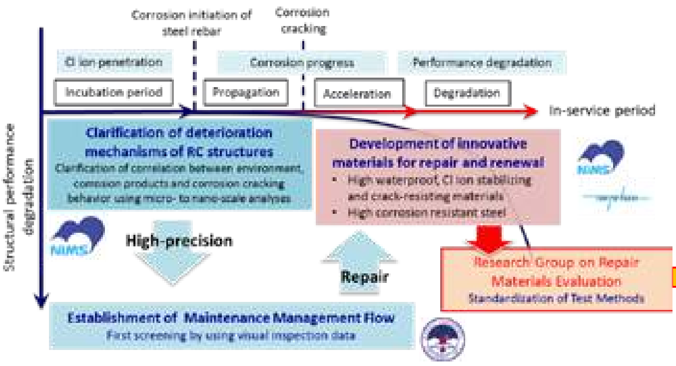
Current Accomplishments (3/4)

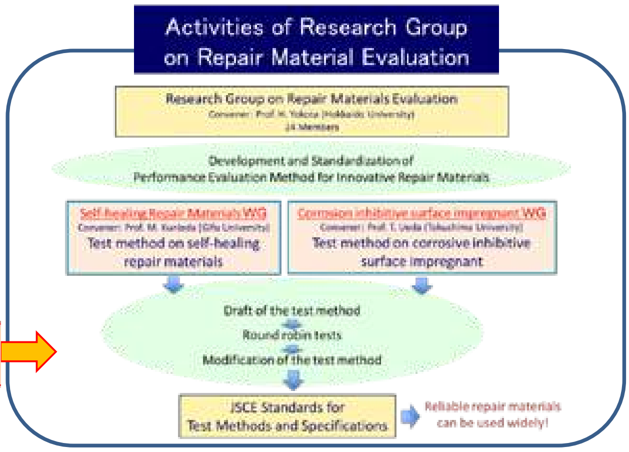
Establishment of new maintenance management flow (Kyoto University) & Development of repair materials and highly durable cement (Tokyo Institute of Technology)

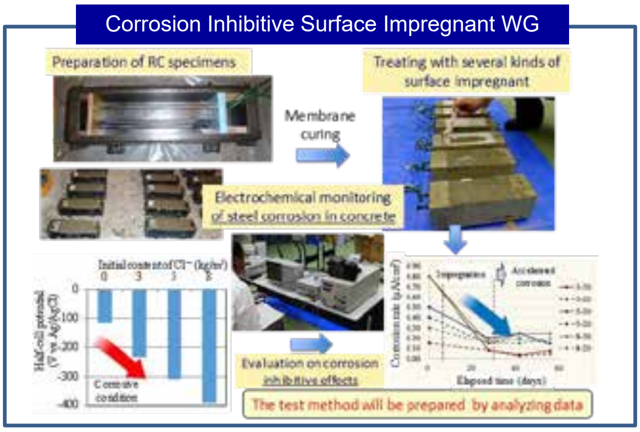


Current Accomplishments (4/4)

Research Group on Repair Materials Evaluation







Goals

Actual Reflection of R&D Results to the Society

Strong promotion at "Infrastructural Materials Cluster" to establish the high-efficient Maintenance Flow

	2014 – 2016	2017 – 2018
Center of Excellence	Information exchange, personal training and implementation through TOPAS activities	
Environment in service & corrosion products	・Adjustment & Comprehension about environment in service of RC structure under several conditions from the view-point of corrosion	・Solid maintenance flow checking degradation in RC structure even in a local government without problem ・Demonstration test for long-life materials
Cracking behavior &loading capacity	・Clarifying the relationship between loading capacity and corrosion products ・Performance diagnosis of RC structures using advanced model for corrosion crack	
Development of repair materials and high durable cement	・Development of water curing repair agent for concrete ・Optimization of cementitious materials with immobilization of Cl ions (C_4AF, leavening agent) ・Clarification of multi-barrier mechanism ・Development of high corrosion resistant steel	・Mass production and further application ・Establishment of the technology for newly repair materials through demonstration test

- Establishment of a Core of Excellence for infrastructure materials in the SIP Project
  - Introduction of research facilities for R&D of infrastructural materials
- Sustainable network formation with industrial - academic - government cooperation
  -Co-production with infrastructural companies registered in TOPAS
- "Intellectual accumulation" concerning infrastructural materials
  -Cooperative R&D with Kyoto University, Tokyo Institute of Technology, University of Tokyo and other institutions
- Fostering great young talents to be future multi-disciplinary researcher/engineer

36 Developing hybrid mechanoluminescence materials for visualization of structural health

Principal Investigator Chao-Nan Xu (Principal Research Manager, AIST)

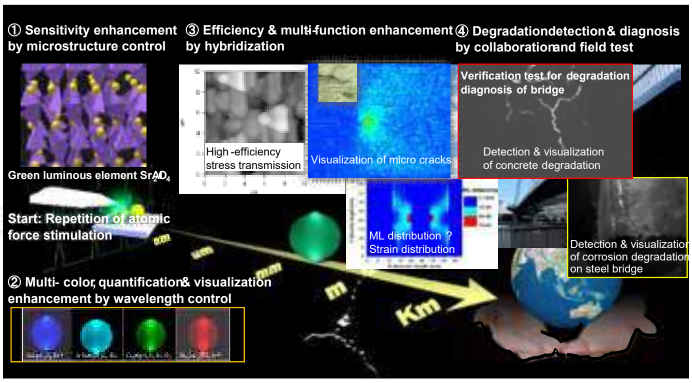
R&D Objectives and Subjects

Objectives

- We develop novel mechanoluminescence (ML) materials for nondestructive inspection of structural degradation and damage by visualization of the stress/strain distribution. The novel ML materials have a unique property that the ML intensity increased quantitatively with the stress/strain change, and such a property can be employed to quantitatively evaluate degradation distribution and status at the same time for efficient inspection and repair.
- We develop ultrasensitive ML materials for a direct view of the micro-cracks and degradation in the structures, such as welded areas, etc., in steel bridges, even without removal of the surface paints/films. The preventive detection of fatigue cracks and preventive repair can ensure effective maintenance.

Subjects

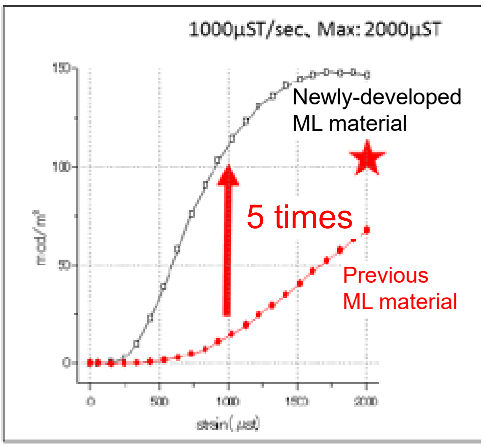
- Development of ultrasensitive ML materials for effective visualization of structural degradation, stress/strain concentration and cracks
- Development of hybrid materials for quantitative analysis of degradation/damage degrees
- Implementation of the field verification test of developed technology aiming to use during the periodic inspections of infrastructures (highways, etc.)

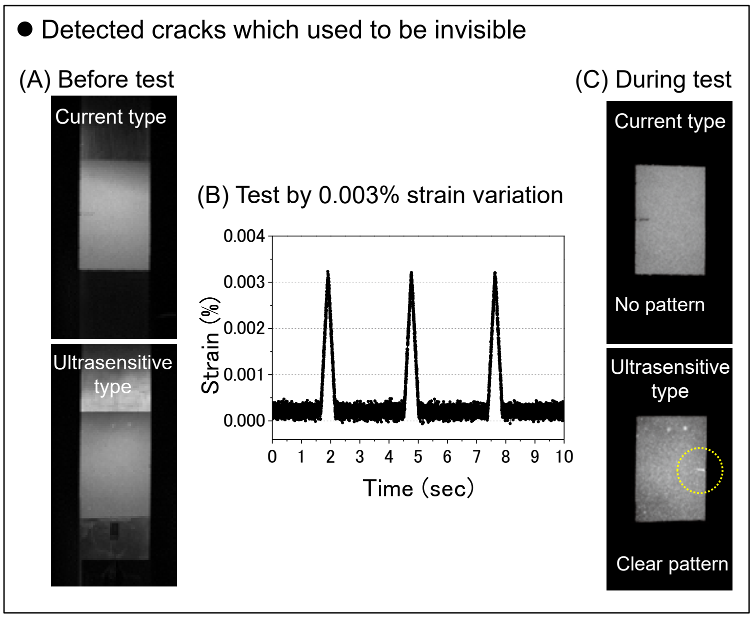


Current Accomplishments (1/2)

Ultrasensitive ML materials for visualization of the invisible fatigue micro-cracks

- We developed a new ultra-bright and sensitive ML material, which can emit higher than 100 mcd/m² to a small strain of 0.1%
- Using the newly-developed ultrasensitive ML materials, effective visualization of fatigue micro-cracks could be achieved with 0.003% strain variation.
- Under the same experimental condition, the newly-developed ML material enhanced the ML to 5 times compared to the previous materials.





(A) Metal specimens coated with current (top) and SIP newly-developed ultrasensitive ML sensors (bottom).

(B) Strain curves of the test with maximum strain of 0.003% are used to simulate vehicles passing by on a highway.

(C) ML image of micro-cracks during the vibration – cracks can be clearly seen by the new sensor, whereas they cannot be seen by the previous sensor.

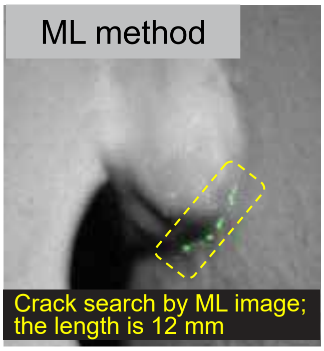
Current Accomplishments (2/2)

Newly-developed ML materials toward efficient, low-cost and labor-saving maintenance

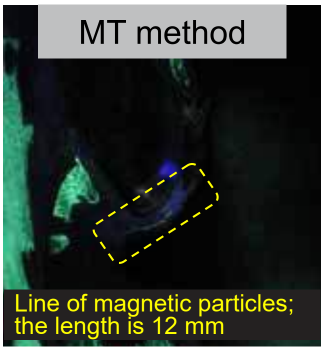
- Field test of newly developed ML method was carried out on the steel welding joints with paint cracks occurring at highway bridges, without the removal of the anticorrosion paint to search if fatigue cracks had occurred or not.
- After the ML test, conventional magnetic testing (MT) was carried out to confirm the reliability of inspection results of the ML method. The result strongly confirmed the reliability and effectiveness of the ML method. Compared to ML, MT is time- and cost-consuming, the pretreatment of paint removal damages the inspected target also.
- SIP newly-developed ultrasensitive ML method was confirmed to be effective to search for cracks and visualize stress/strain concentration even without paint removal.
- The maintenance specialists highly appreciated the ML method to be of great merits in both labor and cost saving and to be a practically useful technology to detect fatigue cracks in steel without paint removal, to evaluate repair status, and to visualize stress concentration.

Effective detection and visualization of invisible cracks underneath the anti-corrosion paints

Field demonstration: Fukuoka Urban Expressway



Paint removal is not necessary. ML enables visualizing the crack in the structure underneath the paint.



Paint removal is necessary. Crack visualization by particles dues to magnetic flux leakage.

A crack was successfully found by the ML method (before paint removal), and was also confirmed by MT method (after paint removal)

Goals

Quantitative targets

- ML performance
  Quantitative analysis of stress/strain concentration, visualization of strain distribution level of 0.01%
- Crack detection sensitivity
  Detection of micro-cracks with depth shallower than 1 mm

Social implementation

- We are developing a business environment on the fatigue crack visualization of steel bridges, effective confirmation of crack repair status, and stress concentration evaluation for repair necessity determination.

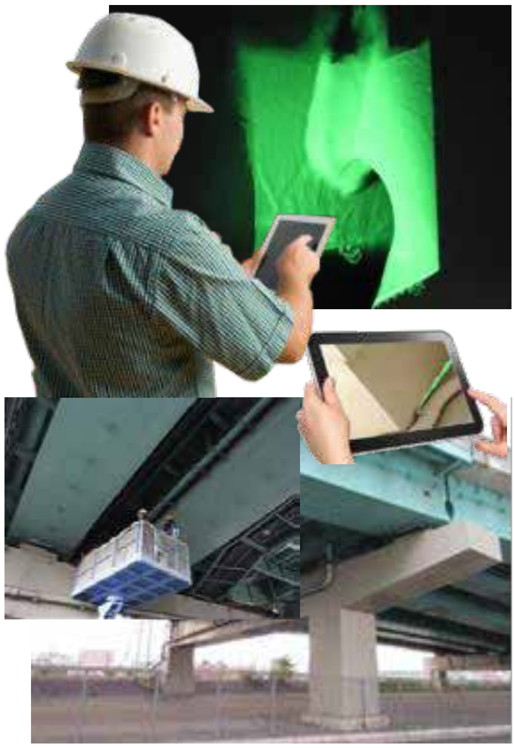
The world's first ML technology

Contribution to effective infrastructural maintenance and management

To improve ML materials ・Sensitivity ・Quantitative ・Optimization ・High durability	→	Field verification test for robustness and reliability	→	Standardization, guidelines and user manual preparation	→	Generalization and dissemination of technology

Established the *Mechanoluminescence Technology Consortium* for technology innovation, standardization, generalization.
https://unit.aist.go.jp/kyushu/MLTC/index.html
Contact: mltc-s-ml@aist.go.jp

Implementation and periodical inspection in infrastructures (e.g., steel bridges, highways)



37 Technology of repairing the corrosion damage and deterioration to steel structures using newly developed flame coating material

Principal Investigator: Kenji Higashi (Professor, Osaka Prefecture University)

Collaborative Research Groups: Osaka Prefecture University, Technology Research Institute of Osaka Prefecture,Coaken Techno Co., Ltd., Kanmeta Engineering Co., Ltd., Osaka Prefecture University College of Technology

R&D Objectives and Subjects

Objectives

Objective: To realize safe and secure infrastructure by developing a repair technology that enables easy maintenance and control with the utilization of a newly developed thermal spraying alloy of excellent corrosion durability; the developing repair technology is suitable for solving problems determined through field study on the corrosion damage to steel structures, especially to steel bridges.

Development of a thermal spraying alloy: Developing a thermal spraying alloy with an excellent corrosion prevention performance, especially for dents, the edge portions and the small end faces of steel bridges, as well as with the high durability in severe salt-attack environments.

Development of a thermal spray method in narrow spaces: Accelerating the progress speed of the technology we are developing by utilizing a compact and lightweight plasma arc spraying technique, which was developed by the West Nippon Expressway group and establishing its application to narrow spaces.

Subjects

Field study: To clarify the problem as a repair technology through the investigation of the actual corrosion damage.

Development of a thermal spraying alloy: Developing a thermal spraying alloy excellent in corrosion resistance and self-repairing ability; the alloy composition was designed based on the first - principle calculation and the evaluation of corrosion resistance using electrochemical techniques.

Adaption to the plasma arc spraying method: Carrying out the tests for confirming the adaptability of the plasma arc spraying method, which is considered as an adequate technique for a thermal spraying on a narrow space.

Evaluation of corrosion prevention performance: Performing the verification testing of the developed thermal spray coating by a combined cyclic testing of up to 6,000 hours with a cross-cut sample. Carrying out atmospheric corrosion tests in heavily corrosive salt-attack environments, such as along the coast of the Sea of Japan.

Partial repair as field trial: Preforming a partial repair as a field trial, to the girder end structure of a bridge to verify the workability, the cost and the performance of thermal spray coating with the developed alloy.

Current Accomplishments (1/2)

To develop a new thermal spraying alloy with high durability for salt-attack environments, as well as high resistance to the corrosion of dents, edge portions and small end faces.

Problems of damage and deterioration due to corrosion

Examples of corrosion sites in steel bridges

Girder end structures, including shoes

Splice parts and bolts

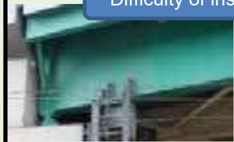
Survey results of corrosion sites in steel bridges

①Girder end structures, including shoes
→ Narrow part and imperfect drainage
②Splice parts, bolts and small end surfaces
→ Decrease in thickness of thermal spray coating.
③Steel girders built across a railway track and a road with a heavy traffic volume → Difficulty of inspection and repair
④Salt-attack environments, such as the seashore
→ Problem of durability

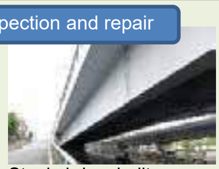
Proposal of a repair method with good workability and a thermal sprayed coating with high durability.

①Development of new thermal spraying alloy exhibits high durability for salt-attack environments and high corrosion resistance for dents, edge portions and small end faces.
②Adapting to plasma arc spraying method capable of easily repairing narrow part.

Difficulty of inspection and repair

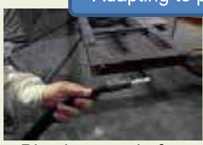


Steel girders built across a railway track



Steel girders built across a road with a heavy traffic volume

Adapting to plasma arc spraying

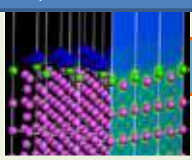


Blasting nozzle for narrow part

Small and lightweight spraying gun

Development of new thermal spraying alloy “Al-Mg-Ca”

Fourteen selected kinds of alloy compositions based on the first-principles calculations.

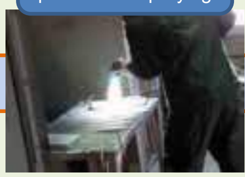


Electrostatic potential on Al-Mg surface

Al-Mg-Ca was selected from fourteen kinds of alloy compositions based on electrochemical tests.

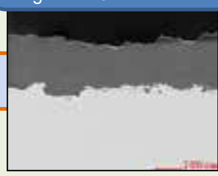
Measurements of polarization curves

Flame spraying, arc spraying and plasma arc spraying



Thermal spraying of Al-Mg-Ca alloy

Adhesive strength of Al-Mg-Ca thermal spray coating is about 10 Mpa, which is the same as that of conventional Al-Mg in achieving the target strength of 4.5 MPa.



Sprayed coating of Al-Mg-Ca alloy

Fabrication of Al-Mg-Ca alloy wires for various thermal spray methods.

Wire for thermal spraying of Al-Mg-Ca alloy

Current Accomplishments (2/2)

To demonstrate durability of the newly developed thermal spray coating and establish a repair technology using it, based on the results obtained by combined cycle testing and the partial repair as a field trial at an actual steel bridge.

Determination of alloy composition with excellence in corrosion resistance using electrochemical techniques

Target	Problem	Corrosion resistance performance
Salt-attack environment	Rapid dissolution of the coat due to high corrosion rate	Cathodic protection to the coated defective part
Edge portion, small end face	Poor durability resulting from a small thickness of the coat	Anti-self corrosion of the coat
Dent	Rusting from the defect in the coat	Self repairing ability of the coated defective part

		Cathodically protecting performance	Resistance to self-corrosion	Self-recovering performance
Testing method		･Corrosion potential measurement ･Polarization measurement	Polarization measurement	Combined cycle testing
Evaluation criteria		･Level of corrosion potential ･Passivation or de-passivation	Intensity of corrosion current	Appearances
Conventional material	Al	○	○	×
	Al-Mg	○	○	○
New alloy	Al-Mg-Ca	○	○	◎ Improved by 25 %*

◎ very good, ○ good, × poor

(Samples for evaluation were prepared by flame spraying)

* A time for a start rusting from cross-cut area

Combined cycle testing

Carrying out an accelerated test using the combined cycle testing, which is assumed showing a satisfactory correlation with outdoor exposure.

A time for a start rusting from cross-cut area was improved by 25%.

Al-Mg-Ca　Al-Mg

The appearances of the coats (100 μm thickness) after being subjected to combined cycle testing for 6,000 hours.

Partial repair as field trial at an actual steel bridge

A partial repair as a field trial was carried out on an actual steel bridge of West Nippon Expressway Company Limited by the plasma arc spraying using a newly developed thermal spraying alloy.

The workability of thermal spraying and the quality of the sprayed coat satisfied the in-house quality control provisions of West Nippon Expressway Company Limited.

Steel bridge under repair

Finish state; after repair

Goals

- Development of new thermal spraying alloy with high durability by utilizing state-of-the-art computational materials science and the latest knowledge about corrosion and corrosion protection mechanisms.
- Demonstration of the workability of the repair method and the durability of sprayed coating that uses the developed thermal spraying alloy.

Adapting to JIS thermal spraying : flame spraying and arc spraying

↓

Performance confirming tests
- Workability on thermal spraying
- Electrochemical test

↓

Demonstration tests
- Combined cyclic testing
- Exposure test
- Sliding friction test

↓

To develop new alloy for JIS thermal spraying

Adapting to plasma arc spraying used in West Nippon Expressway Company Limited

↓

Performance confirming tests
- Workability on thermal spraying
- Combined cyclic testing

↓

Test construction work
- Exposure test
- Partial construction work

↓

Establishment of repairing method at end parts of steel girders

38 Practical Application of PCa with Super-High Durability Concrete

Principal Investigator Toshiki Ayano (Professor, Okayama University)

Collaborative Research Groups Oriental Shiraishi Corp., Landes Co., Ltd., JFE Steel Corp.

R&D Objectives and Subjects

Objectives

In order to extend the lifespan of damaged bridges and to shorten the period of traffic regulation during renewal construction, a precast concrete member with high durability has been developed with blast furnace slag sand.

- PC (Pre-stressed Concrete) PCa member
  ⇒ Durable to traffic load under water supply conditions
- RC (Reinforced Concrete) PCa member
  ⇒ High resistance to freezing and thawing without AE agent

Subjects

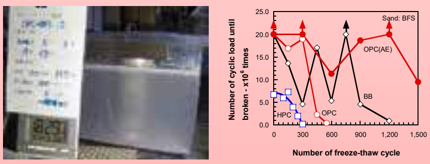
Publication of the guidelines for the manufacturing of highly durable PCa members with blast furnace slag sand, and construction with it on a site.

- Clarification of the mechanism of blast furnace slag sand to improve the durability of concrete
- Establishment of a supplying system for the blast furnace slag sand in the domestic precast factories
- Establishment of the inspection and quality control system to manufacture the reliable products

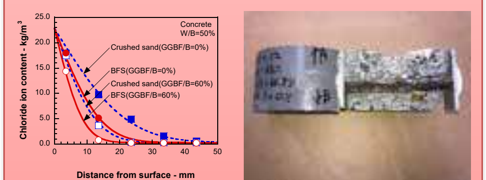
Current Accomplishments (1/2)

Effects of thickener
【P2015-143297】

Resistance to freezing and thawing



Fatigue in water
【P2016-216284A】



Performance to protect against the rusting of steel

Effects of the Quality of Blast Furnace Slag Sand on Concrete Properties

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Quality Standard of Blast Furnace Slag Sand

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Characteristic value of concrete for durability ⇔ Manufacturing specifications

↓

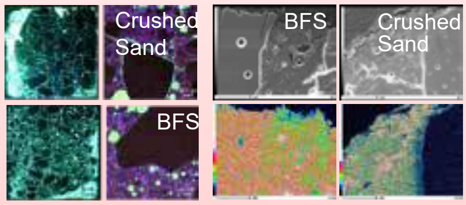
Demonstration at Factory

↓

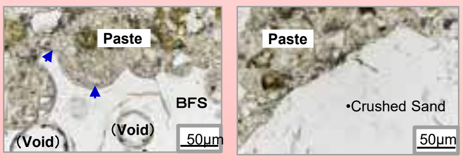
Performance of PCa ⇔ Design

↓

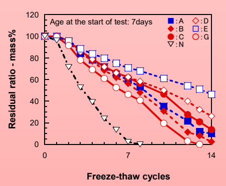
Performance Verification



Clarify the mechanism of BFS to improve the resistance to freezing and thawing

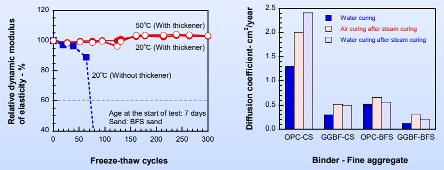


Reactivity of blast furnace slag sand

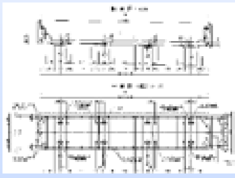


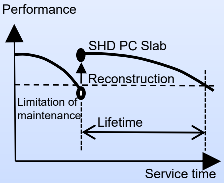
Difference of quality of blast furnace slag sand in manufacturing plants
【P2015-242333】

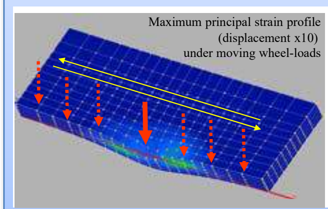
Current Accomplishments (2/2)

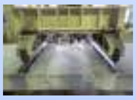


Effects of Adimixture and Curing Method









Numerical Analytical Approach

Effects of the Quality of Blast Furnace Slag Sand on Concrete Properties

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Quality Standard of Blast Furnace Slag Sand

↓

Characteristic value of concrete for durability ⇔ Manufacturing specifications

↓

Demonstration at Factory

↓

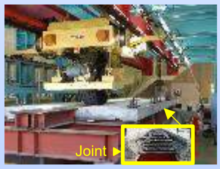
Performance of PCa ⇔ Design

↓

Performance Verification

Decision of Specification

Check of Workability



Check of Durability to Traffic Loads

Demonstration at a site (11,000 ton in 2015)

Goals

① BFS for Highly Durable Concrete

JIS A 5011-1

Quality Standard of BFS for High Durable Concrete

- Establishment of a Quality Standard of BFS
- Supplying system of BFS in Domestic Areas

② PC PCa Products

The characteristics of products are as follows;

- High resistance against freezing and thawing attack, and fatigue in water
- The losses of pre-stress is low by small shrinkage and creep of concrete

③ RC PCa Products

The characteristics of products are as follows:

- High resistance to freezing and thawing attacks without an AE Agent
- High resistance to chloride attacks

39 Research, development, and social implementation of screening technologies on pavement and bridges based on large-scale sensor information fusion toward preventive maintenance of infrastructure

Principal Investigator Masataka Ieiri (Director, JIP Techno Science Co., Inc.)

Collaborative Research Groups The Graduate School of Engineering, Institute of Industrial Science (IIS),and Research Center for Advanced Science and Technology(RCAST), The University of Tokyo

R&D Objectives and Subjects

Objectives

To reduce the risk due to earthquakes, typhoons, and accidents, and the cost of maintenance, screening technologies to extract those needing detailed inspection or retrofitting from infrastructure stock are developed and socially implemented.

Subjects

① **Large-scale road condition evaluation using commercial vehicles** : DRIMS, a system for evaluating the International Roughness Index (IRI) based on vehicle responses, is installed in various commercial vehicles; vehicles' response data is collected and analyzed on a large scale. The condition of road networks, including even residential roads, is obtained in pseudo-real-time.

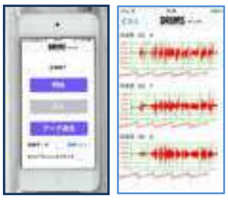
② **Monitoring of bridges and analysis** : Wireless sensing system capable of capturing bridge responses at a cost 10 times lower than conventional sensors has been developed. Wireless sensor systems to monitor multiple bridges on a large-scale have been developed.

③ **Fundamental technologies for low-power wireless sensor networks** : Based on "routing-less multi-hop wireless communication techniques", low-power synchronized sensing with a battery life time of about 20 years has been developed.

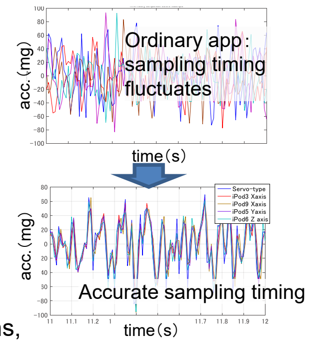
④ **Fundamental technologies for big-data analysis and visualization** :Peta-byte class data obtained from about 100 vehicles and 100s of sensors on bridges are stored, processed, and visualized.

Current Accomplishments (1/2)

Sophistication of Measurement app



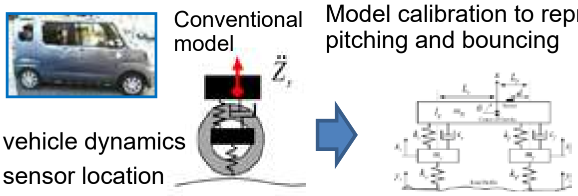
Acceleration/angular velocity, etc.（on store）



Depending on conditions, higher accuracy than conventional sensors

Feedback from social implementation to development

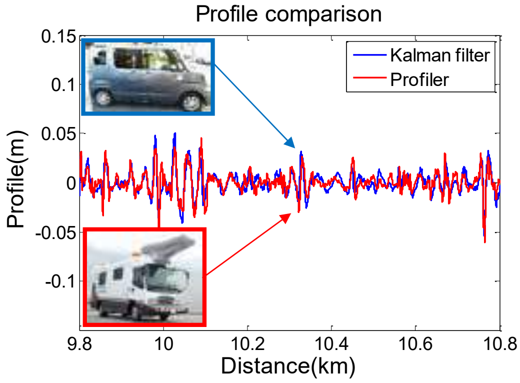
Vehicle parameter identification



Model calibration to reproduce pitching and bouncing

Road profile estimation

Profile estimation (0.02−0.5cycle/m)



Estimation accuracy is close to the Profiler

Large scale social implementation and visualization

Network-level visualization

Drive records (H27)

	Number	Mileage(km)
Company A	41	23,286
Company B	10	55,062
Company C	6	76,823
Municipality A	10	501
Municipality B	5	6,503

Local visualization

- Psuedo-real-time data from 10s of vehicles
- Smooth visualization at various scales

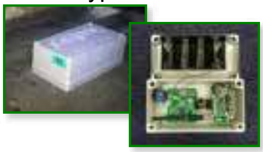
Current Accomplishments (2/2)

Wireless sensor node development

Inexpensive & easy-to-use and accurate & reliable node

1. Seismometer-like accurate acceleration measurement
2. Synchronized sensing network quickly created over multi-hop communications
3. Long battery life of up to 20 years

Prototype

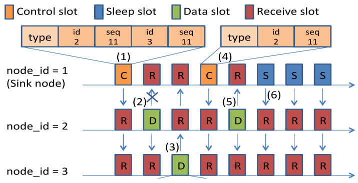


Communication module

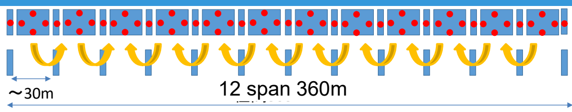
Routing-less multi-hop communication

- Flooding communication completes in 10 ms. By scheduling CTF, dozens of packets are sent via flooding.
- MAC and routing are significantly simplified. Fast data collection, reprogramming, high reliability, and other functionalities are realized

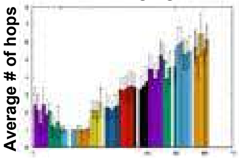
Measurement system development is essentially simplified.

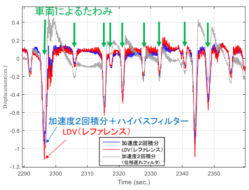


Field test 1 : traffic-vibration measurement at viaducts

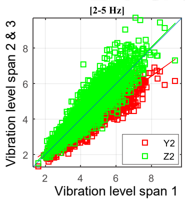


Robust multi-hop network is established under a challenging environment





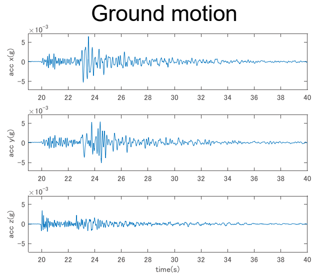
Spans with large deflection and vibration amplitude are extracted



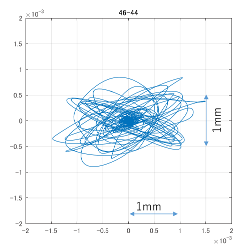
Field test 2 : earthquake response monitoring

- Kumamoto earthquake aftershocks are monitored using more than 10 nodes/bridge. Battery-operated nodes captured more than 50 aftershocks during 2 weeks.
- Bearing motion under seismic events were clarified.

Ground motion



Trajectory of bearing motion



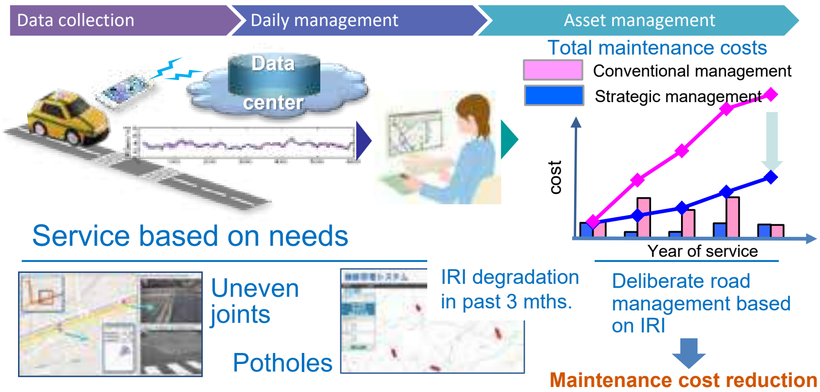
※We appreciate Kumamoto Office of River and National Highway for their kind advice on the measurement

Goals

Road evaluation

Target

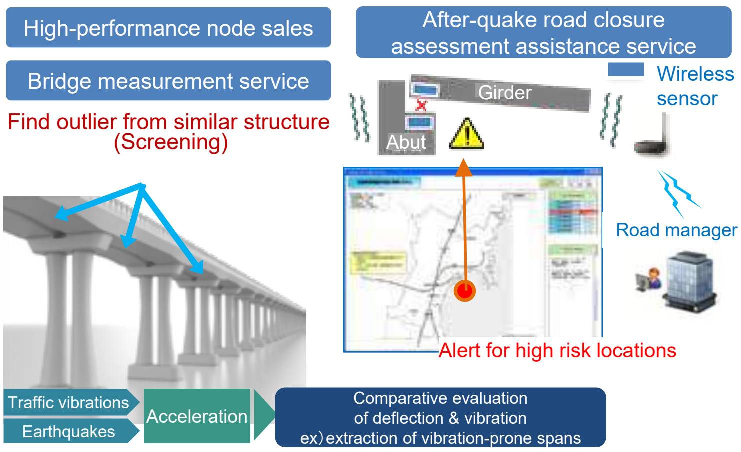
- IRI estimation accuracy 10-20%
- Local damage detection (joints & potholes)
- Road asset management system using deterioration prediction based on IRI
- Data process & visualization platform for 100 vehicles x several years.
- Technology transfer to foreign countries



Bridge evaluation

Target

Sensor node	Seismometer-class accurate measurements
	Robust multi-hop network over kilometers
	1-month to 20-year battery life
	Strain, inclination, temperature
	Time synchronization to GPS time. Power-efficient connection to external network
Extraction of bridges of large responses/loads	



40 R&D on Technologies for Collecting, Transmitting, and Processing Sensing Data of Civil Infrastructures (Underground Structures)

Principal Investigator: Shuichi Yoshino (Senior Manager, NTT Network Innovation Laboratories)

Collaborative Research Groups: NTT Advanced Technology Corporation,Tokyo Metropolitan University, and FUJI TECOM INC.

R&D Objectives and Subjects

Underground structures with severe communication environments can be monitored by collecting and using sensing data using wireless communication suitable for the environment.

Objectives

	Conventional	Improvements achieved through our R&D
Inspection	･Periodic inspection every several years ･Reports from residents and others	･Installing and utilizing long-term maintenance-free sensors
Monitoring	･Traffic blocking at manhole openings and closing and installing/removing work	･No need for manhole opening/closing ･Automatic data collection by mobile and stationary APs
Diagnosis	･Judgment only with the data at inspection ･Diagnostic variation due to workers ･Degradation diagnosis and prediction are impossible	･Improved leakage detection accuracy by utilizing past data ･Workers' skill independent diagnosis ･Soundness evaluation of water pipes by constant monitoring ･Speed up response in case of disaster

Subjects

Technology	Contents of R&D
A) Sensing data collection and transmission technology	• Drive-by data collection: activation of terminals from running vehicles • Static data collection: long distance data communications to APs
B) Sensing data handling technology	• Infrastructure facilities monitored data handling technology • Techniques to lower power consumption of sensors
C) Optimal planning of water leakage monitoring systems	• Evaluating and determining leakage and accident risks in the area • Optimizing the installation points of water leakage monitoring sensors
D) High sensitivity sensor terminal technology	• Economical data collection and operation methods • High sensitivity sensor terminal technology over wide frequency bandwidth

Current Accomplishments (1/2)

A) Sensing data collection and transmission technology

Established basic data transmission technology

(i) Link budget analysis

- Radio wave propagation characteristics clarified in multiple frequency bands by electromagnetic field analysis and water supply pipeline test bed verification
- Data transmission frequency band (920 MHz band) and terminal activation frequency band (125 kHz band) selected
- Link budget analysis completed by selecting modulation method, error correction method, antenna, etc.

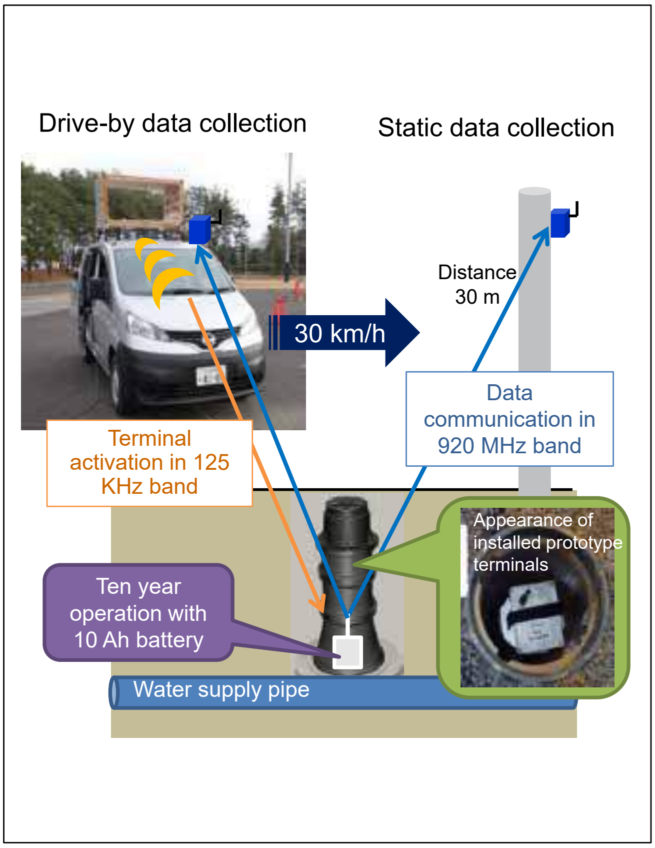
(ii) Basic performance of data transmission technology evaluated

- Transmitter/receiver circuit for terminal activation/data transmission prototyped
- Static data collection method goal (30 m transmission) confirmed in test bed field between underground and ground. Drive-by data collection goal (running terminal activation and transmission) also confirmed
- Terminal activation and data transmission performance in actual field movements confirmed

B) Sensing data handling technology: saving monitoring sensor power

Target (continuous operation for over 5 years) achieved

- Continuous operation for about 10 years with one battery (capacity 10 Ah) confirmed from power consumption evaluation performed through device circuit design and simulation



Current Accomplishments (2/2)

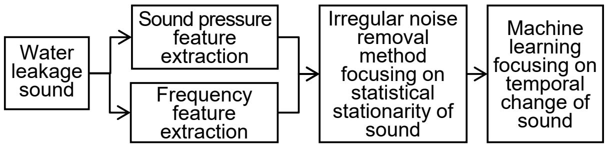
B) Sensing data handling technology: infrastructure equipment monitoring data processing technology

Usage of small/medium diameter metal pipes confirmed effectiveness of basic technology for water leakage

(i) Usage of actual data quantified water leakage determination task
- Micro/fine water leakage sound characteristics propagating through pipes
- Water leakage sound characteristics due to pipe material, tube diameter, leakage volume, etc.
- Particular irregular noise for each place/time slot

(ii) Analytical methods designed to address problems
- Machine learning using multidimensional feature extraction focusing on sound pressure/frequency distribution
- Irregular noise removal method focusing on statistical stationarity of sound
- Individual learning model for each place focusing on temporal change of sound and location-independent common learning models

(iii) Measured data used to confirmed recognition rates of invented technology
- Learning models confirmed recognition rate of 98% plus for long water supply pipes of small/medium diameter. Models covered all verification data places including the actual environment. A common learning model independent of place is now being evaluated.
- Effectiveness of invented technology in various fields is now being evaluated.

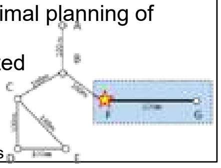


Process flow of invented analysis method

C) Optimal planning of water leakage monitoring systems

Modeling and formulation established as mathematical optimization problem

- Facility location problem "k-median problem" focused on to formulate basic networks to examine optimal planning of leakage sensors
- Fundamental method evaluation completed by designing optimum installation points through weighting taking important risks in formulated networks into account


Formulated network examples

D) High sensitivity sensor terminal technology

Design of high sensitivity sensor and integrated sensor terminal completed

- Pipes efficiently and effectively monitored through high sensitivity sensor terminal design completed over wide frequency bandwidth with doubled conventional sensitivity


Designed integrated high sensitivity sensor terminal

Goals

Final goals

Complete technical verification in actual water supply systems of local governments for social implementation. Complete the function expansion of data collection and analysis technology in conjunction with other themes to expand applicability domain.

A) Sensing data collection and transmission technology	Development of transmission technology that can acquire long-term data without opening and closing manholes from sensors installed underground
B) Sensing data handling technology	Determination of leakage levels without dependence on worker's skill level by utilizing machine learning using multidimensional feature extraction
C) Optimal planning of water leakage monitoring systems	Development of priority evaluation system for optimum water leakage monitoring plan for water supply pipeline network
D) High sensitivity sensor terminal technology	Development of a practical level high sensitivity sensor terminal that can detect micro leakage sound on a long term basis.

Deployment image

Domestic	Monitoring of water pipes to enable early detection and prevention of leakage
Overseas	Reduction in water leakage, development of water supply management projects, improvement in water supply infrastructures

41 R&D of Integrated Data Management Platform for Civil Infrastructure Sensing

Principal Investigator Jun Adachi (Professor, National Institute of Informatics)

Collaborative Research Groups Hokkaido University, Tsukuba University of Technology, Nagaoka University of Technology

R&D Objectives and Subjects

Objectives

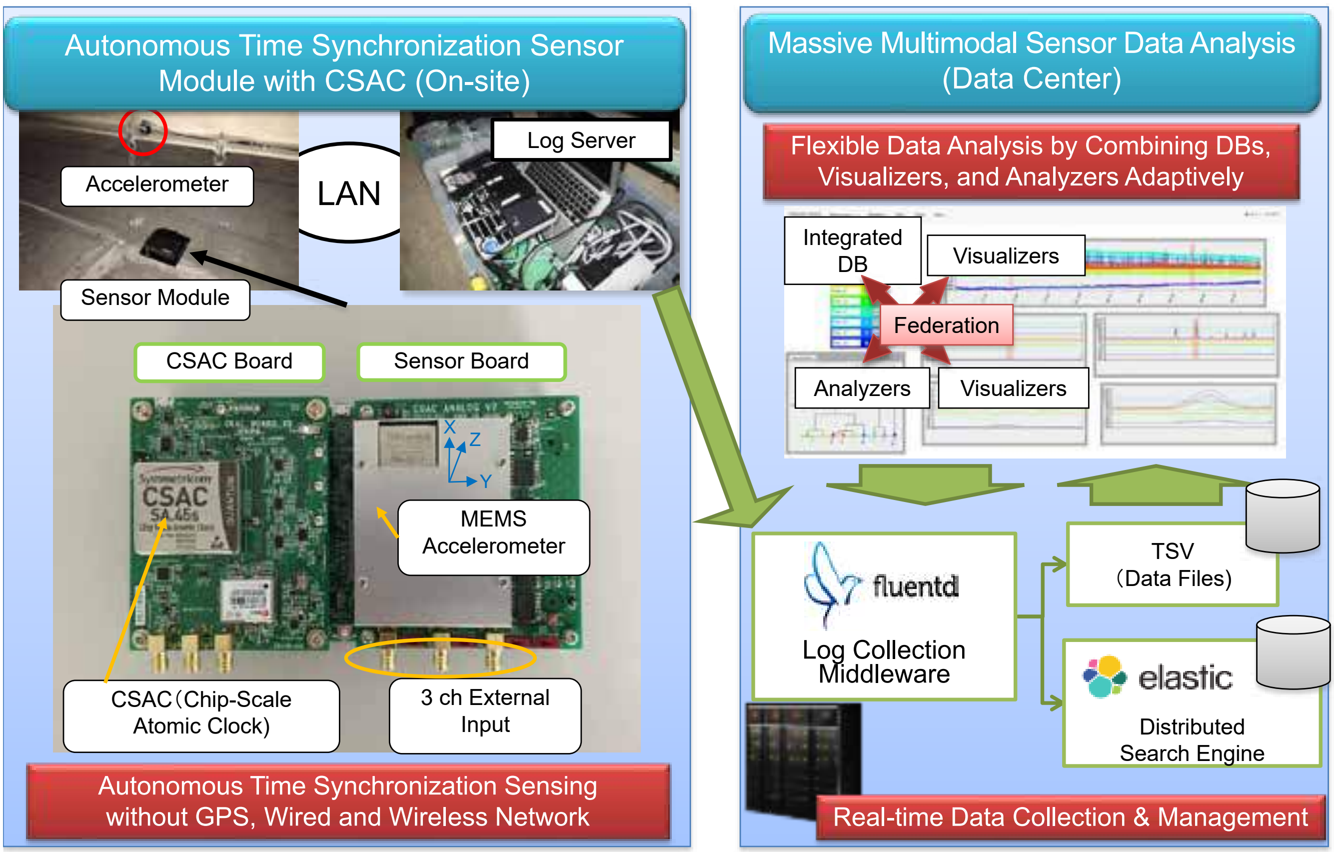
- ❖ Data Management Technologies : to develop efficient multimodal monitoring data management technology for analyzing, storing and utilizing massive data.
- ❖ Analysis Technologies : to extract features that may reflect structural deformation for defining new structural-deformation indices through the collaboration between structural analysts and data scientists.
- ❖ Time Synchronization Sensing Technology : to develop multimodal sensing technology for integration of various sensors with autonomous time synchronization.

Subjects

- ❖ R&D on an exploratory visual analytics environment that integrates varieties of analysis and isualization tools with database systems.
- ❖ Accurate vehicle detection and feature extraction related to structural deformation of bridges by combination of frequency analysis, signal processing and data integration technologies.
- ❖ R&D on a multimodal sensing module with an autonomous time synchronization using Chip-Scale Atomic Clock (CSAC) that integrates various sensors.

Current Accomplishments (1/2)

Data Management Platform



Current Accomplishments (2/2)

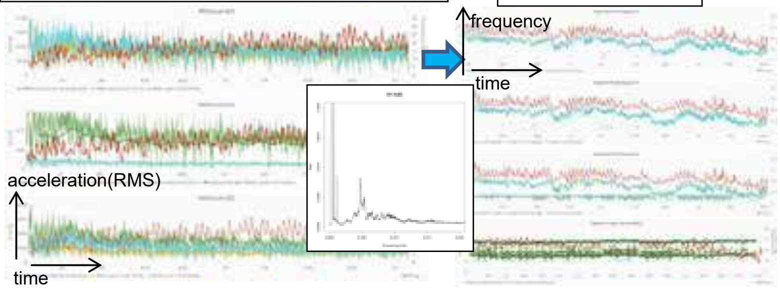
Sensor Data Analysis

◆Vibration analysis system for long-term multi-sensor monitoring with high-precision accelerometers

❖ Detecting vibration characteristic change caused by external factors such as temperature changes, using long-term multi-sensor monitoring

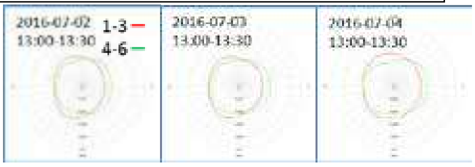
Visual analyses of long-term vibration data

Tracking peak frequency change



Improving the detection accuracy of the natural frequency change caused by the temperature and/or traffic change

Radial distribution of average acceleration differences in 36 directions



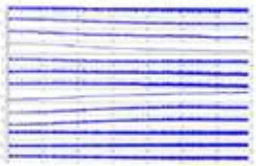
Placement of three neighboring sensors

Analyzing the change of pseudo-stress distribution

◆Accurate Vehicle Detection

❖Integrated analysis of video and sensor data for accurate vehicle detection

Data from cameras and Sensors installed at bridges

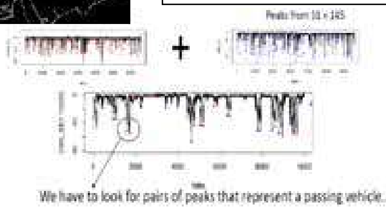


Video Processing

Signal Processing

Vehicle Images

Peaks corresponding to Vehicles



Goals

toward efficient road management

Bridge Management Support

Metrics for structural deformation based on visual and hammering tests, and nondestructive inspection

Bridge Structural Analysts
❖Physical model
❖Simulation

Interpretation of features

Mapping between metrics and features

Features related to structural deformation extracted from sensor data

❖ Feature extraction by data analysis/mining
❖ Flexible and speedy monitoring with portable sensing
❖ Multi-modal monitoring with time synchronization

Output

Sensing data analysis for supporting road maintenance planning

- DB prototype system for managing various infrastructure maintenance data
- Accurate bridge-weigh-in-motion
- Metrics and use guidelines for sensing data analysis

Promotion of Developed Systems

Multi-sensing technology by autonomous time synchronization

Technical specifications of sensor module that can be commercialized

Open source software for integrated sensing data management, visualization and analysis

① Open package software
•Publish integrated software

② Open software libraries easily portable to other systems

•DB system modules, data visualization libraries

•BWIM libraries, feature extractor for structural deformation detection

•Expansion of sensors and data formats

•Tutorial, manuals

Promote software usage by publishing modules and libraries with a commercially usable license (e.g., Apache 2.0, New BSD license)

42 Development of Technologies on Wide Variety of Data Processing, Storage, Analysis and Application to Achieve Advanced Infrastructure Management

Principal Investigator Isao Ueda (East Nippon Expressway Company Limited)

Collaborative Research Groups Social Capital Design (Inc.), Yokosuka Telecom Research Park, Inc

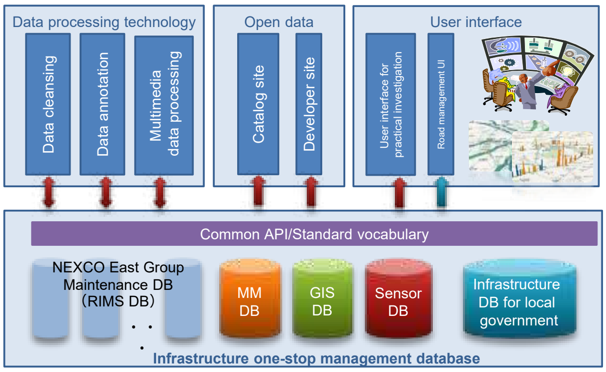
R&D Objectives and Subjects

Objectives

1) Matching needs related to maintenance and technology development requirements: With the NEXCO East Group maintenance operations as the field of evidence, set matching development conditions (seeds) after clarifying the work issues/needs.
2) Development of formats for using new technology in the field: In addition to effectively using existing assets, such as current systems and stored data, we will deploy the actual operation in stages while verifying and evaluating new technology in the field.
3) Improve the standard of maintenance through preventive maintenance: In order to use a wide variety of data effectively, owners, management, and the field should share information functionally, and develop a "user" environment for supporting accurate judgments and smooth enforcement.
4) Achieve at a low cost: Concentrate on the use of current systems and open data, as well as the adoption of standard technology, and utilize this for government bodies.

Subjects

- Visualize various information in an integrated way in accordance with the work of the administrator.
- Realize a circulation of information with external bodies, through open data, etc.
- Valid data for operations, analysis methods and expressions, etc., should be reflected in the DB.
- Grasp issues practically during DB use and set realistic policies
- Apply standardization from to infrastructure from all directions, reorganize and document
- Design data model/API, etc., while envisaging an actual method of use
- Based on site verification, process and correct data in stages
- Fully automate data cleansing and multimedia processing



Current Accomplishments (1/2)

Achievements ①: Data model, System Architecture, and DB Design for Infrastructure Maintenance, with IoT in Mind

■ Overview of Achievements

(1) Develop a data model for managing infrastructure, from acquisition to the use of a wide variety of data. This includes data stored in the past and data envisaged in the future, such as sensor data, and organize this into "Road Information Specification (1st edition)". This model can be applied to administrators of different infrastructures, such as expressways, national highways, and local roads, and it can be described in both the specifications of buildings and maintenance information.

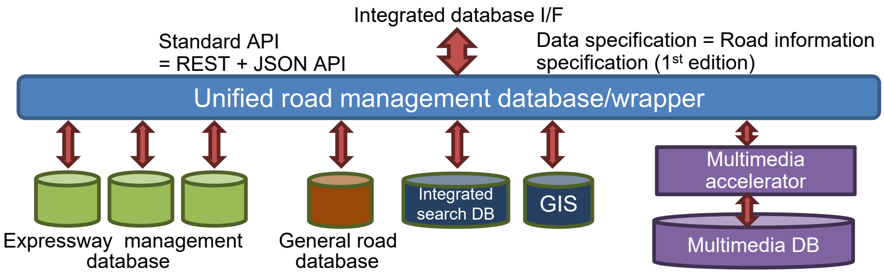
(2) Develop web-based "Road Information Database API Specification (1st edition)" that is not dependent on database software and can search across multiple databases.

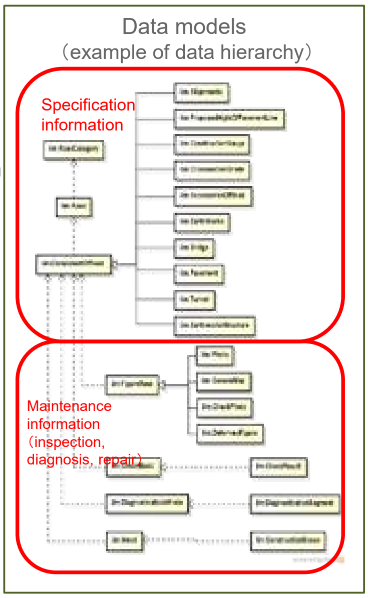
■ Needs/issues and Effectiveness of Main Achievements

The infrastructure administrator has a wide variety of data and there are many issues, such as data format compatibility and data definitions. Therefore, circulating and using data has been difficult.
Through this achievement, through the linking and searching of geographical information located in multiple databases, effective utilization has become possible through data integration and linking.

■ Technical Novelty and Superiority

A data model is essential for circulating and using a variety of data across organizations and operations, but there is no data model in the road management field that can comprehensively express data for both expressways and ordinary roads.
Furthermore, it has become possible to integrate multiple databases, while maintaining existing systems in a short period at low cost.





Data model that can be described as both building "specifications" and "maintenance information"

Current Accomplishments (2/2)

Achievement ②: Develop dialog-based UI according to usage formats in the field

■ **Achievement Overview**

Our goal is to develop a dialog-type user interface, reflecting the format used in the field, to utilize the DB developed under " Current Achievements ①". This can be achieved through API and messaging. Also, while verifying the DB functions, develop test applications that can be verified in the field.

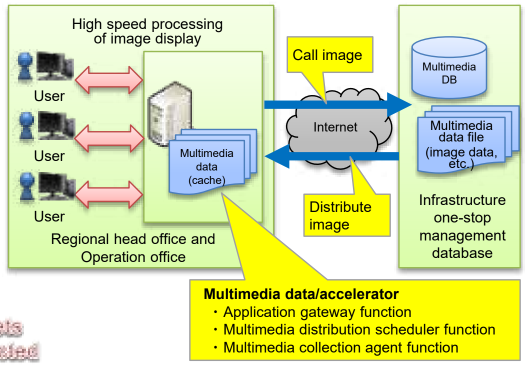
■ **Needs/Issues and Effectiveness of Main Achievements**

In the field of infrastructure management, by sharing the same information at the same time between the head office, regional head offices, business offices, and the field, and by grasping facility and position-related information from complex perspectives, it is possible to make accurate judgments. This achievement has made it possible due to links and display real-time data between different devices in multiple fields.

■ **Technical Novelty and Superiority**

Achieve multi-scale UI to meet the needs of a variety of maintenance fields. By linking and displaying managed objects in a variety of ways from multiple views, this has achieved comprehensive management and decision-making. Furthermore, to meet cases where maintenance is being operated in multiple bases, they have developed mechanisms to automatically collect and synchronize multimedia data managed in a distributed way.

Application for investigation



"Multimedia data/accelerator" function to ensure real-time qualities

Goals

① Overview of Products and Services Using Achievements in SIP

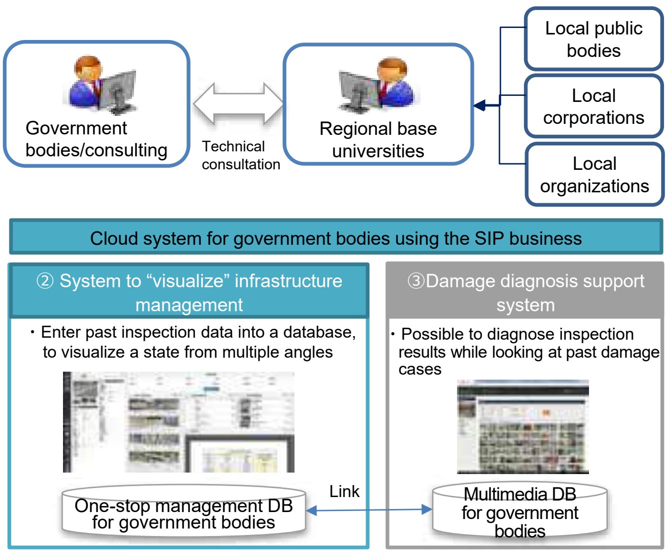
We will construct a framework for supporting infrastructure management in government bodies, in which data (text/images etc.) that is inspected and diagnosed by the infrastructure administrators of local public bodies, etc., is stored in the DB, and undergoes integrated analysis and evaluation. In order to respond flexibly to the scale and financial authority of the infrastructure administrator of the municipalities, ordinance-designated cites and prefectures, Social Capital Design, Inc., have provided this as a cloud system.

Based on a cloud system, they are providing technical support and data cleansing for inspection and diagnosis, in collaboration with regional universities, etc.

② Form of Implementation When Implemented in Society

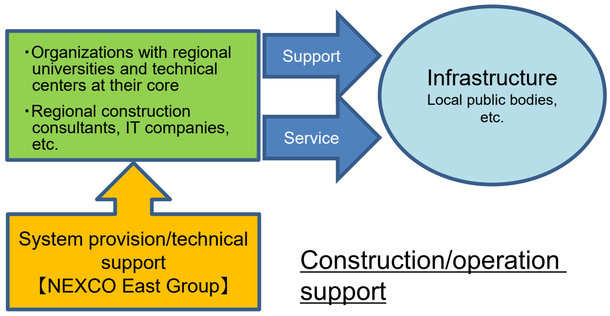
Regional universities and technical centers, etc., provide services such as operational improvement and technical advice, and nurtures human resources using infrastructure maintenance data based on this cloud system to localize public bodies, etc. (this is planned for implementation at Tohoku University and in Yamagata Prefecture in 2017)

It is envisaged that construction consultants and IT companies, etc., shall use this system in various regions, and its services will be provided in regional units.



③ Effect of this business (promoting employment, etc.)

Encourage the employment of consultants related to inspection and diagnosis, construction companies providing repair advice, IT companies developing and maintaining DB/UI, and university researchers providing technical advice and analysis.



Construction/operation support

44 Development of infrastructure inspection system using semi-autonomous multi-copter equipped with flexible electrostatic adhesive device.

Principal Investigator Tadahiro Hasegawa (Professor, SIT Tokyo)

R&D Objectives and Subjects

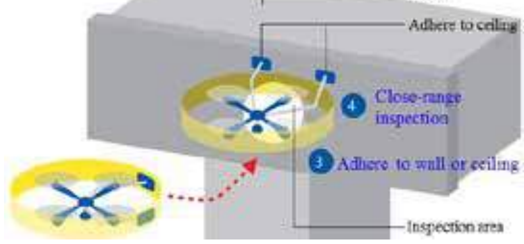
Objectives

Inspection efficiency might be low and a dangerous operation

Low cost, high efficiency, safety inspection is required

Semi-autonomous multi-copters will adhere to the walls of Inspection areas by using electrostatic an absorption device to firmly secure its position. Close-range images are taken by camera to inspect infrastructures.

Image of our R&D theme



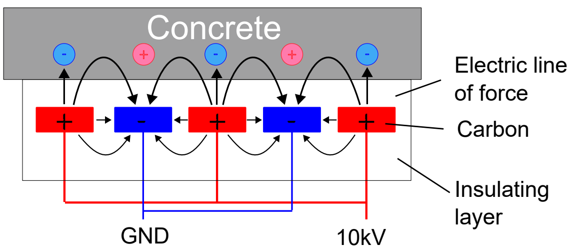
Subjects

1) Technological development to adhere to a concrete wall by using electrostatic adhesive principle
A flexible electrostatic adhesive device with adhesive force of 1 kgf or more, when applying 10 kV

2) Validity verification of infrastructure inspection, by constructing a demonstration system
① Transport inspection equipment and approach infrastructure wall by small UAV.
Development of semi-autonomous multi-copter with wired power supply cable
② Wall inspection using close-range photographic camera.
Development of crack detecting algorithm for close range visual inspections using camera

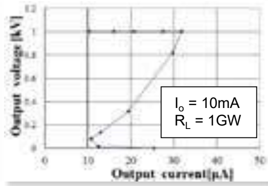
Current Accomplishments (1/2)

Adhesive principle



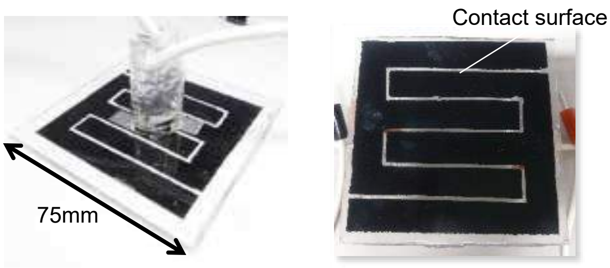
Adhere to concrete walls using an electrostatic force

Compact/Lightweight/10 kV Booster



1) Compact, Lightweight (157 g, 120 x 50 x 30)
2) Output 10 kV stably by using a 9 V dry cell
3) Equipped with current limit circuit of 30 μA

Flexible electrostatic adhesive device



1) Compact, Lightweight (60 g, 75 x 75 mm)
2) Flexibility to fit on a concrete wall
3) Can adhere not only to steel but also to concrete

Experimental verification on concrete

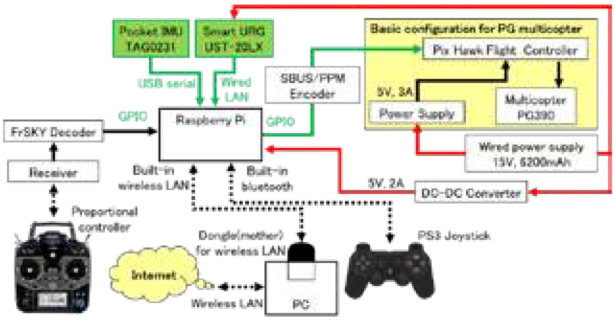
Over adhesive force 1 kgf on concrete wall.

Next Step : Multi-copter with this device

Current Accomplishments (2/2)

Semi-autonomous multi-copter

Fusion system using both
manual and autonomous operations



Easy to apply to
commercially available multi-copter

Development platform

Experimental verification in bridge

Utilizing several sensor data for autonomous flight,
and close-range camera images in bridge girder

Next Step
1) Multi-copter with adhesive device
2) Autonomous flight to approach concrete slab safely for absorption
3) Collision avoidance for operation support
4) Self-localization for bridge girder

Goals

Goals for this R&D theme

1) Flexible electrostatic adhesive device
- Can adhere to a concrete wall, on uneven surfaces of 5 mm or less.
- Adhesive force of 1 kg or more
- Adhere a multi-copter with three adhesive devices on a concrete wall

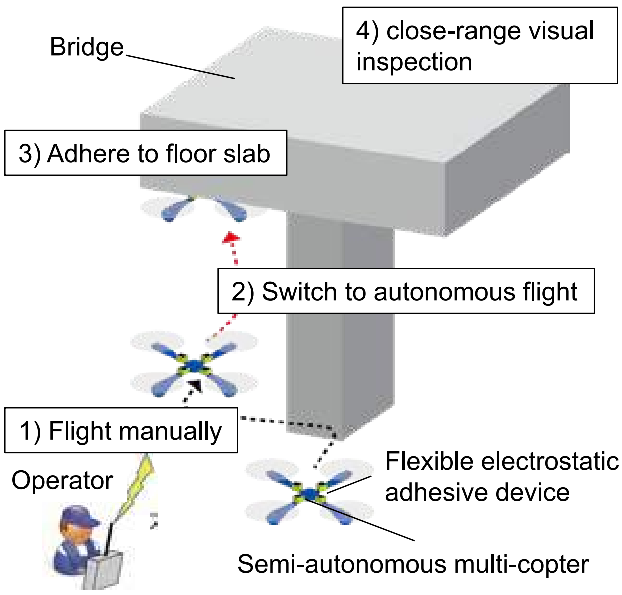
2) Semi-autonomous multi-copter
- Can switch between manual operation and autonomous flight during flight
- Collision avoidance function
- Self-localization accuracy of about 10 cm at bridge girder

3) Realize the flow of our inspection system

Social Implementation Image of this technology

- User : Inspection agency
- Place : bridge
- Application : Close-range visual inspection, crack repairs, fixing an inspection device to a bridge wall

Application image of this technology



By having it adhere to a concrete wall of a bridge, it can be used not only for close-range visual inspection but also for repair work.

45 R&D of Diagnostic Technology Based on Measurement and Analysis by Multi-Copter

Principal Investigator Toshio Fukuda (Professor, Meijo University)

Collaborative Research Groups Meijo University, Okino Industries, Ltd.

R&D Objectives and Subjects

Objectives

- Japanese local authorities are obliged to inspect bridges and tunnels every five years.

Accident Risk | Precision | Cost

Generate new inspecting technology by applying robotics

Realize inspecting multi-copter operating hammering test and carry out stable and precise visual checks.

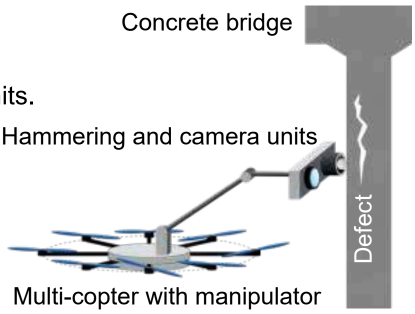
Subjects

R&D Part 1: Develop a multi-copter which implemented inspection units.

1-1 Develop multi-copter with a mounted manipulator and inspection units.
1-2 Develop a simulator for the multi-copter.
1-3 Develop a control system for the multi-copter.

R&D Part 2: Develop diagnostic technique of hammering and visual test.

2-1 Develop diagnostic technique for hammering tests.
2-2 Develop diagnostic technique for visual checks.

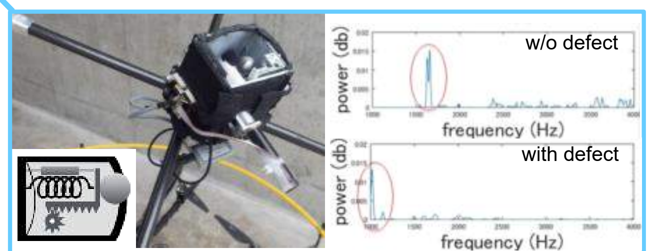


Current Accomplishments (1/2)

Our multi-copter is enabled to inspect concrete bridges effectively as a substitute for a human Inspector.

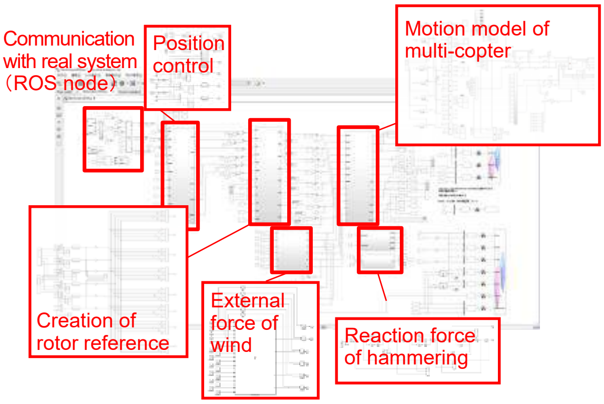
The camera unit enables to acquire the shift of the copter and senses crack by image processing. Quantitative analysis makes crack detection more precise.

One - joint manipulator enables the copter to contact floor slab and bridge pier. The manipulator directs inspection units horizontal/vertical surfaces. Therefore human inspectors do not need to endure working in high places.

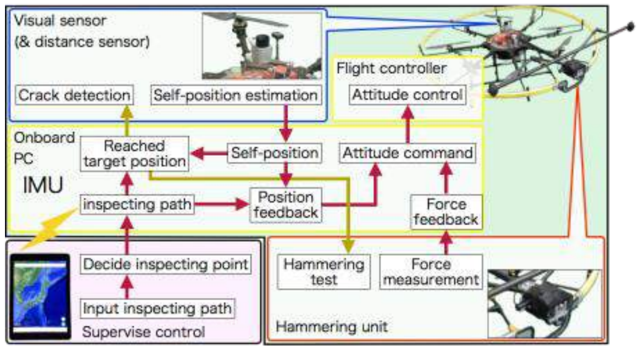


The hammering unit hammers object surfaces and is driven by a motor and a spring. The echo is captured using a microphone and is analyzed to see if there are defects. Quantitative analysis makes defect detection more precise.

Current Accomplishments (2/2)



The motion simulator of the multi-copter accelerates R&D of the multi-copter system.



The control system is being developed; the multi-copter could be controlled by tablet/PC inputting path.

Achievements

International conference

- Takahiro Ikeda, Kenichi Ohara, Akihiko Ichikawa, Toshio Fukuda, “Pilot Study on Control of One DoF Manipulator on Quadcopter for Hammering Check,” Proc. of 2015 Intl. Symposium on Micro-NanoMechatronics and Human Science, pp. 199, November 23 - 25, 2015.
- Junpei Kishikawa, Kenichi Ohara, Takahiro Ikeda, Akihiko Ichikawa and Toshio Fukuda, “Vision-based Localization for Atomated UAV Automated Multicopter Control,” Proc. of 2016 Intl. Symposium on Micro-NanoMechatronics and Human Science, TP-14, November 28 - 30, 2016.
- Domestic conference: 6 presentation

Patent (Japanese Domestic)

Title of invention : Device for flight
Overview : Device enabling easy inspection; the device flying with propeller that is equipped with a simple manipulator implemented inspection device.
Japanese Patent Application No. 2015-091386

Title of invention : Device for moving
Overview : Main moving device controlling own position hanged by plural wire-reel suspension mechanism modulating the length of the wire. The device can move with equipped propulsion mechanism in a direction that it is not bound by the suspension mechanism.
Japanese Patent Application No. 2015-091387

Goals

Numeric goals

Hammering unit:
Hammer objects once/sec at 50 cm distance.
Detect defects at 10 cm depths automatically.

Camera unit:
Detect cracks at a minimum of 0.2 mm automatically.

Flight control:
Supervise control; auto flight with inspecting-path command by user.

Safe | High precision | Low cost

Automatic inspection

Social implementation

<Road Administer>
Ministry of Land, Infrastructure and Transport, Local authorities, Expressway company, etc.

Consultancy and inspection company

Construction company (Construction・mending)

Meijo University, Okino Industries, other cooperative companies.

Commercialize
Processing inspection data
Renting/selling inspecting system

Oversea expansion

46 Development of Intuitive Teleoperation Robot using the Human Measurement

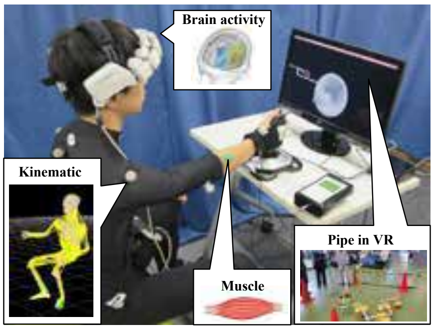
Principal Investigator Shigeki Sugano (Professor, Waseda University)

Collaborative Research Groups Chiba University

R&D Objectives and Subjects

Objectives

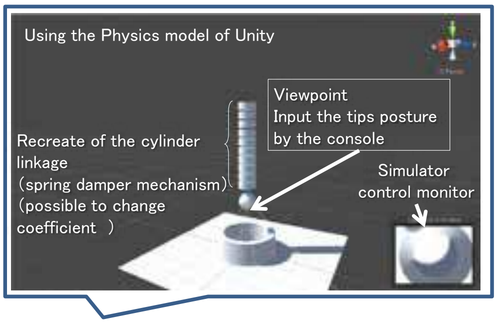
- Development of an intuitive interface between operator and robot
  - To be used in complex and strange working environments, such as pipelines, under bridges.
- Extraction of the standard and common human characteristic model for operation
  - The human measurement when operating the robot or drones.
  - In this study, the pipeline inspection robot control is the test case

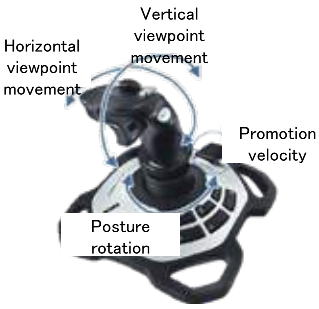


Subjects

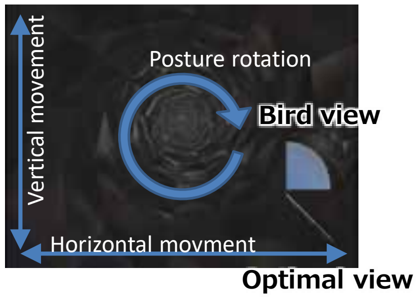
- Construction of the virtual pipeline inspection simulation
- Clarification of the professional human model by measuring the human brain and muscles and a working score, such as the curvature of operations and time of accomplishment
- Design of robot configuration and a control method based on the extracted human model
  - Construction of the intuitive robot design methodology
- Compared with the conventional method, this study focuses on human centered design

Current Accomplishments (1/2)

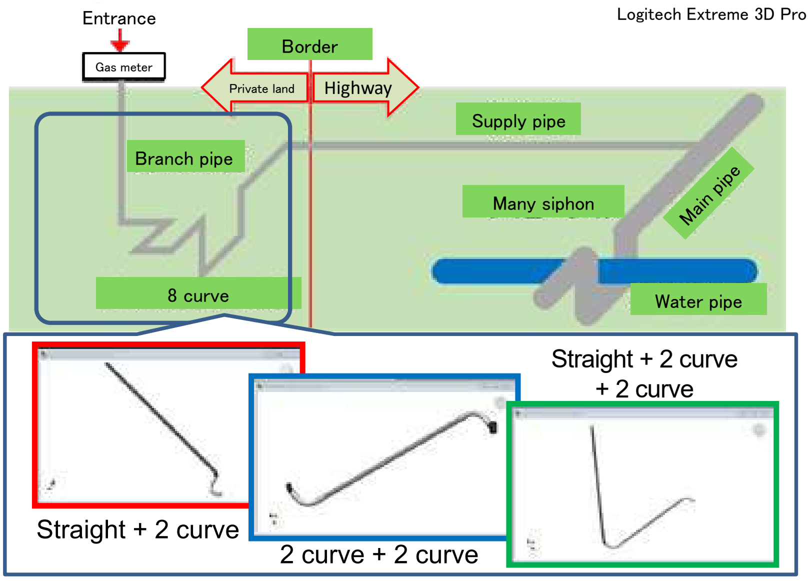




Logitech Extreme 3D Pro



Simulation monitor view



- Pipeline inspection robot design simulator
- Viewpoint located on the tip
- Evaluation by scenario base
- Recreation of the pipe at JIS
- 25 A 8 curved pipe + 50 A pipe siphon

Current Accomplishments (2/2)

Construction of intuitive operability evaluation method

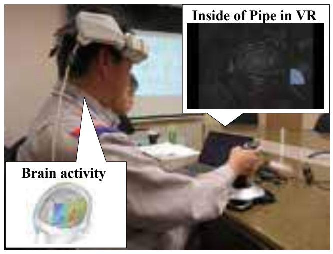
Manipulation
(Viewpoint fixed)

Assumed robot
- Debris removal robot
- Drone with arms

Outcome
- Intuitive hand-eye coordination
- Acceptable error of tips posture between master-slave

Locomotion
(Viewpoint located robot)

Assumed robot
- Pipe checking robot
- Drone



Outcome
- Controlling robot gains speed as the human walks
- Clarification of the stress of operation by brain activation

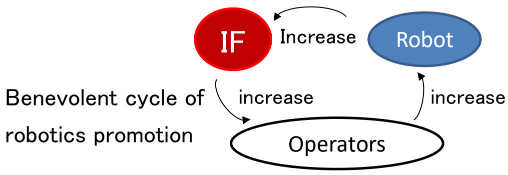
Development device and systems

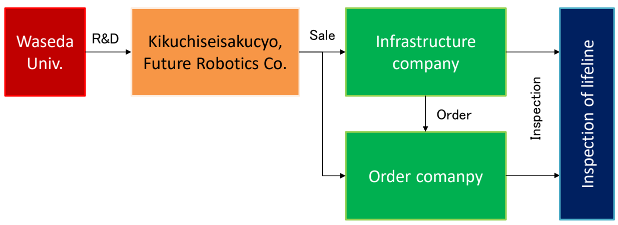
Console
- Pitch, yaw and roll rotation of tip
- Movement of back and forth
- Utilization of wrist range of movement
- Force feedback by spring

Navigation
- Presentation of navigation in the monitor as immersive reality of operators
- Improvement of visibility as correspondence between controller and robot tip

Goals

- Sale of the Interface for operation
  - Applicable of locomotion robots
    - ✓ Drone, submersible, pipe inspection, crawler
  - Contribution
    - ✓ Promotion of robots by increasing the number of operators
- Operation form in society
  - User
    - ✓ Inspector of bridges, pipes, etc.
    - ✓ Operator of crawler robot
  - Location
    - ✓ Bridge, pipe, debris workspace
  - Business
    - ✓ Sale from Future Robotics Co. and Kikuchiseisakusyo
    - ✓ Purchase of infrastructure company and order company





SIP	Sale	User
◆ Getting patent ◆ Construction of technology and outcome ◆ Validation of evidence	◆ Making manufacturing line ◆ Sale ◆ Making of special order item ◆ Maintenance	◆ Integration of the interface and robots ◆ Promotion of robotics installation ➢ Increase of the operators ◆ Inspection of lifeline

47 Development of Bridge Inspection Robot System Supported by the Provisional and Flexible Scaffolding Structure

Principal Investigator Dr. Shigeo Hirose (Representative Director/Chairman, HiBot Corp.)

Collaborative Research Groups CTI Engineering Co., Ltd. / Tokyo Institute of Technology

R&D Objectives and Subjects

Objective

- Proposing a bridge inspection device capable of operating in complicated structures with an extendable arm mechanism. Inspection is carried out with a movable camera and illumination solution.
- Easy inspection is obtained by stitching the acquired images in the bridge virtual 3D model
- Evaluation of the inspected surface is improved by acquiring additional data with a tapping device

Contents

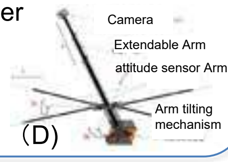
- The inspection device is controlled under the bridge surface by controlling simultaneously the length of 4 wires
- Possibility to carry out visual and tapping inspection close to the surface
- By extending the arm equipped with attitude sensor, operator can further inspect the surface
- Winches are fixed utilizing clamping devices and the arm is control from a movable compact control cart
- UAV and sling shot devices are used for the guiding of the initial wire
- Database for the acquired data to facilitate the inspection

Main Items of Development

- ❖New robotic system to allow new detailed inspections
- ❖The following images show the operation of the new system

(A) (B) (C)

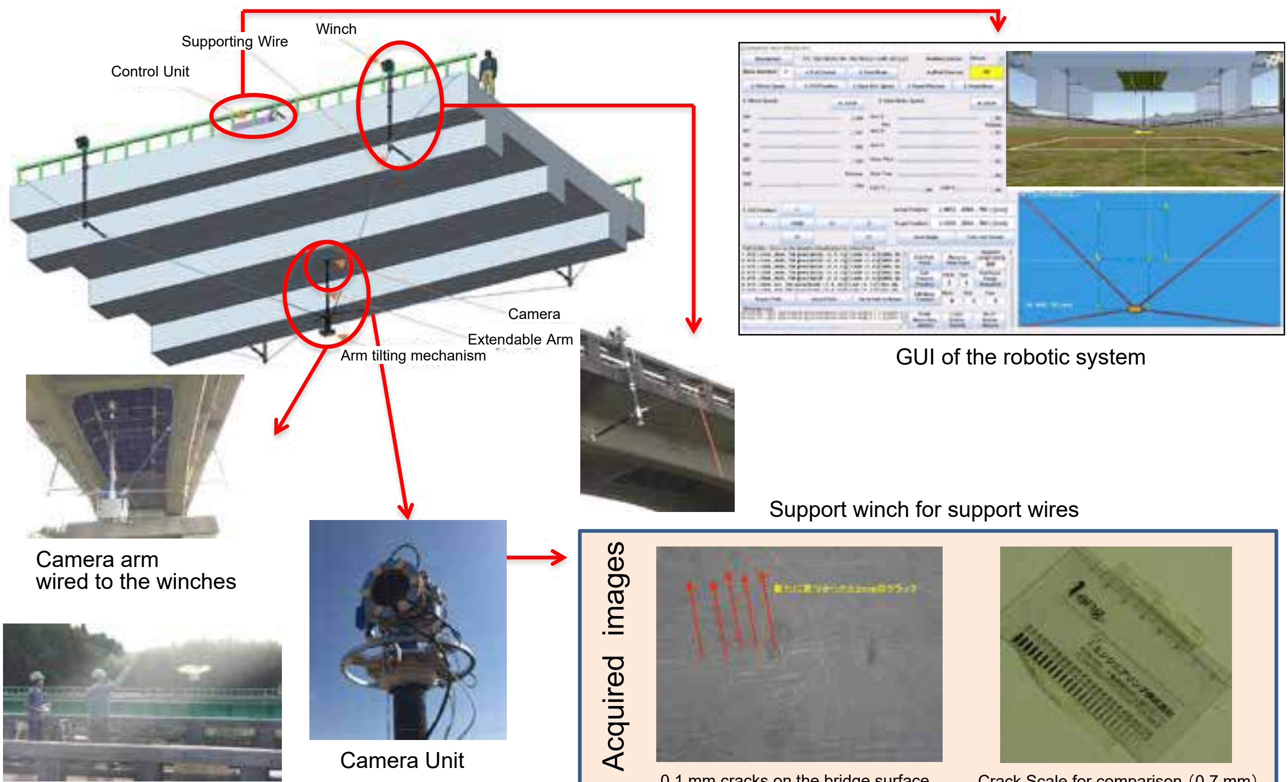
1. Setting of the four clamps for the winches' installations
2. UAV or slingshot is used to take the wire from one side to the other of the bridge. Four wires are set under the bridge (A)(B)
3. By controlling the 4 wires the camera system is moved under the bridge surface (C)(D)
4. The whole system is recovered by following the inverse procedures



(D)

Current Accomplishments (1/2)

Overview of the robotic system "BRIDGEVIEW"



GUI of the robotic system

Support winch for support wires

Camera arm wired to the winches

Camera Unit

UAV for wire guiding

0.1 mm cracks on the bridge surface

Crack Scale for comparison（0.7 mm）

Current Accomplishments (2/2)

Experiments and demonstrations were carried out on November 1st 2016 at Sakiku Bridge (Ibaraki Pref.) and on January 26th 2017 at Tozawa Bridge (Kanagawa Pref.)

Supporting winches（prototype）

Winch

- Each winch can be firmly set on the bridge using clamps and auxiliary wires
- By controlling the four winch wires length, the arm can be arbitrarily set in an area of 5 m by 10 m
- Arm can be moved at a speed of 8 cm/s

UAV for wire guiding (prototype)

UAV flying test

- Confirmed the hovering function based on several sensors' data, such as from cameras, gyro, etc.
- Confirmed stable flight while taking a wire of 10m under the bridge to connect the lateral sides

Extendable Camera Arm（prototype）

Extendable Arm

- Mass：15 kg
- Inspection device as end -effector of the arm
- Arm extension mechanism
  max. extension：3 m
  extension speed：10 cm/s
- Arm tilting mechanism
  inclination angle control：±11 degrees

Camera Unit（Prototype）

Camera Unit

- Attached as end effector of the arm
- Mass：0.7 kg
- Pitch range：-90 ~ +35 degrees
- Yaw range：360 degrees
- Crack resolution inspection, in low luminosity, up to 0.15 mm

Goals

Final Specifications of the Robotic System (March 2019)		
1	Extendable Arm speed	0.3 m/sec
2	Extendable Arm maximum length	2.5 m
3	Arm roll control range	More than 20 degrees
4	Continuous operation time	More than 3 hours
5	Dust and water protection	IP55
6	Mass of the extendable arm	Less than 15 kg
7	Largest area covered by four winches	30 m × 30 m
8	X, Y arm position resolution	within 100 mm

Finale Specification for the visual inspection Unit (March 2019)		
1	Pitch range	±90 degrees
2	Yaw range	360 degrees
3	Minimum crack width	0.05 mm
4	Dust and water protection	IP56
5	Mass	Within 2.0 kg
6	Continuous operation time	More than 3 hours

Inspection system targets	
Number of operators	Inspection operator x 1 Assistants x 2 Total: 3 operators
Setting time	Robotic system 1 h Inspection 3.5 h
Inspection output	Database generation with 3D image rendering and location information（possibility to track the bridge crack changes）
Traffic regulation	No regulation required
Inspection location	Inspection of the lower sides of piers

- The system could be an alternative for the actual inspection vehicles currently utilized.
- Targeting a nationwide cooperation with inspection companies and an increase in the number of bridges that can be inspected

48 R&D of Flying Robot for Bridge/Tunnel Inspection

Principal Investigator: Toshihiro Nishizawa (NEC Corporation)

Collaborative Research Groups: Autonomous Control Systems Laboratory, LTD., Highway Technology Research Center, National Institute of Advanced Industrial Science and Technology

R&D Objectives and Subjects

Objectives

Develop alternative system for infrastructure inspection utilizing a flying robot with hammering test equipment

Problems with the conventional inspection method

① Road closure during inspections
② Difficulties with inspecting high areas
③ High risks for human inspectors

Utilization of flying robot

① Reduction of road closure time
② Easier access to remote areas
③ Less risk during the inspection

Bridge and tunnel environment

Flying robot under development

Hammering test equipment

Research Topics

① Development of flight control technology to cope with **GPS-denied and highly windy environments**
② Research of **inspection technology for concrete structures using hammering test equipment**
③ Research of effective ways of inspection in terms of **safety and time**

Current Accomplishments (1/2)

Current Status :

- Prototyped flying robot for inspection and proved its operational concept in real environments, such as highways
- Realized fully autonomous flight control under a GPS-denied environment with localization, utilizing Total station and LRF
- Achieved stable hammering where a human inspector can differentiate between clear and non-clear hammering sounds
- Conducted wind tunnel testing at a JAXA facility to verify its flight stability under normal winds of 8 m/s.
- Developed easily deployable safety net system

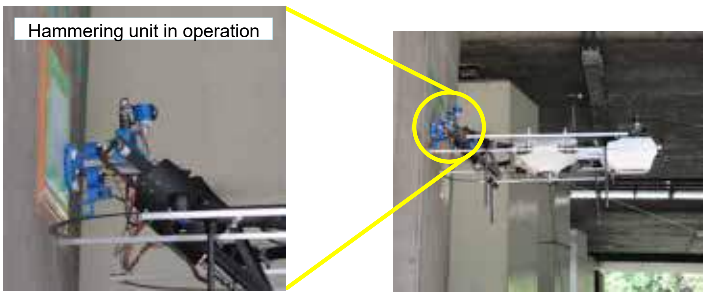
*LRF : Laser Range Finder

Prototype of flying robot

Wind tunnel testing at JAXA facility

Prototype of safety net system

Flight robot keeping hammering test equipment at the bridge surface

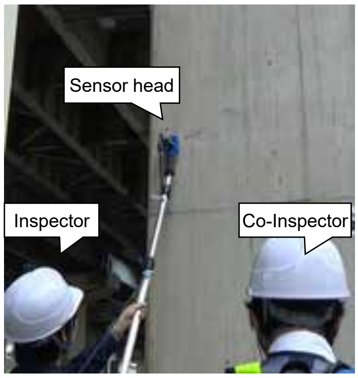


Current Accomplishments (2/2)

Current Status:

- Prototyped hand carriable hammering test equipment for inspection at areas under 6 m
- Proved its performance effectiveness in lowering the inspection cost and time
- Implemented machine learning into the detection algorithm to improve its performance.
- Developed acoustic filter to reduce noise from the flying robot

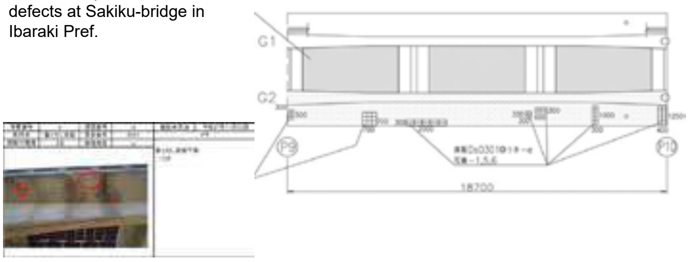
Prototyped handy inspection unit



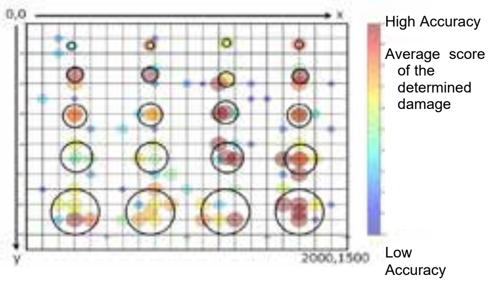
Inspection results recorded to the GUI installed in the tablet

Example of the inspection record generated by the system

Record of spots detected to have defects at Sakiku-bridge in Ibaraki Pref.



Result of concrete defect detection in the test piece



Black area : flacked spot
It was proved that the system can detect those spots with high accuracy

Goals

Final Goals:

<In Common>
- Conduct tunnel/bridge hammering inspection
- Detect flackings in the concrete

<Flying robot with inspection unit>
- Continuous operation for 2 hours
- Operation at 30 m height (max.) and 8 m/s wind (avg.) environment

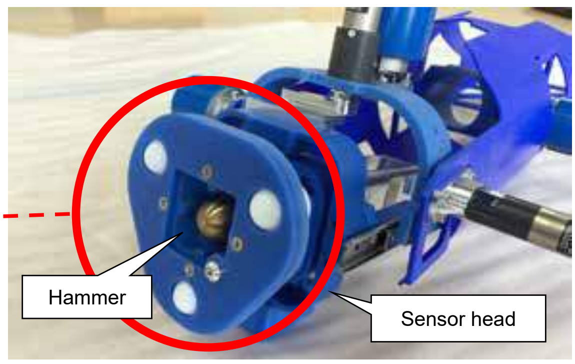
<Handy inspection unit>
- Easy inspection under 6 m high area

Social Implementation Steps:

- Replace aerial work platforms with this system
- Lease the system to inspection companies
- Provide inspection portal service in cloud platform
- Evaluate the system in various environments, such as SIP application project at Gifu Univ., to improve its performance
- Apply its technology to different types of inspection

Flying robot under development

Reduced its weight by 40% compared to the previous flying robot



49 R&D of The Variable Guide Frame Vehicle for Tunnel Inspection

Principal Investigator Satoru Nakamura (Chief researcher, Tokyu Construction Co.,Ltd.)

Collaborative Research Groups The University of Tokyo, Shonan Institute of Technology, Tokyo University of Science, Ogawayuki Seisakusyo Inc., Kikuchi Seisakusyo Co., Ltd.

R&D Objectives and Subjects

Objectives

●Tunnel maintenance engineers have conducted human-eye based close inspection using mobile elevating work platforms up to this point in time. The conventional inspection method requires traffic regulation for road users. One of objectives of this R&D is to reduce the traffic regulations during inspection works that are convenient to both road users and administrators.

●It takes much time for conventional inspection and hammering tests of wide areas. Be sides, conventional depending on inspectors. We have proposed a "Variable guide frame vehicle" that is new maintenance technology.

Tunnel inspection

Subjects

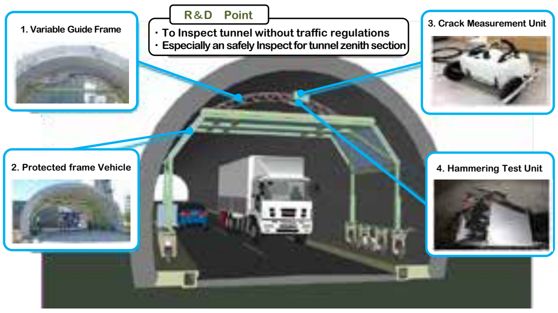
Main Theme

(1) Variable Guide Frame(VGF)
Can be changing shape according to the various tunnel geometries and obstacles.

(2) Protective Frame Vehicle
Can protect road users from falling concrete pieces.

(3) Crack Measurement Unit
Can integrate visible images and 3-dimensional shape depth data (range image) by the light-section method and distinguish between cracks and dirt automatically.

(4) Hammering Test Unit
Can detect possibility of concrete spall from hammering sounds through machine learning.



VGF vehicle

Current Accomplishments (1/2)

Inspection vehicle for regulation less traffic

Variable Guide Frame(VGF)

Change frame shape

Guide frame（1unit）

【Overview】
- Guide frame can deform by expansion and contraction of its actuators.
- It detects obstacle position and determines the quantity of necessary expansion and contraction of the actuators by inverse analysis.

【Topics】
- Performed operation check on experimental tunnel
- Self-lock and others implemented as safety measures

Protective Frame Vehicle

Traveling test

Frame assembling test

【Overview】
- Traveling along a road and inspecting tunnels.
- Dividing traffic areas and inspection areas for safety work.
- Can be assembled and disassembled on-site within a short time.

【Topics】
- Performed traveling test on an experimental tunnel
- Performed frame assembling test on a test field

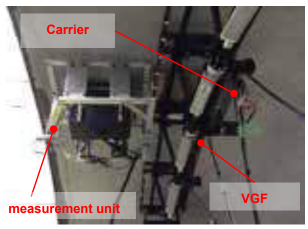
Benefits of the inspection vehicle

・Can take necessary reaction force for hammering test from the Variable Guide Frame.
・Can realize a precise inspection with a little traffic regulation.
・Variable Guide Frame allows us to inspect kinds of tunnels.

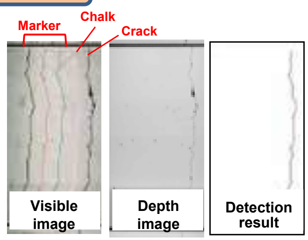
Current Accomplishments (2/2)

Remote control inspection unit

Crack Measurement Unit



Crack measurement unit

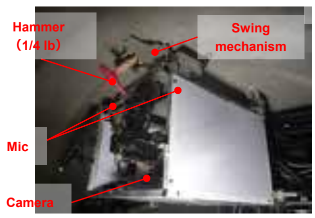


Acquired image and result

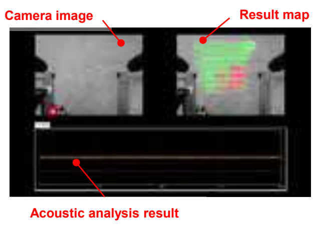
【Overview】
- Can integrate a visible image and a depth image (range image) obtained by light-section methods and can distinguishing between cracks and others.
- Detecting efflorescence too.

【Topics】
- ■ Accuracy rate of the distinction between cracks and dirt were over 70%
- ■ Accuracy of the crack detection test rate was over 95%

Hammering Test Unit



Hammering test unit



Inspection result

【Overview】
- Detecting concrete spall instantaneously from visible images and hammering sounds.
- Visualizing concrete spall from inspection results.

【Topics】
- ■ Detecting concrete spall of experimental tunnel and test pieces.
- ■ We considering calibration method on-site.

Benefits of the inspection device

- Can reduce processing time for removing noise such as dirt in images.
- Can be finding signs quickly such as diagonal cracks that may cause concrete spall.

Goals

R&D Final Goal

Detection accuracy rate of deformation with Variable Guide Frame Vehicle

- Cracks: over 80% (width over 0.5 mm)
- Concrete deformations: over 70%

Target of this inspection system

Road tunnels managed by municipalities severe lack of engineers

Variable Guide Frame Vehicle is applicable to about 55% of tunnels in Japan

Supporting inspection of road tunnels managed by municipalities

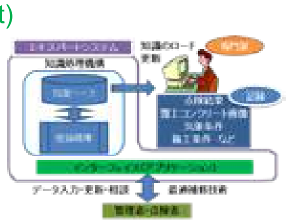
○ We lend out the inspection vehicle and provide technical guidance for local consultants and inspectors. The cost of the inspection vehicle will be lower than a mobile elevating work platform and inspection engineers.

○ We will establish an association about inspection vehicle, which will promote diffusion, lending, operator dispatch, support for planning and report preparation.

R&D for practical application

Tunnel management support system (under development)

Tunnel management support system draws up inspection records and photo ledgers from inspection data acquired by inspection vehicle, and it also presents optimal repair methods, materials, and repair engineers.
This system calculates the Life Cycle Cost (LCC) of the tunnel, and will support municipalities to settle sever lack of engineers.


Support system image

We will make a system to support municipalities to settle sever lack of engineers , and give a basic information of infrastructure.

50 Development of Unmanned Aerial Vehicles for Observing and Hammering Aged Bridges at Short Range

Principal Investigator Kazunori Ohno (Assistant Professor, Tohoku University)

Collaborative Research Groups RICOH Co., Ltd., Chiyoda Engineering Consultants Co., Ltd., Japan AeroSpace Technology Foundation, Tokyu Construction Co., Ltd.

R&D Objectives and Subjects

Objectives

R&D of UAV (Unmanned aerial vehicle) for observing and hammering aged bridges

- Inspect bridges which may not be accessible by a bridge inspection vehicle in a similar time as the conventional system takes
- Minimize cost and time for scaffolding
- Minimize traffic regulation
- Software facilitating formatting inspection reports

Subjects

1. Inspection UAV with a spherical shell that can safely collide with a bridge and reach inner structures of the bridge
2. Communication relaying UAV that can attach to a bridge and connect the inspection UAV and the operator
3. AI (artificial intelligence) that supports detecting the position and level of damage in inspection images
4. Performance demonstrations conducted by specialists of inspection, aerospace, and construction

Final R&D outcomes

Current Accomplishments (1/2)

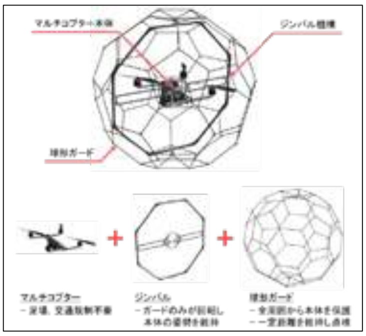
Inspection UAV with spherical shell (Tohoku University)

UAV protected by a spherical shell which does not crush in a collision

Evaluation by MLIT (2016)*

"Does not require scaffolding dislike conventional methods"

"Can take photos of 0.2 mm width damages (e.g. cracks) with onboard full HD cameras"



Structure of shelled UAV

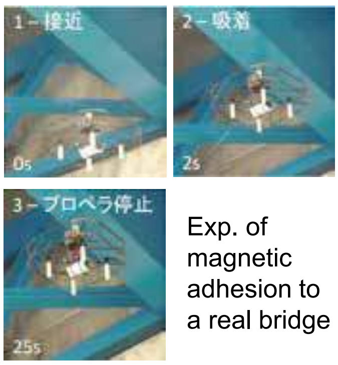
UAV inspecting inner bridge structure (Diameter: 0.95 m, weight: 2.5 kg)

Communication relaying adhesion UAV (Tohoku University)

UAV capable of attaching to a bridge and relaying communication

- Magnetically attaches itself and relays communication to the inspection UAV with minimum power consumption
- Keeps the operator and the inspection UAV connected to avoid accidents that may be caused by communication loss

Operation of comm. relay



Exp. of magnetic adhesion to a real bridge

* http://www.mlit.go.jp/common/001125338.pdf (in Japanese)

Current Accomplishments (2/2)

Detection of damage in inspection images (Tohoku University, RICOH)

Reconstruct a panorama of bridge and detect damages from a close-up video

- Automatic reconstruction of a panoramic image by image processing
- Support making an inspection report by locating damage in respect to the panoramic image
- Support measuring cracks in software

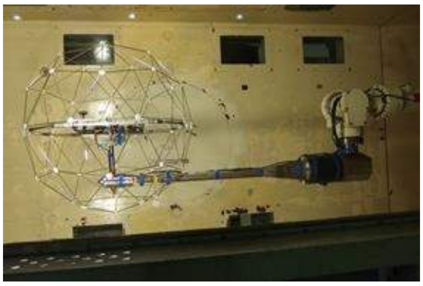
Reconstructed panoramic image of a real bridge

Semi-automatic detection of a crack on a concrete slab

Performance demonstrations (Chiyoda E.C., JAST, Tokyu Construction)

Toward robot technology that works in the real fields, performance demos have been periodically conducted by specialists

Inspection demo at a real bridge (Chiyoda E. C.)



Aerodynamic evaluation in a wind tunnel (JAST)

Repeatable evaluation using artificial weather (Tokyu Construction)

Goals

[Final goals]

Dev. item	Final goal
Close visual and hammering inspection of bridges by UAVs	• Target: concrete and metal bridges • All devices carried by a car • Preparation less than 15 mins • Multiple lightweight cameras (< 300 g) for wide angle • Continuous flights (10 mins/flight) • 30-40 mins flight in total for each span • Hammering device to detect damage
Detection of damages using panoramic images and report generation	• Panoramic image reconstruction from inspection video (few to tens of hours/span) • Semi-automatic position/level detection of cracks and corrosion • Report generation by pipeline of above tools

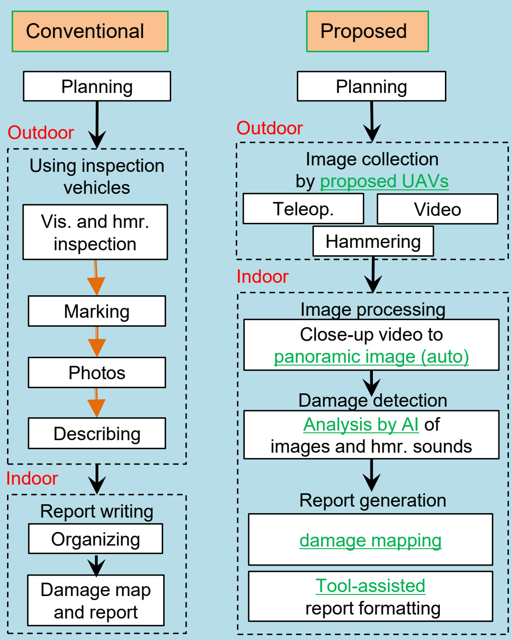
[Social implementation plans]

By member or licensed companies

1. Manufacturing/sales/rental/maintenance of UAVs and/or image analysis and reporting software
2. Education and qualification of operators and instructors

[Bridge inspection solution]

Reduce traffic regulation by using UAVs, and simplify the making of reports by image processing and autonomous functions



51 R&D of a multicopter-based inspection robotic system with visual observation and hammering test devices

Principal Investigator Hideki Wada (Shinnippon Nondestructive Inspection Co., Ltd.)

Collaborative Research Groups Nagoya University, Kyushu Institute of Technology, Fukuoka Industrial Technology Center, National Institute of Technology, Kitakyushu College

R&D Objectives and Subjects

Background

Problems in infrastructure inspections

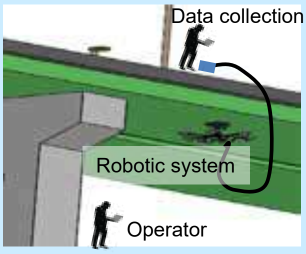
- Costs of the special vehicle
- Safety management
- Dependency on human efforts
- Lack of experts

Special vehicle inspection has limitations

Purpose

Less cost and high efficacy by using drones and automatic data analysis

- Less costs for special materials
- Reduction of road regulations
- High availability of recorded inspection data
- Automatic abnormal detections
- Support for inspection reports



Schematic illustration of the inspection process

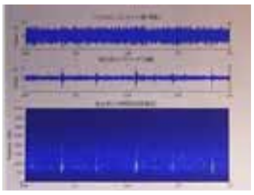
Key points

- **Mobility mechanism** with drones and wheels
- **Inspection** by visual observation and hammering tests
- Image and sound-based **abnormal detections**

Flying close to the target

Running on the target

Hammering test

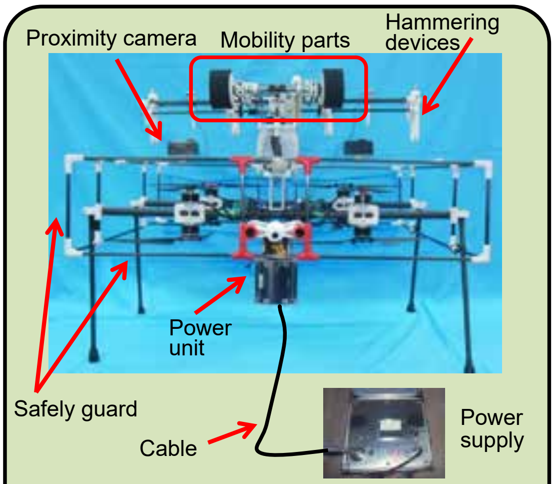


Sound analysis

Current Accomplishments (1/2)

Inspection Robotic System

A multicopter with an inspection system running via independent wheels was developed to realize nonstop running inspections



Size (mm) : 880 × 880 × 725 Weight : 7.5 kg

Alternative inspection methods using robotics

- Contact danger areas easily
- Consecutive inspection as getting into touch with infrastructures

Flying Mechanism

Small sized system can attach to the target directly
⇒ Small but high performance

(Dual Reversal Quadrotor)

Mobility Mechanism

Adaptive for cants of the target
⇒ Flexible wheels

(Pitch : ±15°) (Roll : ±20°)

Field Inspection

Current Accomplishments (2/2)

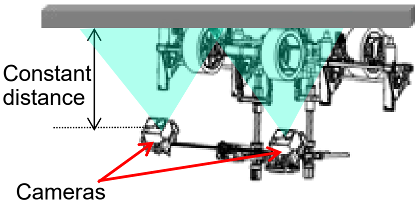
Automatic Inspections

Dual inspection systems with cameras and hammers enable the drone to detect cracks and internal defects

- Prevention of oversight by automatic recording
- Visualization of data

Visual Observation

Close distance video recording



Multi-camera detection

Image Corrections

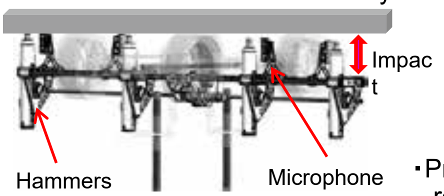
- Fish eye regulation
- Focal correction
- Image conjugation
- Inspection map generation

Image Inspection
- Automatic crack detection (0.2 mm width)
- Measurements (width, length and position)

(Free lime)　　(Cracks)

Hammering Tests

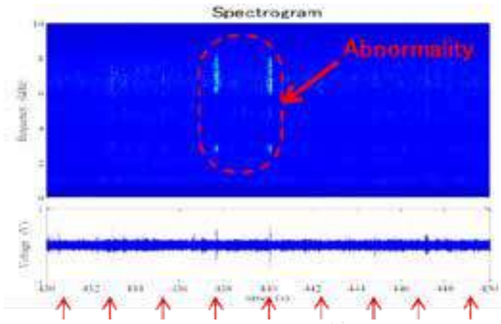
Detection of internal abnormality



Four piston alternative hammers
- Nonstop hammering tests
- Sound recording with microphones

Sound Analysis

- Propeller-induced noise reduction
- Frequency analysis (hole detection at a depth of 60 mm)



Sound Analysis　(↑: Impact points)

Goals

Goals at the Final Stage

Functions	Characteristics at the end
Robotic System	Flying area : 30 m radius Cable length : 40 m
Image Inspection	Crack detection : 0.1 mm Position accuracy : ±10 cm
Hammering Test	Internal test : 60 mm depth RC crack : covering depth 30 mm
Depth Measure (Steel Bridge)	Ultrasonic thickness measurement Accuracy : ±0.2 mm
Operation Requirements	Operators : 3 person/robot Wind speed : less than 6 m/s (ave.) Inspection speed : 250 m^2/hour

Selling/Rental

- Inspection robotic system
- Functional units (robotic system & inspection)
- Software (image & sound analysis)
- Operators*1 and inspection experts*1
- Training course for operators

(*1 : Only in rental)

Ideal Social Contributions

- Service of inspections
- Selling of the robotic system
- Rental business of the system

Inspection Service

○ Concrete Bridges (RC&PC structure)

Visual Observation (cracks, abrasions)
Target : floor slabs, beams, shoes and so on

Hammering test (abrasions, internal crack*2)
Target : floor slab, beam and so on

○ Steel Bridges

Proximity inspection (corrosion, cracks, abnormalities)
Target : floor slabs, beams, shoes and so on

Ultrasonic waves (depth measure, internal crack)
Target : main & sub beam and so on

○ Tunnels (Examination・Partial Inspection)

Proximity inspection (cracks, abrasions, water leakage, corrosion)

Hammering test (abrasions, internal crack*2)
Target : lining part, boxes and so on

(*2 : internal abnormality by steel corrosion)

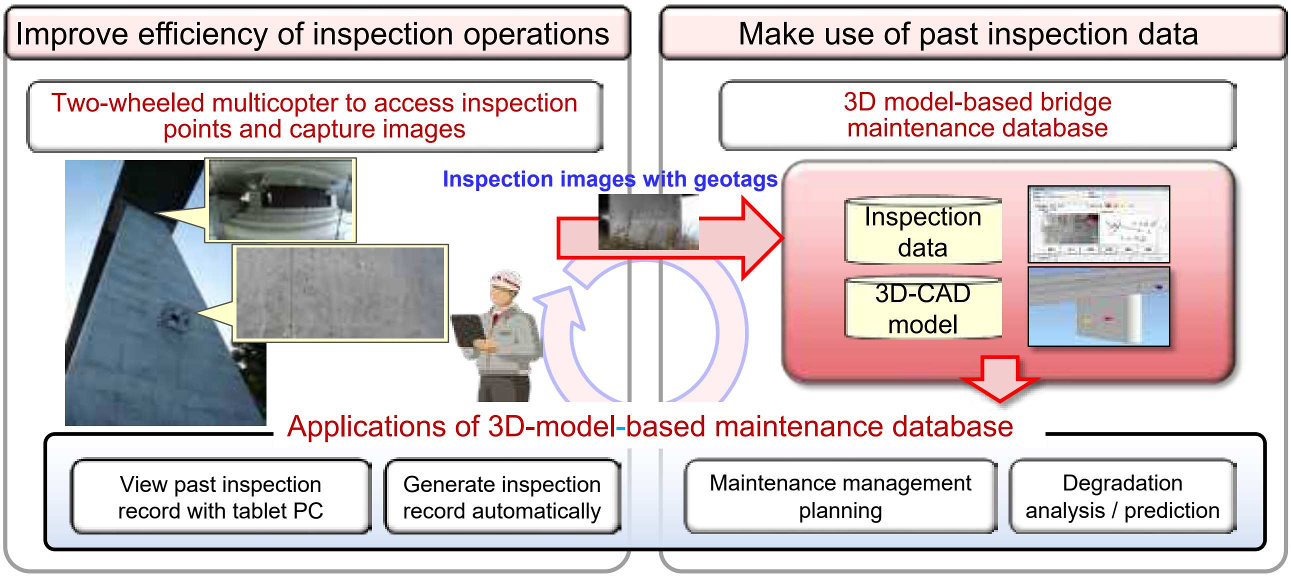
52 Development of a bridge inspection support robot system that uses proximity-images with Geotag and a two-wheeled flying robot

Principal Investigator: Naoyuki Sawasaki (Fujitsu Limited)

Collaborative Research Groups: Fujitsu Limited, Nagoya Institute of Technology,Tokyo University, Hokkaido University, Docon Co. Limited

R&D Objectives and Subjects

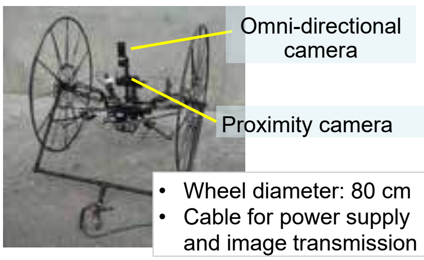
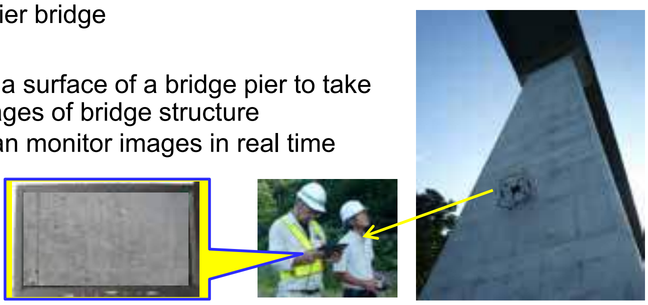
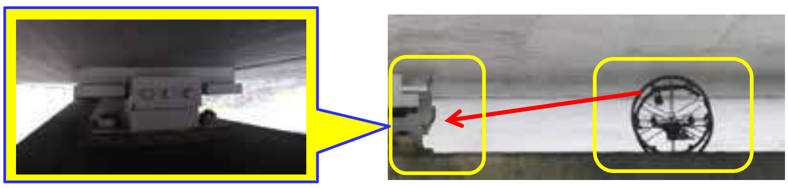
We propose a bridge inspection robot system that captures proximity images and a 3D-model-based maintenance database to link inspection data with 3D models. Our system can make on-site bridge inspections more efficient and support bridge maintenance operations.



Current Accomplishments (1/2)

We prototyped two-wheeled multi-copters for bridge inspection.

Features	
Features	• It can take proximity-images with constant distance to bridge surface. • It is robust against windy conditions because of skin friction of the wheels.

Type	Specifications
①Large size two-wheeled multi-copter  Omni-directional camera Proximity camera • Wheel diameter: 80 cm • Cable for power supply and image transmission	[Target] High pier bridge [Features] ✓It can run on a surface of a bridge pier to take proximity images of bridge structure ✓Inspectors can monitor images in real time 
②Small size two-wheeled multi-coper  • Wheel diameter: 40 cm • Cage for protection	[Target] Narrow space (shoe, and so on) [Features] ✓It can run on a pier to take a picture of a shoe 

Current Accomplishments (2/2)

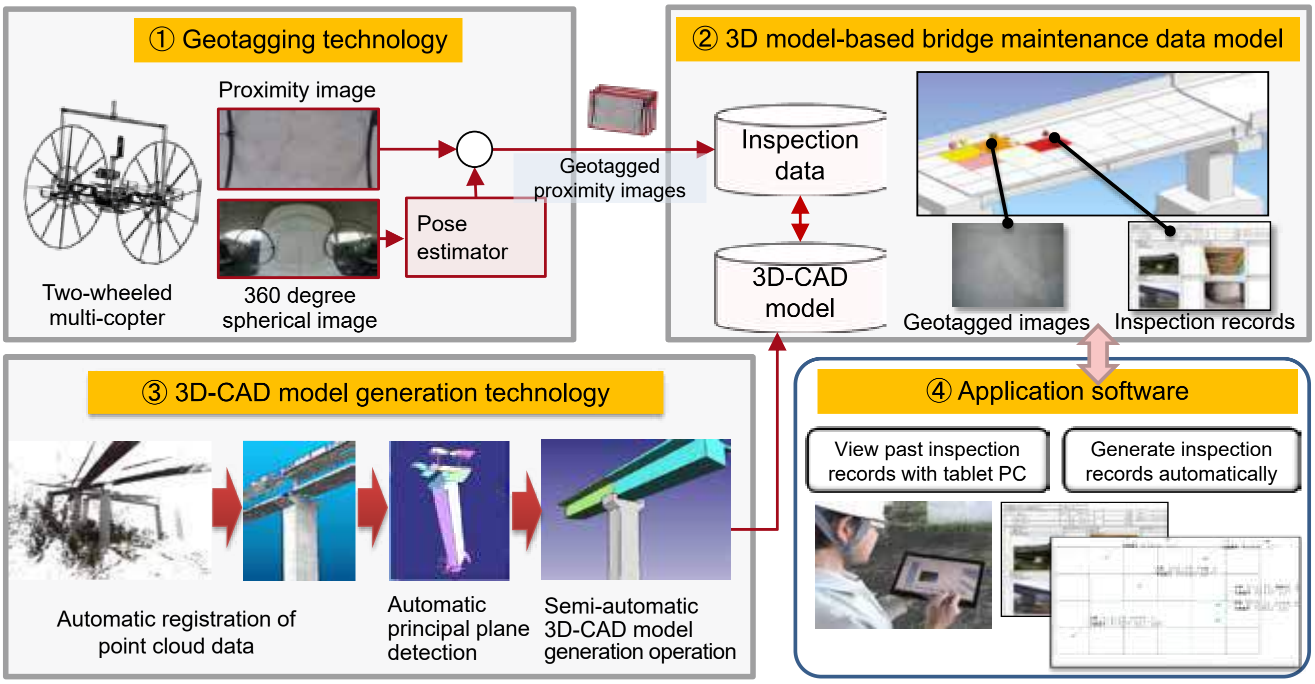
We prototyped a 3D model-based bridge maintenance system for long-term use.

① Geotagging technology based on SFM (Structure from Motion) using 360 degree spherical camera

② A 3D model-based bridge maintenance data model which is as extension of the ISO standard of the 3D-CAD model

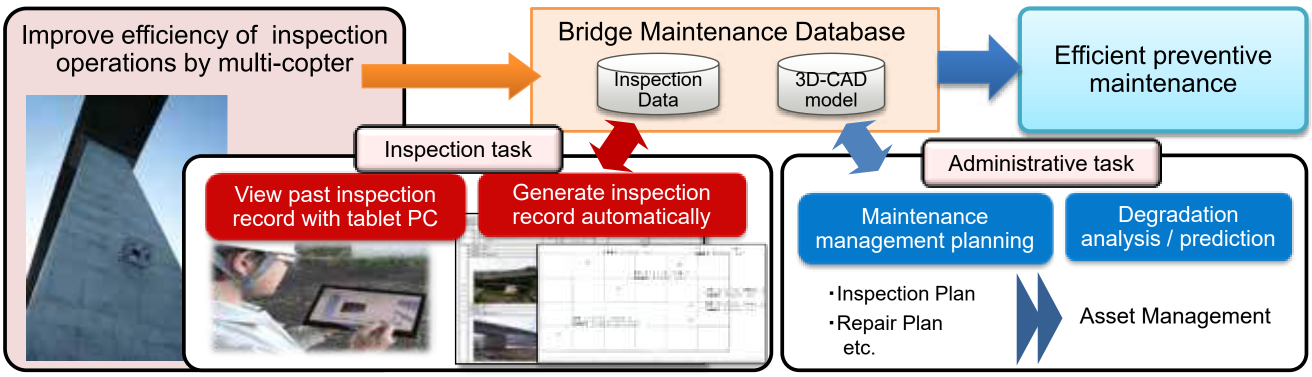
③ Semi-automatic 3D-CAD model generation technology

④ Application software for viewing past inspection data on 3D-CAD models using tablet PCs



Goals

- Development of multi-copters for taking proximity images of high pier bridges
  - Wind-resistant stability available for practical use, mechanism and a control system for safe remote control
- Utilization of inspection data to make bridge maintenance tasks more efficient
  - Establishment of basic technology for high level utilization of inspection data



	Merits in inspection task	Merits in administrative task
Efficiency	○Collect inspection images effectively instead of a human ○Simplify viewing past inspection data at inspection sites ○Reduce man-hours for inputting inspection data and generating inspection records ○Utilize past inspection data easily	○Simplify planning of inspection and repair ○Rational reasoning for requiring budgets
Quality	○Reduce omission of inspection ○Reduce human errors ○Level quality of inspection task and generating inspection record	○Maximizing cost-effectiveness for maintenance

53 New Development of Unmanned Construction ~Realization of Remote Operated Working System in Shallow Water Area~

Principal Investigator: Shin'ichi Yuta (President, New Unmanned Construction Technology Research Association)

Collaborative Research Groups: New Unmanned Construction Technology Research Association

R&D Objectives and Subjects

Background

- Remote/Unmanned Construction is an unique technology which is developed in Japan for emergency construction in an eruption or earthquake disaster.
- Recently, water disasters (landslides, debris flows, floods) have occurred frequently because of torrential rain.

Disaster of typhoon No.12 (H23)


Anan, Tokushima (H26.8)

- An amphibian heavy carrier robot is requited for post-disaster restoration work at river edges or semi-underwater places.

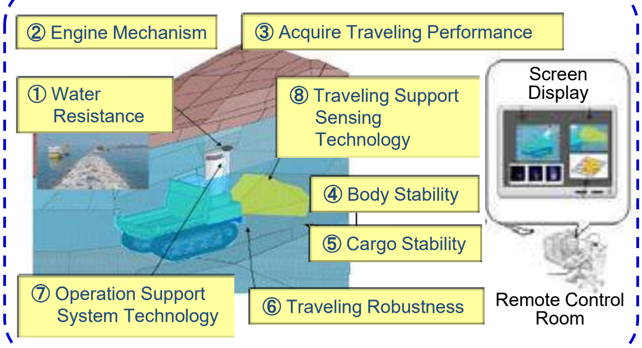
R&D Objectives

Expand applicable scope of unmanned construction to dangerous river edges and shallow water areas for the quick post-disaster restoration of frequently occurring water disasters

R&D Subjects

- Construct an unmanned construction system which realizes the series of post-disaster restoration work at river edges or semi-underwater places at a depth of about 2 m.
- Develop remotely operated heavy carrier robot which runs efficiently and stably under various conditions in several hundred meters from shallow water to land areas.

【Concrete R&D Subject】



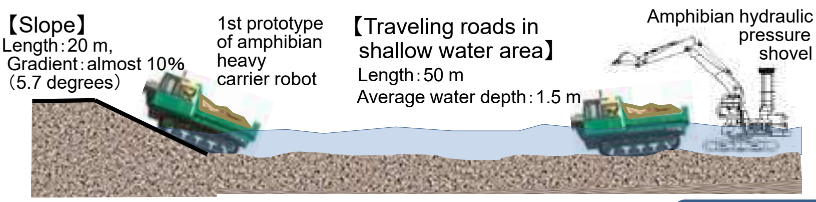
Current Accomplishments (1/2)

I. Development of the Semi-underwater Heavy Carrier Robot

R&D Achievement (H26～28):
Development of 2nd prototype remote operated type heavy carrier robot based on the evaluation of 1st prototype which runs in semi-underwater area.

【Experiment which images the removal of dirt of river channel vessel occlusion】

- ■ Excavated earth and sand: 6.0 m^3 Bucket ×5 times＝Almost 7.0t capacity
- ■ Underwater traveling: 2.0 km/h, water depth 1.5m, traveling distance about 50m



【Water Resistance Test】

【Land Travel Test】

【Driver Seat Submerge Test】

【Suction & Exhaust Test】

Reflection of Experiment Results


Lading of excavated earth and sand


Water Depth 1.5 m Real Career Traveling


Slope traveling underwater


Slope traveling on land

Reflection of Experimental Results

Remote Operated Type Heavy Carrier Robot (2nd Prototype)

- Engine with a waterproof bulkhead
- Utility part with submersion measures
- Leakage sensor in bulkhead
- Overheating measures
- Submersion measures of electrical components, rigging
- Mounting of suction & exhaust snorkel
- Mounting of remote operation system
- Maximum water depth of traveling : 1.8 m
- Maximum load : 10t

Current Accomplishments (2/2)

Ⅱ. Development of Remote Operation Support and Guidance System for Semi-underwater Traveling

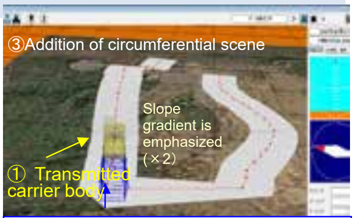
R&D Achievement (H26～28)

【Development of Remote Operation Guidance System Using GNSS-IMU】

The following improvements and experiments are executed in H28 for the better operationality in the operation screen of the operation guidance system

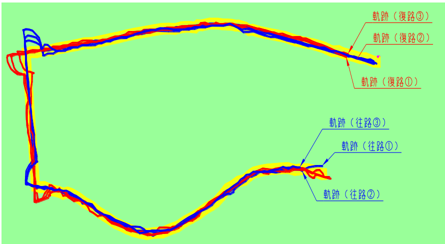
①Transmitted carrier body (for better visibility of planned trajectory)
②Rectangle display of traveled trajectory (for easy recognition of traveling direction)
③Addition of circumferential scene (for improvement of operationality on land)

Test road for the experiments



Revised display screen of remote Operation support guidance system

Results of on land traveling comparison test using revised remote operation support guidance system



- Planned travel course (goal point)
- Position and orientation of remote operated heavy carrier robot (moving point)
- Absolute position data is measured by RTK-GPS positioning method of GNSS system
- Traveling direction and body tilt angle are measured by IMU.

The error of real trajectory from planned trajectory was a maximum 50 cm using a revised remote operation support guidance display system.

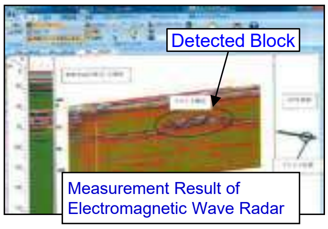
【Development of a recognition technology for traveling course soil conditions at underwater places】

Experiment of traveling course soil condition recognition using electromagnetic wave radar is executed to compensate for camera image in H28.

Experiment at water depth of 1.5 m

Electromagnetic Wave Radar

Blocks (height 20 cm) in the underwater traveling course are measured by electromagnetic wave radar



Detected Block

Measurement Result of Electromagnetic Wave Radar

- Carrier position data and measurement result are linked and displayed on the traveling course soil condition.

Information Service System for Operator

- Sensor which compensates for the camera image
- Operational support (guidance) based on self-position measurements

H29～30: These achievements will be integrated into the semi-underwater carrier robot and evaluated in the actual field

Goals

(At the end of SIP Project) Increase the toughness of the country

【Development Goals】

Semi-underwater Carrier Robot

1. Water-running abilities:
   - Maximum load: 10t
   - Travel speed: 3 km/h
   - Gradeability: 10%
   - Gradient(Right and Left): 3 degrees
   - Overcome step: 20 cm
   - Continuous traveling distance: 200 m
2. Features of Remote Control
   - Wireless remote control
   - Implementation of remote-control operational support interface

Realization of Unmanned Construction in Semi-underwater

- Building a model system.

【Representational utilities under disaster】

Example of Disaster expansion prevention in unmanned construction

Conventional remote-controlled underwater backhoe

- Excavating underwater earth that could block rivers.
- Excavating watercourses.
- Installing foot protection blocks to prevent levee collapses and so on.

The Semi-underwater Carrier Robot we developed

Remote Control Room

- Carrying earth, debris, etc.
- Carrying foot protection blocks, etc.
- Carrying equipment.

【Social Implementation: Expected System for Disaster Coping】

Possessor and User

- MLIT／Regional Development Bureau／technical office
- Local governments
- River administrators
- Private Company e.g. construction and rental firm
- Research Institute (broaden the scope of application and their evaluation)

Management system for use

- Possessor: operation planning／storage／transportation／regular maintenance
- User: on-site／education of operator (usage, safety)／daily check

【Common and regular use for their diffusion and maintenance (under consideration)】

Regular Usage

(Use as an amphibian carrier: Mainly by on-board operation)

- Dredging and revetment construction of rivers and lakes
- Disaster prevention construction at rivers, lakes and coastlines

Common system for regular usage and in a time of disaster

- Maintain semi-underwater carrier and remote operation system, separately
- Construct system under the initiative of central and local governments

Expansion of the number of their service, production and sales

- Consideration of the rental and lease system for regular use
- Overseas deployment (Export carriers and their operation techniques)

54 Research and Development of Infrastructure Structures and Inspection Devices for Advanced Inspection of Civil Infrastructure

Principal Investigator Kenichi Fujino (Principal Team Leader, Construction Technology Research Department, Public Works Research Institute)

Collaborative Research Groups Public Works Research Institute, Japan Bridge Engineering Center, Japan Construction Machinery and Construction Association

R&D Objectives and Subjects

R&D Objectives

- Aging social infrastructures (bridges, tunnels) require reliable maintenance for people to be able to use them safely and securely. However, concerns are being expressed about a labor shortage in the construction industry and a technician shortage in public organizations, etc., due to the declining birthrate and aging population.
- This research looks at inspecting social infrastructures (bridges, tunnels) safely, efficiently, and economically. In addition to examining the structuralization of infrastructures that better suit inspection work, this research also proposes an optimal inspection system where infrastructures, robots, and people work together to clarify concerns about the design of structures in order to introduce equipment, such as robots, more efficiently.
- As a target to be reached by the end of FY2018, taking the development and dissemination of robotic technologies into consideration, we will work toward the early realization of “support and efficiency improvement of our existing close visual inspection” using robotic technologies on the precondition that existing control standards and techniques are used as a base.

R&D Subjects

- We will work on the following support (research and development) to achieve the early introduction of robotic technologies on-site in order to realize “support and efficiency improvement of our existing close visual inspection” using robotic technologies. Target sites for introduction include locations where we expect the introduction of robotic technologies to produce effects, such as “hard-to-inspect spots” (according to the needs of infrastructure administrators, etc.).

(1) Examine the structures of infrastructures (new and existing) that take inspection into consideration.

(2) Prepare procedures for installing additional equipment.

(3) Establish performance requirements for robotic technologies to solve "hard-to-inspect spots," etc.

(4) Develop operation guidelines for location sensing technology (markers), examine methods to deliver damage diagrams.

* The main objective of (1) and (2) is to take measures against "hard-to-inspect spots".

Current Accomplishments (1/2)

Bridges

Main hard-to-inspect spots and proposed countermeasures (proposal to improve work efficiency and improving hard-to-inspect spots)

<Classification of hard-to-inspect spots (classified in the previous years)>
Cases of about 120 typical hard-to-inspect spots were extracted and analyzed in order to classify hard-to-inspect spots based on data from about 23,000 bridges across national roads under direct control of Ministry of Land, Infrastructure, Transport and Tourism by conducting field surveys on Honshu-Shikoku Bridges and the Tokyo Bay Aqua-Line, etc. Measures which contributed to improving the inspection efficiency, etc. were examined and proposed based on the relevant classification.

(1) Examine the structures of infrastructures (new and existing) that take inspection into consideration

Proposals to improve girder edges and a bridge collapse prevention unit

[Hard-to-inspect spots] Shielding condition using a bridge collapse prevention unit

E.g. Adopted a bearer method (upsizing, etc.), instead of a block type and wire type

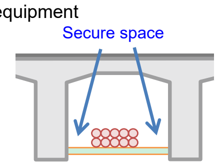
Examination and proposal to remove lateral bracing

Improve inspection efficiency and accuracy by reducing the number of inspection targets and securing enough space for inspection, etc.

Safety needs to be secured (**reinforcement using stiffeners,** etc. as necessary) through structural calculations, etc., since lower lateral bracing needs to be installed in principle according to the Specifications for Highway Bridges.

(2) Prepare procedures for installing additional equipment

[Hard-to-inspect spots] Shielded by additional equipment



E.g. Proposal to secure space of 50 cm of width or wider around the additionally installed equipment to facilitate inspection by robots, etc. Created "Guidelines for installation of additional equipment (draft)" (planned for 2016)

(3) Establish performance requirements for robotic technologies to solve hard-to-inspect spots, etc.

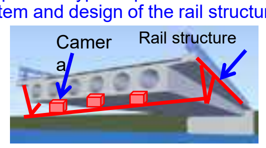
○ Proposal of a new inspection system (no equipment development)
Confirm whether or not hard-to-inspect spots, etc. can be inspected with the outline design

[Hard-to-inspect spots] Narrow area with the water surface under the girder

Design of float type inspection equipment

[Hard-to-inspect spots] Narrow area under the girder

Suspension type inspection robot system and design of the rail structure



○ Establish robotic technology performance requirements (planned for 2016)
- Classify inspection work that is applicable to robots
- Classify the robotic technologies that are expected to be utilized for inspection work

(4) Develop operation guidelines for location sensing technology (markers), examine methods to deliver damage diagrams

Examine markers, propose installation

Survey the visibility of robotic technologies, targeting about 5 types of markers (planned for 2016)

Effects of introducing markers
- Prevent misunderstanding of inspection sections
- Improve work efficiency when making a photomontage (about 40%)

Current Accomplishments (2/2)

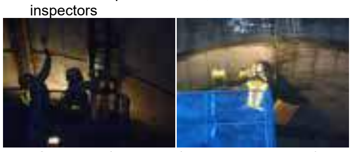
Tunnels

Develop inspection support equipment (platform)

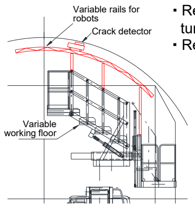
Inspection work issues (according to the interviews)	・Reduced inspection efficiency due to pain or exhaustion, etc. caused by work in an overhead position (unnatural posture), ・Relocation of working floor of trolley is time consuming
Countermeasure	Develop a platform where the working surface angle can be changed freely in accordance with the shape of the tunnel section (design phase in 2016)

[Expected effect 1] Support the introduction of robotic technologies

・ Get robots closer to conduct the inspection by installing rails which can be equipped with crack detectors, etc.
→ Substitute inspection works, and reduce the number of inspectors



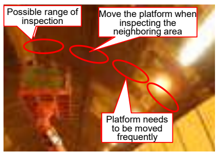
Chalking/beating (current situation)



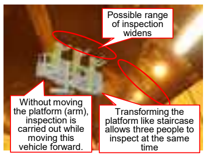
・Conduct inspections using robots
・Reduce the number of inspectors

[Expected effect 2] Countermeasure against hard-to-inspect spots

・Reduce inspection works in an unnatural posture by having a working surface that suits the shape of the tunnel section.
・Reduce the trolley working floor relocation work during inspections to shorten the inspection work time.



Replacing the platform (current situation)



Assumed the effect of shortening the inspection time by about 10 to 20% (according to test calculations based on the field survey)

・Omit replacement work for shoulder inspections
・Shorten the work time by conducting shoulder inspections concurrently

Examine location sensing technology (markers)

Inspection work issues, usage of robots (according to the interviews)	・Difficult to understand the location information since no identifiable characteristics can be found in the tunnel. ・Diagnostic work during the inspection can be more accurate if construction information is provided in the tunnel.
Countermeasure	Carry out a basic examination of the various information required for human and robots, and of the marker specifications that will make the information recognizable to improve tunnel inspection efficiency.

[Expected effect 1]

・ Robots can recognize their own locations even under conditions where GPS radio waves cannot reach and no identifiable characteristics can be found inside the tunnel.
・ Markers can be used as identifiable characteristics when merging images obtained by the robot.

[Expected effect 2]

・ Human inspectors can identify the construction information, etc. that is used to understand their own locations and used as a reference for diagnosis.

・Reduced inspection time or reduced office work time can be expected.
⇒ Specific effects of this reduction will be examined by future demonstrations, experiments, etc.

A mark that enables inspectors, etc. to recognize information during construction of the tunnel

A marker that can be recognized using camera, radar, etc.

Representation of the lining span No.

A mark for other additional information (such as coordinate information)

Marker (draft), currently under consideration

Goals

The following table summarizes the results in order to introduce robotic technologies for infrastructure maintenance to realize "support and efficiency improvement of our existing close visual inspection" as an exit strategy at the end of FY2018.

Issue	Final result
(1) Narrow inspection space (measures against hard-to-inspect spots)	・Proposal of structures (new and existing) that take inspection into consideration ・Design of an inspection support equipment (system)
(2) Hard to inspect visually due to obstacles (measures against hard-to-inspect spots)	Preparation of Guidelines for installation of additional equipment (new and existing)
(3) Infrastructure inspection using robotic technologies	・Clarification of a utilization method and performance requirements for robotic technologies on-site ・Design of an inspection support equipment (system)
(4) Improve inspection efficiency and accuracy	Development of operation guidelines on location sensing technology (markers)

[R&D Objectives and Subjects]

〇Support measures for introducing robotic technologies on-site
(Structures of infrastructures, inspection support facilities, etc.)
(1) Examine the standard of infrastructure structures (new and existing) that takes inspection into consideration
(2) Prepare procedures to install additional equipment (system)
(4) Develop operation guidelines on location sensing technology (markers), examine standards to deliver damage diagrams

＋

〇 Clarify the utilization method and performance requirements of robotic technologies on-site
(3) Establish performance requirements for robotic technologies that are utilized for infrastructure inspection

[Outcome]

Improved efficiency in infrastructure maintenance by introducing robotic technologies, etc.

＋

Promoted development of required robotic technologies, etc.

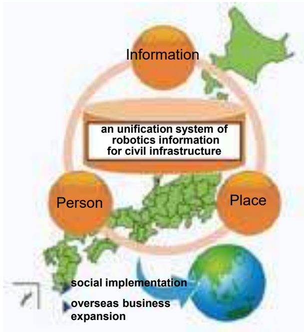
56 Establish an unification system of robotics information for civil infrastructure

Principal Investigator Hirokuni Morikawa (National Institute for Land and Infrastructure Management)

(Supported by Advanced Construction Technology Center, Nomura Research Institute)

R&D Objectives and Subjects

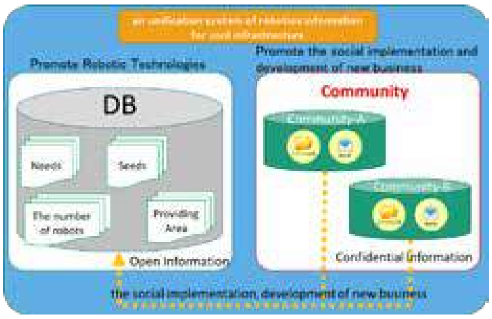
Objectives



- It is important to assume a robotic technology at the maintenance of civil infrastructure and a disaster effectively.
- This research contributes to developing robotic technology through the matching between needs and seeds.
- And more, this research supports the social implementation, Development of new business and the evolution of the global market.

Subjects

- Unification about robotic technologies for the maintenance of infrastructure and the disaster.
- Establishment of an unification system of robotics information related to civil infrastructure for robotic developers and users.
- Administration of the community for an implementation and an industrialization of robotic technologies.
- Provision of information and procurement will support Ministry of Land, Infrastructure, Transport and Tourism and local governments in time of the disaster.



Current Accomplishments (1/2)

- Running on Simple Data-Base for Infrastructure Maintenance and Disaster

- We have pigeonholed robotic technology and added search function to the system based on the evaluation results of the field demonstration which is for maintenance of bridge, tunnel,underwater structure and for disaster response including disaster investigation,disaster recovery.

  The field demonstration is held by the Ministry of Land, Infrastructure and Transport project "Development and Implementation of the future generation civil engineering robotic technology"

Section	Needs	The number of Seeds
Bridges	Support/alternative of crossed-eyes	28
	Support/alternative of HAMMERING TEST	5
	Move/Approach of inspector	0
Tunnels	Support/alternative of crossed-eyes	6
	Support/alternative of HAMMERING TEST	6
Underwater	Support/alternative of crossed-eyes of Dam	11
	Evaluating bottom sediment and water of Dam	2
	Support/alternative of crossed-eyes of river	2
Disaster Investigation	Picture/topographic data of mass failure /volcanic hazard	12
	Physical property investigation/measurement of mass failure/volcanic hazard	4
	Information acquisition of tunnel collapse gas	0
	Image capture of tunnel collapse	6
Disaster Recovery	Emergency rehabilitation of excavation, dozing and banking	4
	Emergency rehabilitation of drainage	1
	Circulation of information of mechanical excavation	4

The Map Search dialog box

The Advanced Search dialog box

Current Accomplishments (2/2)

- Start the community for development of robotic & social implementation to construction site

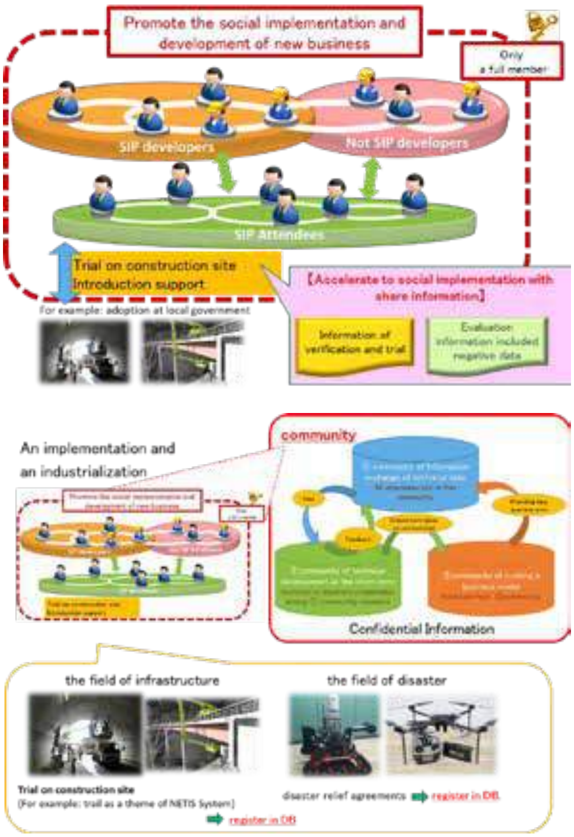
- The interchange of robotic developers and users is started on this year.

- Now, 71 attendees communicate about how-to/know-how for robotic technologies on this community.

- There are especially themes for the summary of bridge inspection;

–an application of UAV for inspection

–a development of 3D modeling technology

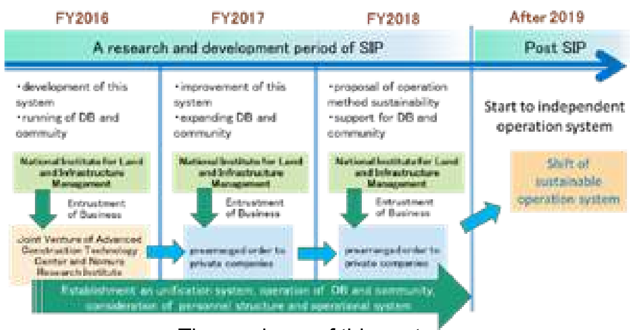


Overview of community

Goals

Preparation for the sustainable administration of this system

- ➢ Need more consideration of improvement, convenience, effectiveness and sustainability by using this system .
- ➢ Study for the systems management after SIP.
- ➢ Start an unification system of robotics information for civil infrastructure by the autonomous system from 2019.
- ➢ This system will become as "an intellectual information hub" for all robotics users in Japan.



The roadmap of this system

Valued creation and cooperation with measure of MLIT

- ➢ After full-scale operation in 2019 will cooperate with the integration disaster information system (DiMAPS)
- ➢ Positioning as the part of the infrastructure maintenance national meeting
- ➢ Positioning as the part of WG of the i-Construction promotion consortium

The integration disaster information system (DiMAPS)
Source: http://www.mlit.go.jp/river/bousai/bousai-gensai/bousai-gensai-4kai.html

57 Global R&D on the management cycle of road infrastructures

Principal Investigator: Koichi Maekawa (Professor, The University of Tokyo)

Collaborative Research Groups: Nihon Univ., C.E.Management Integrated Laboratory Co., Ltd., NIPPO Corp., East Nippon Expressway Co., Ltd., Metropolitan Expressway Co., Ltd., Yokohama National Univ., Tohoku Univ., Kyoto Univ., Osaka Univ., Kochi Univ. Tec., National Inst. Tec. Kochi Col., Tokyo Inst. Tec., Tsukuba Univ., JSCE, Hokkaido Univ., Shutoko Eng. Co. Ltd., Highway Tec. RC, Kyushu Univ.

R&D Objectives and Subjects

Objectives

R&D of Innovative hardware and software :
We are developing various technologies to reduce the life cycle cost of road infrastructures. Our research covers whole maintenance processes such as Inspection, Performance verification, repair & strengthening and renewal.

R&D of management system :
We are also developing a maintenance system for infrastructures in municipalities.

Implementation at home and abroad is our final goal. Developed technologies are implemented for domestic road infrastructures and municipalities. The scheme will be prepared to export the developed system.

Subjects

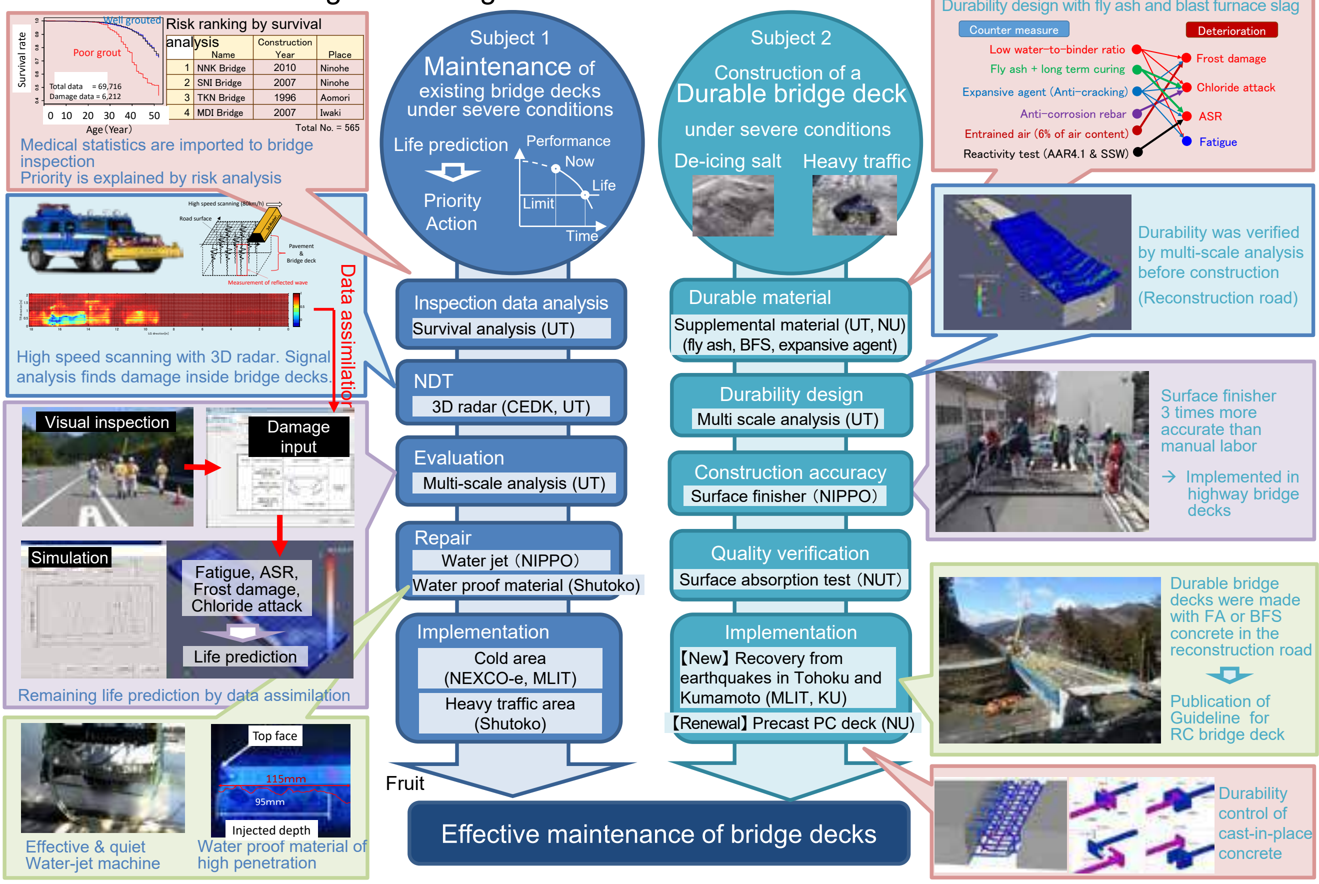
Key technologies for road maintenance :
3-D radar, Multi-scale simulation, Data assimilation, Survival analysis, Durable bridge decks, Water jets, Surface finishers, Water proofing material, Pre-cast bridge decks, Quality control system

Maintenance system for administrator :
Asset management system, Management database, Education system, PDCA cycle of maintenance, Bidding model & Contract model, Business model

Exportation :
Preparation of ISO on the maintenance of concrete structures, Formulation of international hubs in other Asian countries, Information transmission

Current Accomplishments (1/2)

R&D of various technologies for bridge decks



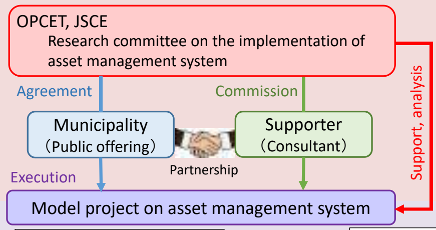
Current Accomplishments (2/2)

R&D of Maintenance systems for road administrator and municipalities

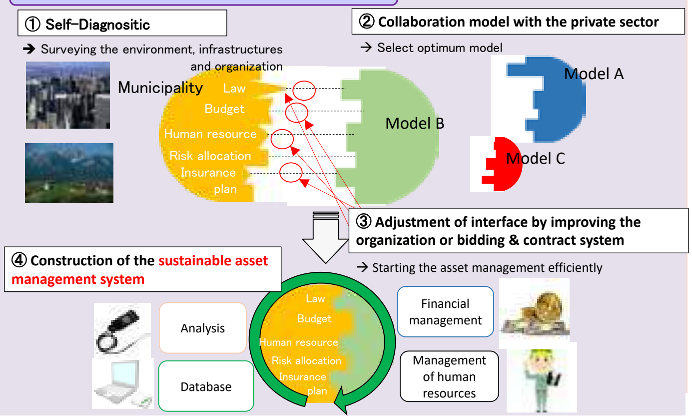
Asset management system for road administrator

- Kyoto model (Pavement & Bridges) → Installed in Kyoto pref. & Vietnam
- Osaka model (Bridges) → Used in Hanshin Expressway Co., Ltd.
- Kochi model (Bridges) → Installed in Kochi pref. & Indonesia

Bidding and contract system for municipalities

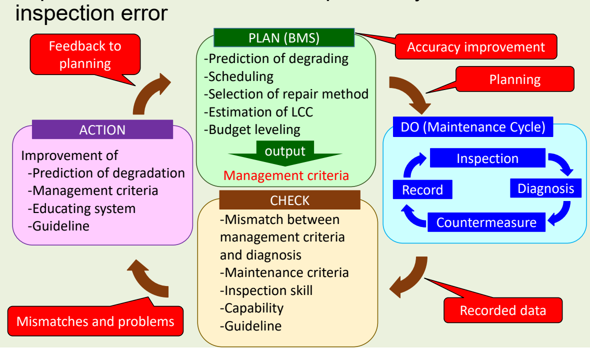


The academic society supports the installation of asset management in municipalities



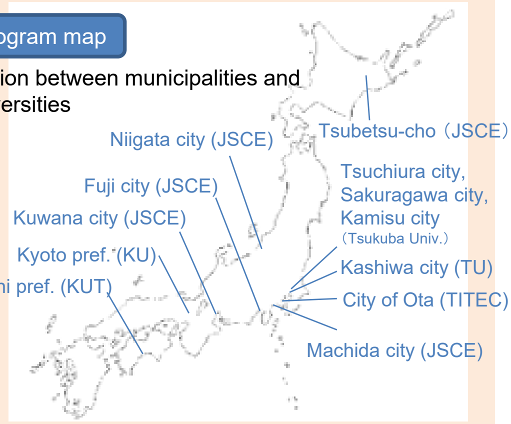
Kaizen cycle in maintenance

Improvement in education & inspection system to reduce inspection error



Pilot program map

Cooperation between municipalities and local universities



Goals

Implementation at home and abroad

Cutting edge technologies for the maintenance of road infrastructures

-3D radar	-Water jet machines
-Multi scale analysis	-Water proof materials
-Data assimilation	-Surface finishers
-Survival analysis	-Water absorption tests
-Durable bridge decks	-Quality control systems

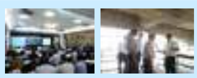
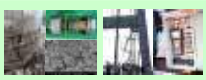
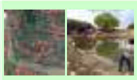
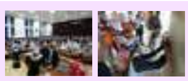
→ -Trial operations
-Lengthen the track record
（Shutoko, NEXCO, National road）
→ Standardization（Standard, Guideline）
→ Widespread use of technologies

Maintenance system for road infrastructures

-Asset management	-Education
-Bidding & Contract system	-Analysis
-Kaizen cycle	-Database

→ - Trial operations
- Lengthen the track record
（Hanshin expressway, Municipalities）
→ Widespread throughout Japan

International hubs in Asia (Hokkaido Univ., Tokyo Univ.)

	～2015	2016
Thailand	 -SIP office was opened Seminar	 Inspection
Vietnam	 Seminar Educational tour	Lectures about the maintenance in University
Myanmar	 Inspection Monitoring	 Bridge database
Cambodia	 Seminar, Inspection demonstration	Translation of Japanese standards

Exportation of SIP technologies

① International networking

Hub Seminar Information center

② Infra report, Asia version

Current status of infrastructures

③ Education program

Training facilities for visual inspection

④ International standard

Proposal V&V of proposing standard

58 Resolution of Early-aged Deterioration Mechanism & Development of Total Management System Based on Evaluation for Material and Structure Quality Performance

Principal Investigator Kazuyuki Torii (Kanazawa University)

Collaborative Research Groups Kanazawa Institute of Technology, Ishikawa National College of Technology, Nagaoka University of Technology, University of Fukui

R&D Objectives and Subjects

Objectives

Bridges in Hokuriku region are exposed to the following severe environments :

- In the coastal areas, salt damage deterioration due to airborne salt brought by monsoon
- In snowy regions, salt damage deterioration due to the spraying of anti-freezing agents
- ASR degradation in bridges using reactive aggregates, e.g., andesitic stone
- In mountainous areas, frost damage spreads easily at high altitudes


Salt damage deterioration

Main purposes : unlike aging deterioration, this degradation occurs early and complexly. This R&D proposes a sequential flow, i.e., inspection–diagnosis–monitoring, evaluation–judgment, countermeasures (reinforce, repair, renovation) as the basis maintenance management system

Implementation : the Hokuriku region and other areas with the same kind of early deterioration


ASR degradation

Subjects

○Elucidating the early-aged degradation mechanisms of salt damage and ASR damage, and developing methods for using roads safely for long periods of time

- Investigating actual conditions of salt damage & ASR deterioration in road bridges of the Hokuriku region
- Making the girders and slabs simulated degradations with actual sizes, then evaluating safety and serviceability
- Standardizing fly-ash concrete, slowing down the process of salt damage and ASR degradation
- Developing sensible inspection techniques, including simple monitoring technology

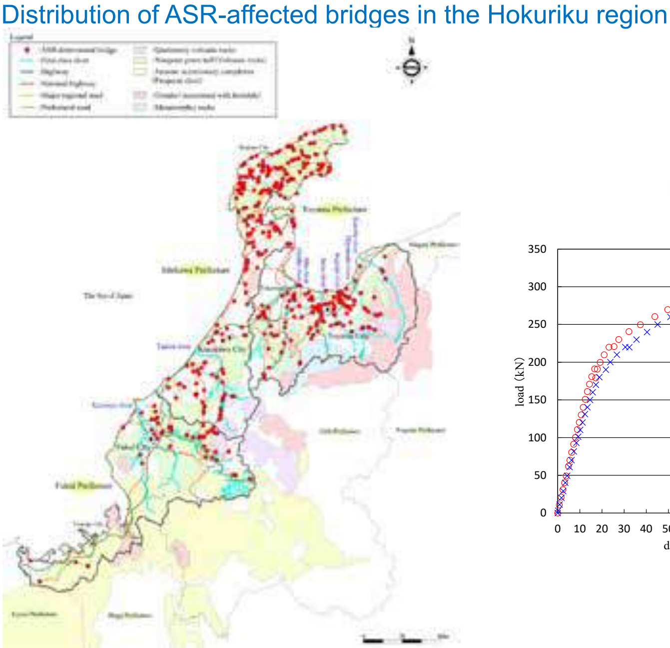
○Developing a maintenance management system which can be operated by local governments

- Establishing evaluation methods for structural health, a method of ranking for repair work, budget methods, and proposing an evaluation-judgment method corresponding to early deterioration
- Holding open seminars regularly, developing human resources

Current Accomplishments (1/2)

Elucidate the relationship between rock types/mineralogical features and ASR degradation

Distribution of ASR-affected bridges in the Hokuriku region

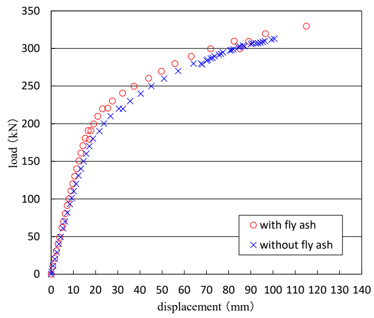


Developing a database for the characteristics of ASR degradations is important in the inspection and diagnosis of ASR deterioration

Elucidate the degradation mechanisms by investigating PC girders undergoing ASR degradations


Without fly ash


With fly ash



As a result of the load tests, ultimate strength and toughness were improved due to the use of fly ash concrete

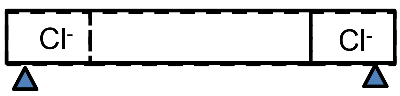
Current Accomplishments (2/2)

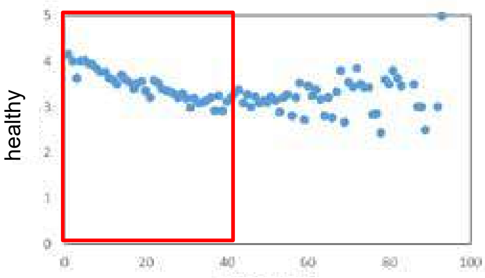
Diagnose the health of early-aged deteriorated slabs by using a large, mobile impact vibration exciter

FWD Light

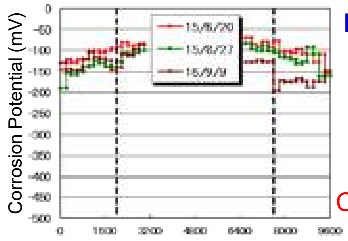
Self-propelled Impact Vibration Equipment

Monitoring for early-aged degradation bridges

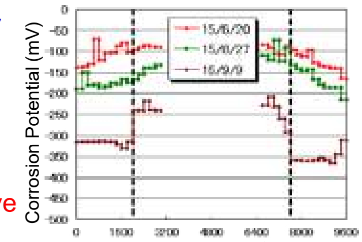




From an age-healthy relationship, a tendency of monotonous deterioration until the 40th year can be observed and some recovery work is done after 40 years.



With fly ash



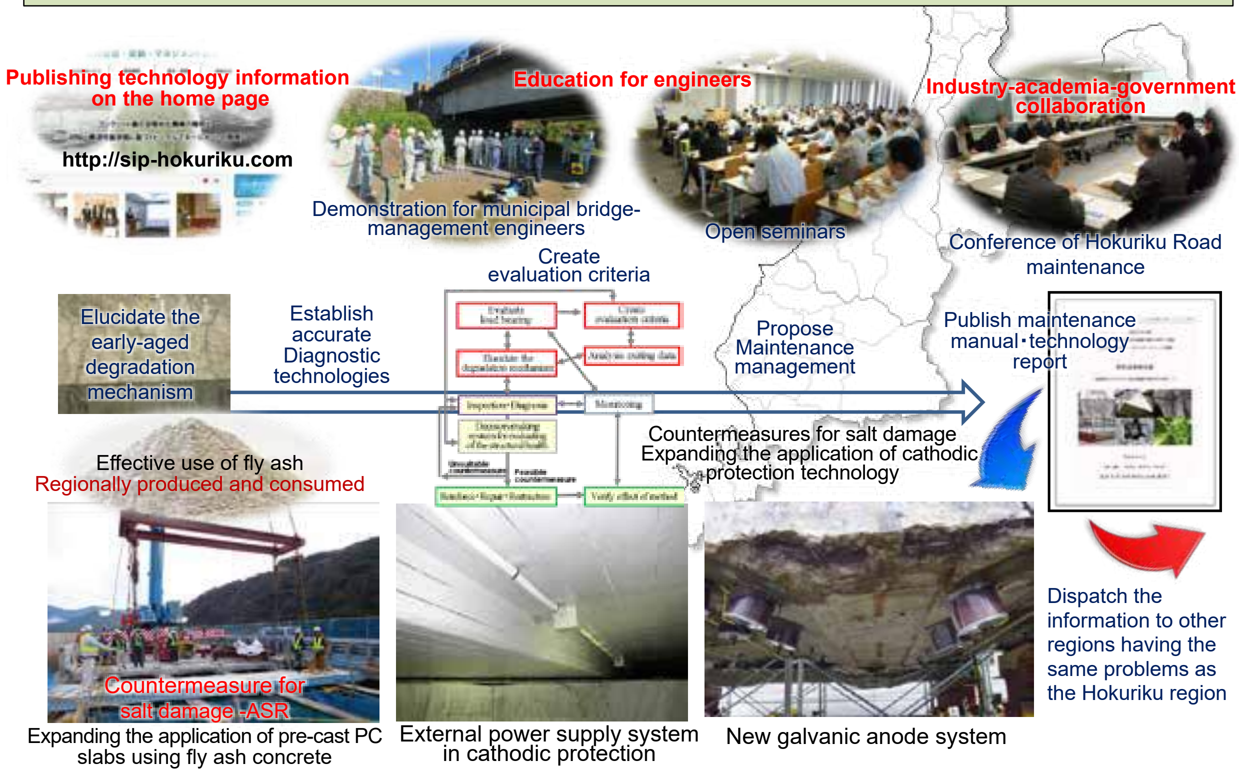
Without fly ash

Confirm the effects of fly ash on salt damage

Goals

Grasping the actual conditions of structures accurately, improving the accuracy of diagnostic technology, repeating effective maintenance and establishing maintenance management which can be turned into preventive maintenance carried out by local governments in the next 50 years

Features : This project does not propose a nation-wide standard maintenance system; it develops a standard one for the Hokuriku region based on regional characteristics, to improve the safety of infrastructure and to reduce wasteful spending



Expanding the application of pre-cast PC slabs using fly ash concrete

External power supply system in cathodic protection

New galvanic anode system

59 Development of Life-Cycle Management System for Port and Harbour Facilities - Integrated Framework from Inspection to Assessment

Principal Investigator: Ema Kato (Port and Airport Research Institute, MPAT)

Collaborative Research Groups: Tokyo Institute of Technology, Tokyo University of Science, Toa Corporation, Nakabohtech

R&D Objectives and Subjects

Objectives

<u>Implementation of maintenance and management support tools for port facilities based on a life-cycle management system</u>

- Development of inspection and monitoring technologies for port concrete/steel structures
- Proposal of appropriate maintenance and management techniques for individual port facility management bodies
- Improvement of formulation methods of maintenance and management plans for the optimization of life cycle costs

The proposed tools contribute to simplifying maintenance work and reducing maintenance cost, aiming to enhance the international competitiveness of Japanese ports and improve disaster prevention functions of port facilities.

Subjects

<u>Development of inspection and monitoring technologies for piled piers</u>

✓ Development of 4 types of inspection devices; 1. ROV equipped with a camera system for visual inspection of concrete superstructures, 2. Non-contact ultrasonic thickness gauging system, 3. Sensor for anti-corrosive coatings, and 4. Sensor-aided maintenance system with IT

✓ Proposal of an inspection scheme according to requirements of maintenance and management

<u>Improvement of evaluation and prediction of performance for piled piers</u>

✓ Development of performance evaluation methods for anti-corrosive coatings of steel piles

✓ Development of performance evaluation methods for concrete superstructures

<u>Improvement of the Life-Cycle Management system for open-type wharves</u>

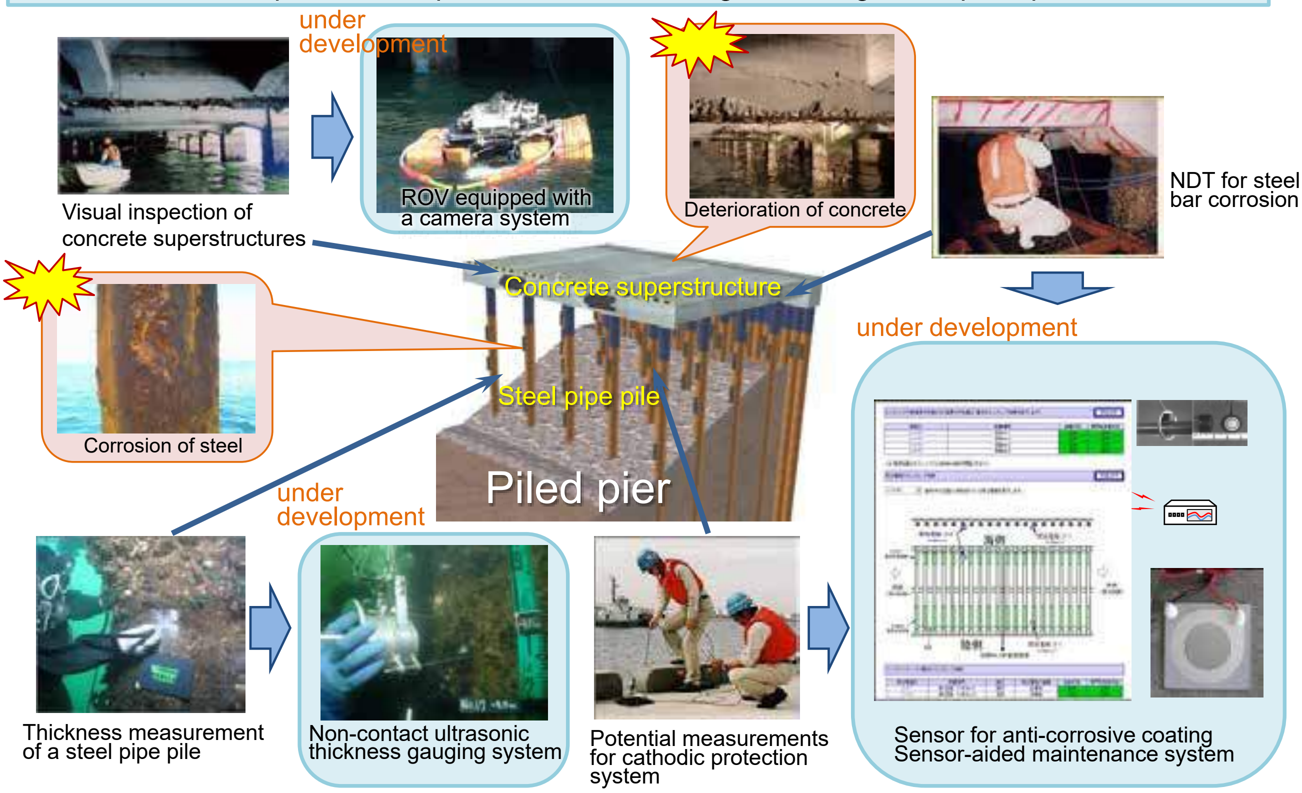
✓ Methodology establishment of maintenance and management plans for optimization of life cycle costs

Current Accomplishments (1/2)

Problem

- Limited working hours due to tidal actions
- Possible accidents during inspection work
- Hazardous underwater work
- Operation restrictions due to inspection work

Development of inspection and monitoring technologies for piled piers



Current Accomplishments (2/2)

For implementation of efficient inspection and diagnosis of piled piers

ROV equipped with a camera system for visual inspection
- ✓ Improvement of location identification and operation-supporting systems
- ✓ Promotion of demonstration tests

Non-contact ultrasonic thickness gauging system
- ✓ Enhancement of precision by improving detection of multiple reflection waves

Sensor for performance evaluation of anti-corrosive coating
- ✓ Examination of the threshold value of sensors for corrosion
- ✓ Promotion of demonstration tests

Sensor aided maintenance system with information technology
- ✓ Development of monitoring systems for protection against corrosion of steel piles and superstructures

+

- Conventional inspection technology for marine structures
- Cooperation with the Society of Maintenance Engineers for Maritime, Port and Harbor Infrastructure
- Conventional inspection technology for land structures
- Inspection, Monitoring and Diagnostics Technologies developed by SIP

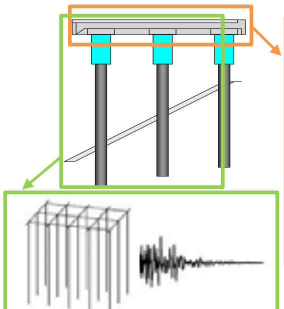
Investigation for inspection schemes according to requirements of maintenance and management

Inspection data

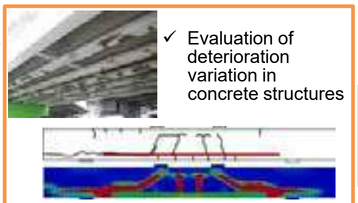
Accuracy of data for performance evaluation

Threshold of performance degradation detection

For enhancement of performance evaluation techniques with accuracy evaluation of inspection data



- ✓ Development of seismic performance evaluations

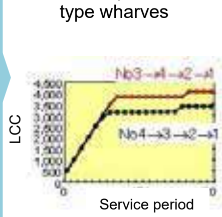


- ✓ Evaluation of deterioration variation in concrete structures
- ✓ Development of performance evaluation methods for deteriorated RC
- ✓ Improvement of constitutive models based on a deterioration mechanism

Improvement of performance evaluation

For implementation of practical maintenance and management based on an LCM system

- ✓ Improvement of maintenance and management planning methods for reducing LCC in an open-type wharf
- ✓ Development of maintenance prioritization methods for open-type wharves



Ex. LCC simulation

Image of maintenance prioritization

Goals

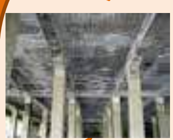
Enhancement of practical maintenance and management technologies

S I P R&D

- ✓ Development of inspection and monitoring devices
- ✓ Proposal of inspection schemes according to requirements of maintenance and management

Verification experiments

Development of performance evaluation methods for steel pipe piles and concrete superstructures



Verification experiments

- ✓ Improvement of maintenance and management planning methods for reducing LCC in an open-type wharf
- ✓ Development of maintenance prioritization methods for open-type wharves

Examination of applicability of developed technology to other structural types in port and harbor facilities

Discussion of the reflection of R&D technologies in Technical Standards

Maintenance and management plan
- Inspection and diagnosis
- Assessment
- Countermeasures
- Recording

<u>Reflection in Technical Standards for maintenance and management of Port and Harbour facilities</u>

Technical Standards and Commentaries for Port and Harbour Facilities in Japan
Manual on Maintenance and Rehabilitation of Port and Harbour Facilities
Guidelines on Strategic Maintenance for Port Structures

60 R&D of development of strategic asset management technologies for trunk agricultural water facilities

Principal Investigator: Isamu Nakajima (Head of Facilities Maintenance Unit, Institute for Rural Engineering, NARO)

Collaborative Research Groups: Walnut Ltd., TRIBOTEX Co. Ltd., Kubota Corp., Reitaku University, Ishikawa Prefectural University, Fukushima Agricultural Technology Centre, Okayama University

R&D Objectives and Subjects

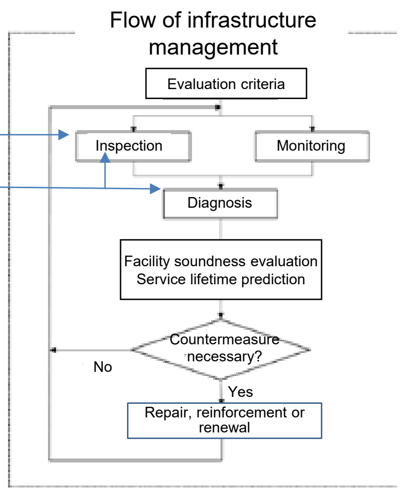
Purpose of R&D

① To develop new inspection and diagnosis technologies to maintain the functions of agricultural water facilities, including a total of 400,000 km of agricultural water canals and about 12,000 km of pipelines.

② To develop a maintenance information database and a personnel development system in order to support organizations and technologists who maintain facilities.

Contents of R&D

Inspection and diagnosis	① Development of technology to detect locations of leaks in water pipes
	② Development of technology to monitor the state of and to maintain pumping equipment
Support technologies	③ Development of systems to support preparation of trunk water facility renewal and improvement scenarios
	④ Development of a method of providing information to pass on agricultural water facility management technologies
	⑤ Building a personnel training and research network centered on local universities

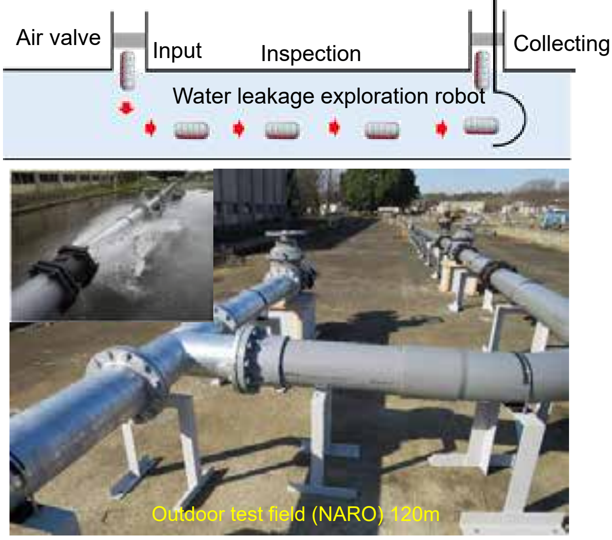


Current Accomplishments (1/2)

Inspection and diagnosis countermeasure technologies

① Development of technology to detect locations of leaks in water pipes

- Detection of water leakage position by small submarine type leakage exploration robot



Measurement precision of prototype leak investigation robot now being tested in an outdoor pipeline leak test field.
Proving test underway on Miyakojima Island.

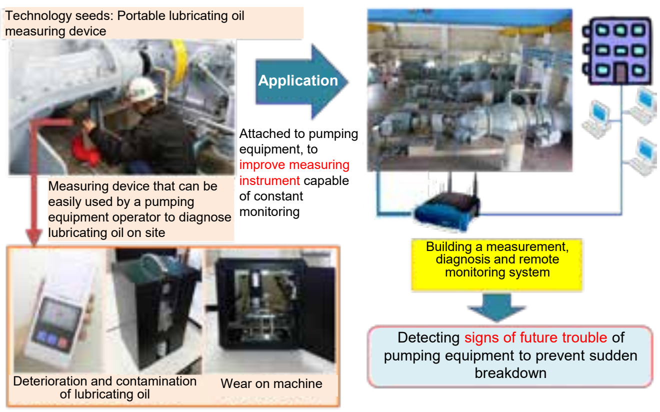
② Development of technology to monitor the state of and to maintain pumping equipment

Conventional method

Disassembly inspection of pump equipment (once every 10 to 20 years)

Development technology

Lubricating Oil Diagnosis method (oil extraction - analyze and quantitatively diagnose equipment deterioration)



Proving test equipped with measuring devices attached to drainage pumping stations at 2 places (Niigata, Aichi)

Development of methods of inspecting and diagnosing facilities that used to be difficult to inspect visually

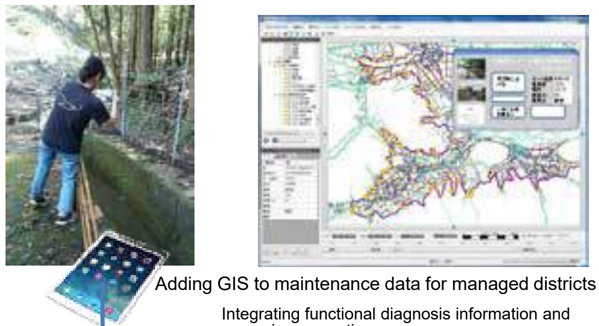
Current Accomplishments (2/2)

Maintenance organization support systems

③ Systems to support preparation of trunk water facility renewal and improvement scenarios

④ Method of providing information to pass on agricultural water facility management technologies

A web-based application to enable an iPad or cell phone to be used easily to build a GIS database of maintenance/disaster information accumulated in land improvement districts where day-to-day management of facilities is conducted.



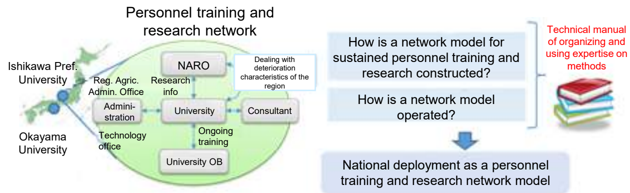
Adding GIS to maintenance data for managed districts

Preparing function diagnosis and renewal scenarios

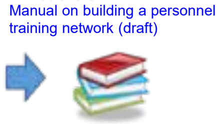
Completing the prototype; Proving tests now underway in 3 districts; Scheduled to start advance sales of some functions (web applications) in FY2016

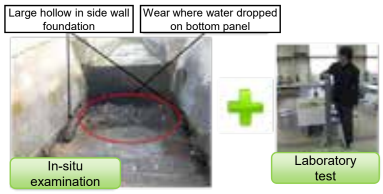
⑤ Building a personnel training and research network centered on local universities

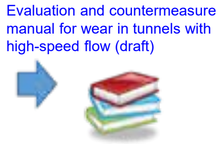
Building a personnel training and R&D network model centered on regional universities and contributing to regional asset management while creating organizations and preparing a technical manual containing expertise on operation methods



Giving on-site lectures (using site channels)





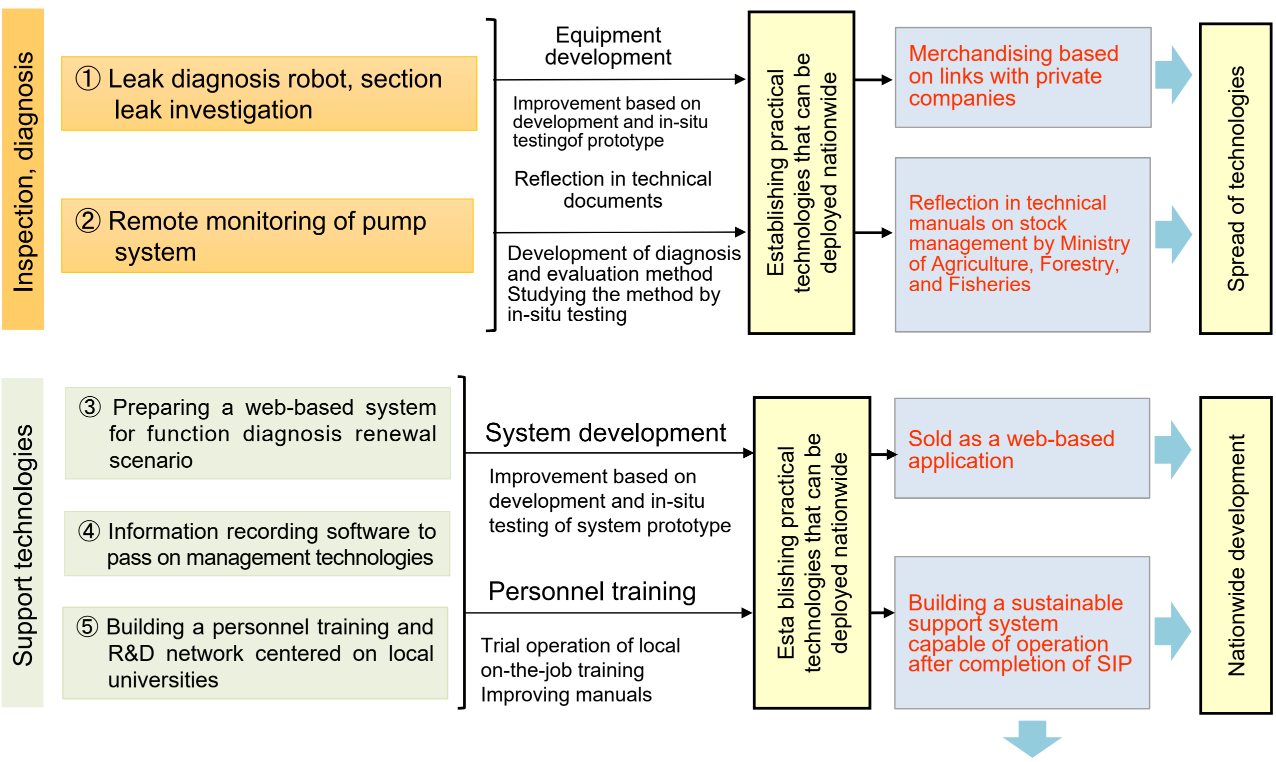


Clarifying and evaluating in advance the deterioration characteristics of the region

Development of support and personnel training system to prevent weakening of maintenance organizations

Goals

SIP development technologies are implemented as agricultural water facility maintenance technologies



Overseas development as maintenance technology for agricultural water facilities in Monsoon Asia

MEMO

Infrastructure Maintenance,
Renovation and Management


Courtesy of the Ministry of Land, Infrastructure, Transport and Tourism (Image taken by Tokyo Dome Corporation)


Courtesy of Metropolitan Expressway Company Limited


Courtesy of Obayashi Corporation

For Safe and Resilient Civil Infrastructure Systems

Cross-ministerial Strategic Innovation Promotion Program (SIP)
Website (Cabinet Office)
http://www8.cao.go.jp/cstp/panhu/sip_english/sip_en.html

内閣府
Cabinet Office