Missions and Projects of Center of Advanced Engineering Structural Assessment and Research (CAESAR)

by

Osamu Matsuo[1] and Masahiro Shirato[2]

ABSTRACT

With recent increase in demand for the structural condition assessment and rehabilitation of existing highway bridges, CAESAR, Center for Advanced Engineering Structural Assessment and Research was established in April 2008, as one of the four Research Institutes and Centers of the Public Works Research Institute, Tsukuba, Japan. This paper reviews the background, mission, organization, and focused research areas of the new organization, CAESAR, and discusses their impacts on highway bridge administrative practice.

KEYWORDS: disaster mitigation, highway bridge, maintenance, older bridge, structural assessment

1. BACKGROUND

CAESAR, Center for Advanced Engineering Structural Assessment and Research, is one of the four Research Institutes and Centers of the Public Works Research Institute (PWRI), Tsukuba, Japan, as shown in Figure 1, and has just opened since April 2008. The origin of the PWRI dated back to 1921, almost eighty years ago, and it was established as the Highway Material Laboratory, Civil Engineering Bureau, past DOI. Since then, PWRI has served as the national leading institute for the technology development, disaster mitigation, and codification for infrastructure including highway bridges.

The stock of highway structures in Japan rapidly increased in 1960s in response to the rapid economic growth at the time, and now they are getting older than 50 years. Over the years, highway structures in Japan have been operated under heavy traffic loads and exposed to severe climate and disaster conditions. The issues we will face must be getting complicated and comprehensive technology developments and proactive actions to assess their soundness have to be rushed.

Therefore, in April 2008, the PWRI re-organized their Institutes and Center and set the new research Center, CAESAR, Center for Advanced Engineering Structural Assessment and Research. The CAESAR leads national efforts to raise the technology levels of the design and construction for new bridges and the structural condition assessment and maintenance for older bridges. In addition, it also conducts research that will prevent and mitigate disaster damage to highway bridges.

2. MISSION STATEMENTS

The Center for Advanced Engineering Structural Assessment and Research is the nation's administrative research agency leading the structural safety of highway bridges. Specifically, the Center conducts clinical research, the collection and dissemination of technology, the incorporation of state-of-the-art treatments into practice, and education and training activities.

Clinical Trial and Research: Together with highway administrators, the Center treats the bridges that have serious structural deficient, while the current practice levels in inspection, diagnostic examination, and prognosis are not necessarily high enough for treating them. The Center provides the state-of-the-art type of strategies and solutions for the structural

[1] Research Coordinator for Earthquake Engineering, Center for Advanced Engineering Structural Assessment and Research, PWRI , 1-6 Minamhara, Tsukuba, Ibaraki-ken 305-8516 Japan

[2] Senior Researcher, Center for Advanced Engineering Structural Assessment and Research, PWRI

assessment and rehabilitation. The follow-up investigation is also conducted after the treatment. Once a disaster happens, the Center supports highway administrators in restarting servicing damaged bridges with an emergency countermeasure as soon as possible. Needless to say, it is mandatory to conduct basic laboratory research on the cause, damage mechanism, diagnosis, prevention, and treatment of damaged bridges, finding a more reasonable approach and leading a clinical trial.

Collection and Dissemination of Technology: The Center collects and disseminates the information on the new technology of design, construction, and maintenance for highway bridges. The Center encourages and supports the networking of highway administrators concerning the inspection and management of existing highway bridges. The Center also collaborates in research and development with voluntary organizations such as universities, companies, and other national and foreign highway administrators and research institutions.

Incorporation of State-of-the-art Treatments into Practice: The Center feeds back their state-of-the-art experience and clinical trial results into practice. The Center sets out design and maintenance codes, resulting from basic and advanced research on design of longer life-time structures, maintenance of existing bridges, and seismic damage prevention and mitigation.

Education and Training: The Center continues to develop, maintain, and renew human resources that will ensure the national highway bridge maintenance system. As the national center of excellence in the state-of-the-art practice and research on structural condition assessment and maintenance for highway bridges, the Center welcomes engineers and researchers and gives them an opportunity to earn fundamental sciences and clinical disciplines through participation in basic and clinical research programs.

The Center is also established to support highway administrators about the verification of design/construction technologies and devices that are not specified in the design codes but also about the maintenance issues such as the diagnostic examination, rehabilitation, and reinforcement of damaged bridges due to salt attack, alkali silica reaction, fatigue, decaying etc, and the seismic vulnerability assessment reinforcement and reinforcement.

Figure 2 shows a summary of the relationship with other sectors. As the center of excellence in highway bridges, the Center collaborates with voluntary organizations of public, academic and private sectors engaged in research, education, or training activities.

3. INTERDISCIPLINARY ORGANIZATION OF CAESAR

Rehabilitation and seismic strengthening of older bridges are much more multifaceted and complicated than conventional design/construction issues, in which a comprehensive structural assessment of a total structural system is required. For example, when designing a seismic reinforcement of an existing steel bridge, the state of decaying should be taken into account. Or, the reinforcing may give a side effect on the fatigue vulnerability. Therefore, we need a more flexible and interdisciplinary organization. While the former highway bridge-related research teams in the PWRI were organized by major highway bridge parts and materials such as metal superstructures, concrete superstructures, substructures, and seismic design, the Center for Advanced Engineering Structural Assessment and Research (CAESAR) adopts a completely interdisciplinary research system.

Figure 3 shows an organization chart of the CAESAR. The old Bridge Engineering Research Team, Foundation Engineering Research Team, Earthquake Engineering Research Team, and Structures Management Research Team were shuffled into the CAESAR. There used to be the chief researcher (PI, principal investigator) in each research team and they were delegated to make decisions within their research fields so that a speedy decision making can be encouraged to follow a rapid motorization. However, there is no research team section in the CAESAR and a chief researcher and other researchers are matched on a project basis by the executive board to work out interdisciplinary collaborations across the past research sections and develop human resources who are not only specialists in some fields but also comprehensive engineers. The executive board also reviews on-going projects and makes decisions on future strategies from the interdisciplinary viewpoint.

Research Coordinator for Earthquake Engineering coordinates research on earthquake disaster prevention and mitigation for infrastructure including highway structures and river structures beyond CAESAR and the Research Coordinator covers Tsukuba Central Research Institute and Civil Engineering Research Institute for Cold Region as well as CAESAR. Once a large-scale earthquake happens, the Research Coordinator organizes an emergency scanning and support team from the researchers of the CAESAR, Tsukuba Central Research Institute, and Civil Engineering Research Institute for Cold Region and directs the emergency scanning and every technological support for national and local highway authorities.

Director of Bridges and Structures Research leads the researchers of the CAESAR. Double responsibilities are assigned Chief Researchers to solve basic design and construction issues as well as to focus on our most pressing maintenance issues. The group conducts research on improving highway bridge maintenance, disaster damage prevention and mitigation, and design and construction methods. Especially, basic and applied inspection technology, structural condition assessment methods, object-related diagnostic examination methods, rehabilitation methods, and reinforcement methods are also focused and developed. The group also tackles to develop and improve national bridge management programs that enable to account for individual bridge's conditions of design, construction, and environmental background. An ad hoc research unit also will be flexibly composed of selected researchers and engineers from the CAESAR and other academic and private sectors when something the CAESAR needs to intensively focus on and immediately take action for is discerned.

As of April 2008, there are 23 researchers and 11 visiting researchers in the CAESAR. In addition, 4 researchers from the Tsukuba Central Research Institute and Civil Engineering Research Institute for Cold Region are also involved. 40 projects are going on including five collaborative research projects with volunteer private sectors, using large-scale test facilities such as a full-scale and 30 MN loading test machine, large-scale continuous wheel load test machine, 1000 kN fatigue test machine, and large-scale earthquake loading simulator for structural members.

It is worth noting that several related research fields, namely physical material properties including geomaterials and painting materials, are studied in the Tsukuba Central Research Institute and severe winter effects are studied in the Civil Engineering Research Institute for Cold Region. If needed, the CAESAR can coordinate a research project with such research teams bridging over the Center and the Institutes and act together, taking full advantage of ample PWRI research resources.

The CAESAR’s research projects can be categorized into the following three programs:

1. Fighting decaying nation’s infrastructure
2. Enabling a disaster resilient nation
3. Providing performance-based design and verification measure.

4. RESEARCH PROGRAM FOR FIGHTING DECAYING NATION’S INFRASTRUCTURE

For example, in the US, highway bridges were vastly stocked in 1930s along with the New Deal Policy, and 50 years later, in 1980s, damage that caused traffic shutdowns, becoming a big social issue, was noticeable for over and around 50-year old highway bridges.

In Japan, infrastructure development in quantity initiated during the rapid economic growth period of 1950s through 1970s. Accordingly, highway bridges older than 50 years are increasing, and, as shown in Figure 4, statistical data predicts that, in 2026, 47% of the national highway bridges are going to be older than 50 years, in which the total number of highway bridges is 140,000 in 2006. Already, three major types of distress that greatly affects the strength capacity of bridges, fatigue in steel structures and deck plates, and salt attack and alkali silica reaction (ASR) to concrete structures, have been discerned. Figure 5 shows the typical distress types. The MLIT (Ministry of Land, Infrastructure, and Transport and Tourism) has been rushed to act for them such as conducting special inspection programs, making rehabilitation manuals, and starting a new mandatory every-five-year inspection program for the bridges of the national highway system, which used to be an every-ten-year program. The requirement level of the every-five-year inspection seems to be in between the US ``routine’’ and ``in-depth’’ inspections.

Therefore, the CAESAR conducts research projects that involve a microscopic management, namely, the customized diagnosis, prognosis, and rehabilitation for individual older bridges to prevent from resulting in critical failure, rather than a macroscopic management, namely, a performance measure at the national level for funding allocation and national initiatives that considers the large-scale functional and geometric characteristics of bridges.

Individual bridges were designed and constructed under their specific conditions and their historical background. Surrounding traffic and environmental conditions are different and the maintenance history is also different. Accordingly, they behaved differently as time goes by. As a cutting edge approach to provide customized structural condition assessment and rehabilitation for individual bridges, the CAESAR applies a clinical trial approach including anatomic and pathologic types of approach to fight decaying nation’s highway bridges. The conditions of several sample highway bridges will be assessed, using cutting-edge inspections (with nondestructive or slightly-destructive methods), monitoring, diagnostic tests, and numerical simulations. In addition, the CAESAR will follow up and measure the effectiveness of the bridges that the highway administrator asked the CAESAR to guide the structural assessment, maintenance, repair, and rehabilitation. Such clinical trial results and follow-up examination results will be transferred to practice via manuals and standards.

First, the CAESAR has projects to develop nondestructive or minor destructive inspection methods to assess the internal condition of a structural member. In the current practice, visual inspection is the standard as shown in Figure 6 and it is needed to upgrade to find out distress in hidden parts or the difficult parts to conduct a hands-on inspection such as under water and simplify them. For example, as shown in Figure 7, the CAESAR has been testing nondestructive tools such as a UT (ultrasonic scanning) technique to detect defects in metal deck plates and a self-potential method to detect the corrosion of a reinforcement bar in concrete.

Second, the CAESAR has projects for studying the mechanism of distress that is necessary to invent cutting edge diagnosis examinations on the current structural condition and remaining performance of an existing highway bridge. For example, Figure 8 shows an example of the past anatomic study, in which the strength capacity of a damaged concrete girder from an older bridge was tested. The CAESAR also has started a new project to measure the influence of a structural deficient in parts on the overall bridge behavior.

Third, the CAESAR also has projects to develop reinforcement or rehabilitation techniques to provide a customized maintenance program for individual bridges. For example, Figure 9 shows an example of on-going project on a fatigue prevention technique for steel deck plates with SFRC (steel fiber reinforced concrete) pavement. In addition to technology developments, the CAESAR has started a new project to conduct follow-up examinations for bridges that were rehabilitated or strengthened in the past to measure the effectiveness of such countermeasure works.

Fourth, the CAESAR has started establishing a knowledge database that includes past and future case histories of either no-countermeasure or a countermeasure for the bridges highway administrators asked for the CAESAR. The national bridge management system has been used, but it is primarily used to decide a national level or regional level future maintenance budget estimation. The new database will enable to choose relevant customized countermeasure works considering individual bridge's design, construction, and environmental conditions and facilitate to follow up the reexamination of the effectiveness of the past engineering judgment.

In addition to above projects, the CAESAR also has projects for seeking bridge types and structural details for improving the long-term performance. For example, a jointless abutment design manual is being drafted. As shown in Figure 10, an integrated structure of the super and sub structures will enable to remove joints and bearings that can cause major defects because of corrosion by surface water coming through joints.

5. ENABLING A DISASTER RESILIENT NATION

In Japan, the 1995 Hyogo-ken Nanbu (Kobe) earthquake (Mj7.3) damaged infrastructure, as shown in Figure 11. a number of bridges were toppled. Massive earthquakes frequently rocked Japan such as the 2004 Niigata-ken Chuetsu earthquake (Mj6.8), 2005 Earthquake off the west coast of Fukuoka (Mj7.0), 2007 Noto Peninsula earthquake (Mj6.9), 2007 Niigata-ken Chuetsu-oki earthquake (Mj6.8). The urgency of future large-scale earthquakes is a national concern such as the Tokyo Metropolitan Area earthquake near Tokyo, Tokai earthquake near Shizuoka and Aichi Prefectures, Nankai Earthquake and Eastern Nankai Earthquakes near Shikoku island, Miyagi-ken-oki earthquakes in northern part of Honshu Island and so on, which are predicted with a magnitude order of 7 to 8. The PWRI has been the center of excellence in disaster mitigation technology for highway bridges against large earthquakes. For example, Figures 12 and 13 show case histories of the PWRI’s research and development achievements in seismic vulnerability assessment and reinforcement research and development. The Center for Advanced Engineering Structural Assessment and Research (CAESAR) will continue to be the center of excellence to make Japan resilient against earthquakes.

First, the CAESAR continues to conduct research for improving the seismic design technology for new bridges and the seismic vulnerability assessment and reinforcement techniques for existing bridges. Structural dynamics, nonlinear soil-pile interactions, soil liquefaction and liquefaction-induced lateral soil spreading are considered to measure the seismic performance. For example, the CAESAR started up a research project to develop new generation seismic design codes for foundations that use a dynamic verification method.

In terms of disaster mitigation, the CAESAR also supports national initiatives, developing a step-by-step upgrade program for the seismic performance of the highway bridge group on emergency transportation highway networks. With limited budget and time resources but with a number of existing highway bridges that are not satisfied with the latest seismic design criteria, the one-by-one full-spec seismic reinforcement tactics of individual bridges are not always right. Administrators have requested a scheme that requires reinforcement at minimum but achieves at maximum, that is, a priority ordering on the basis of the degree of vulnerability and a minimum requirement of reinforcement to stop the prioritized bridges from toppling, so that not only individual bridges but also their emergency transportation highway network system will survive. For example, a 2005-2007 three-year national urgent seismic reinforcement program for older bridge piers of emergency transportation network was enforced from the MLIT.

Another CAESAR's important goal is to provide post-earthquake emergency inspection and recovery tools for highway bridges to resume emergency service dramatically quickly. Even though a large-scale earthquake causes damage to highway bridges, it is necessary to restart emergency service as soon as possible to rescue people and transport aids. Therefore, as shown in Figure 14, the CAESAR has been testing super rapid repair work methods that are simple, easy, and quick with material that is easy to get like carbon fiber sheet and polyester bands. As shown in Figure 15, the CAESAR also has been developing an automatic damage detection monitoring system that can detect degree of damage during the earthquake and storage to pass on an emergency patrol road administrative engineer. The distress can be noticed even when the earthquake occurred at night or the damage is caused at a part difficult to be visually inspected.

Needless to say, the CAESAR will feedback research results as well as past experience in earthquake damage to structure into the practice of seismic vulnerability assessments and disaster mitigations and the design practice of new and replacement structures.

6. PERFORMANCE-BASED DESIGN AND VERIFICATION MEASURE

To ensure nation's bridges are structurally safe, technology developments in private and academic sectors are crucial. To encourage them as well as to guarantee the quality level of individual technologies, the Center sets out not only the performance requirements but also develops verification measures. For example, as shown in Figure 16, the PWRI's standard tests for the fatigue durability of deck plates and the seismic ductility for piers have been widely used.

In addition, the Center has been preparing for the next revision of the Japanese Specifications for Highway Bridges that will be based on a performance-based specification concept, involving a reliability design concept.

7. INTERNATIONAL COLLABORATION

The CAESAR serves as like a portal site to exchange information and knowledge between Japan and international communities, and collaborate with other foreign institutions. For example, under the framework of the Panel on Wind and Seismic Effects, UJNR (U.S.-Japan Cooperative Program in Natural Resources), the CAESAR co-organizes U.S-Japan Bridge Engineering Workshop with the Federal Highway Administration, US, and shares knowledge, experience, initiatives, and research results with other US and Japanese highway administrators, national institutes, and academic and industry partners. The CAESAR also has frequent communications with foreign government institutions and universities such as German Federal Highway Research Institute, (BASt) and so forth, in which some of them are under agreements.

In addition to that, the CAESAR also sends researchers and helps a technical cooperation in response to requests from foreign highway administrators via Japan International Cooperation Agency <http://www.jica.go.jp/english/>.

8. REMARKS

Safety is an essential factor for communities and the CAESAR has been established for providing the structural safety of highway bridges. The acronym CAESAR is named after Julius Caesar of the Roman Empire. He established and maintained infrastructure of long highway network spanning throughout the Roman Empire and it is still available over more than 2000 years. Caesar, when crossing the Rubicon river, said ``the die is cast, " meaning he crossed the point of no return with a strong will. We hope our new research center, CAESAR, goes ahead with a strong will to complete our missions, partnering with this UJNR panel.

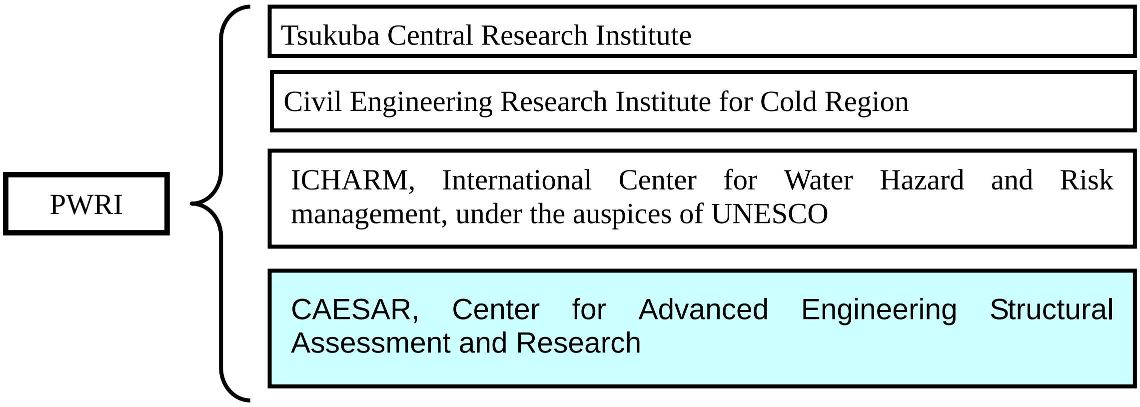


Figure 1 Organization chart of the PWRI as of April 1st, 2008

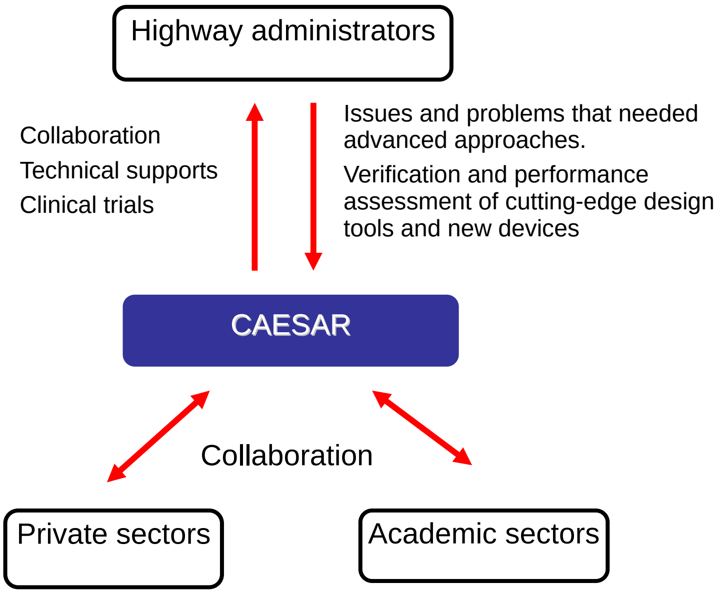


Figure 2 Support to highway administrators and collaboration with academic and private sectors

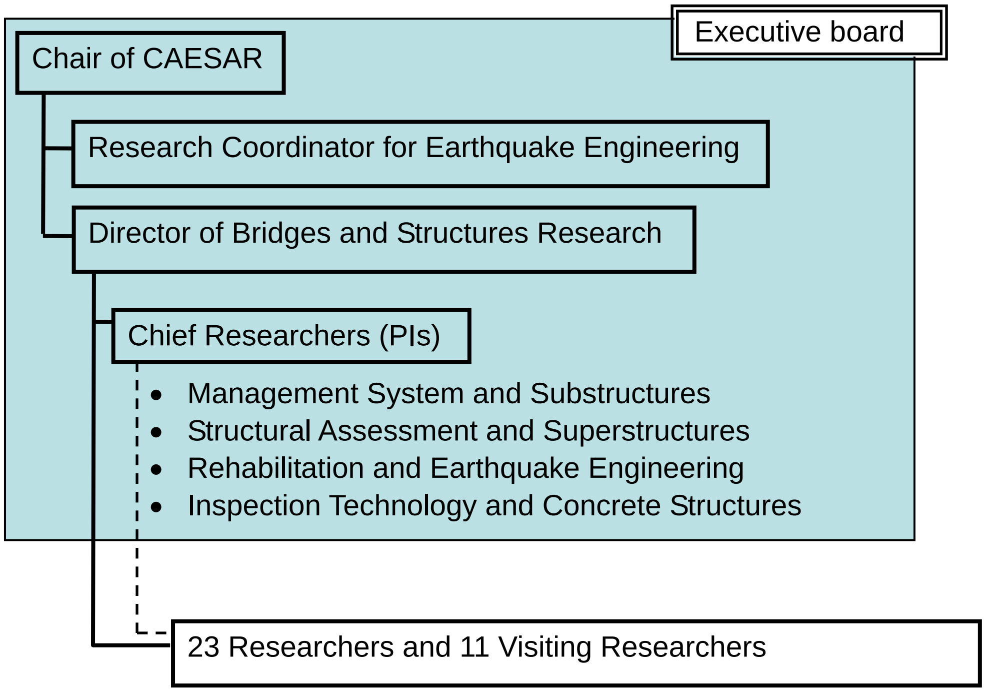


Figure 3 Organization charts of the CAESAR

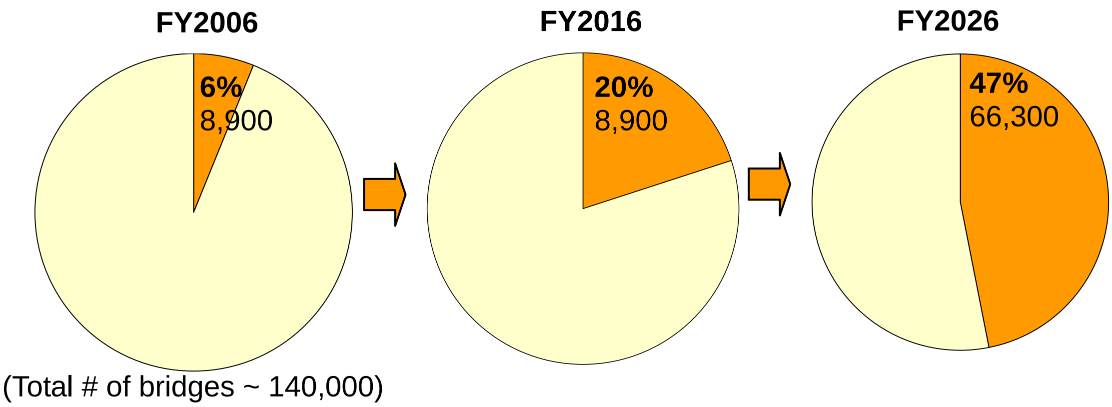
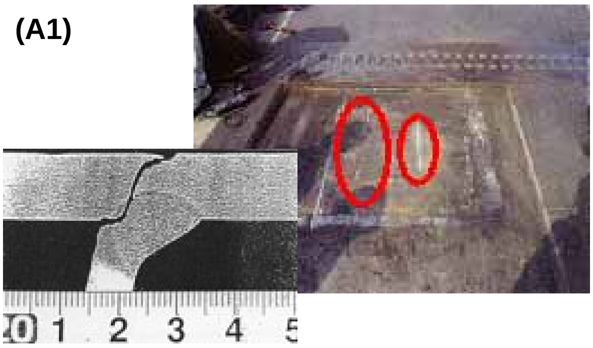


Figure 4 Percentage of bridges older than 50 years

(A1)



(A2)

Fatigue fracture in a steel main girder

(B)

Anatomic survey for an overpass that suffered from salt attack.

(C)

Figure 5 Three major types of distress to highway bridges, fatigue (**A1** and **A2**), salt attack (**B**), and ASR, alkali silica reaction, (**C**)

Figure 6 Typical bridge inspection. Visual inspection is the standard in the current routine inspection practice.

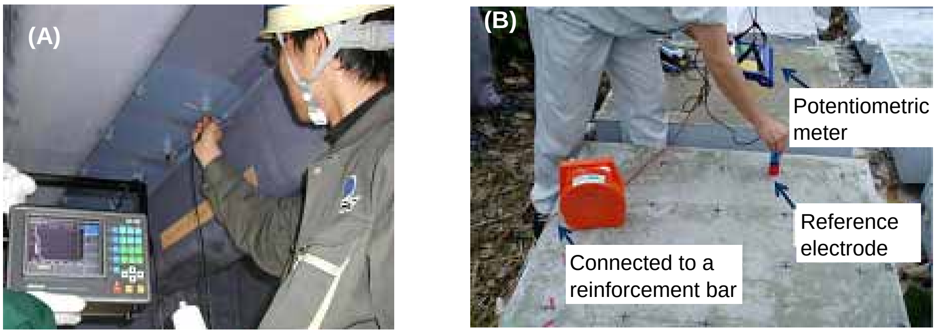


Figure 7 Nondestructive inspection techniques to visualize hidden distress. (A) Field test of a UT (ultrasonic scanning) method to detect defects in metal deck plates and (B) Test of a self-potential method to detect corrosion of reinforcement bars inside concrete.

Figure 8 Field load test of a damaged member from an older bridge

Figure 9 Countermeasure to prevent metal deck plates from fatigue failure using steel fiber reinforced concrete (SFRC) pavement

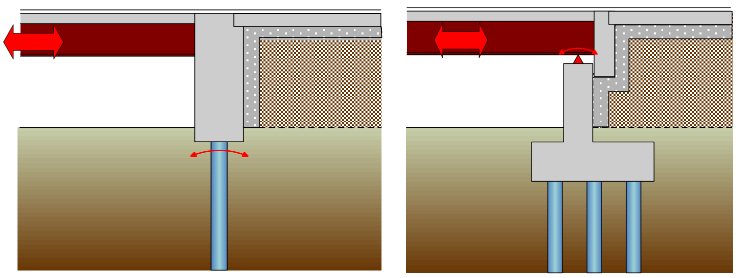


Figure 10 An example of fundamentally maintenance-less structural details – jointless abutments – integrating super and substructures and removing joints and bearings

Figure 11 Collapse of a highway viaduct of Route 3, Kobe route, of Hanshin Expressway during the 1995 Hyogo-ken Nanbu earthquake

Figure 12 Undamaged and damaged piers next to each other during the 2004 Niigata Chuetsu earthquake (Mj6.8), in which undamaged piers were reinforced in the middle of the seismic reinforcement program by the administrator

Figure 13 A long span bridge did not undergo damage during the 2007 Niigata-ken Chuestu-oki earthquake (Mj6.8) because of seismic reinforcement supported by the PWRI.

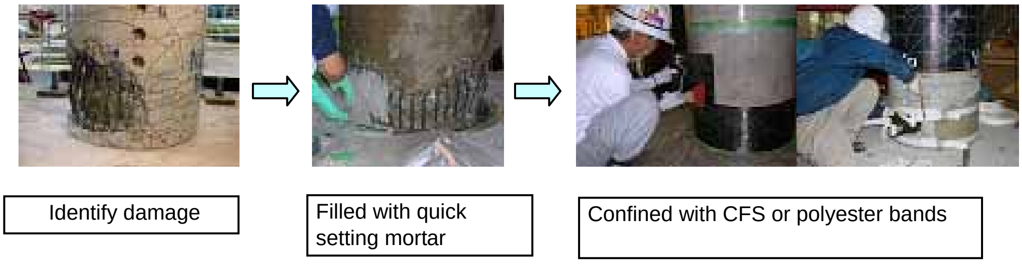
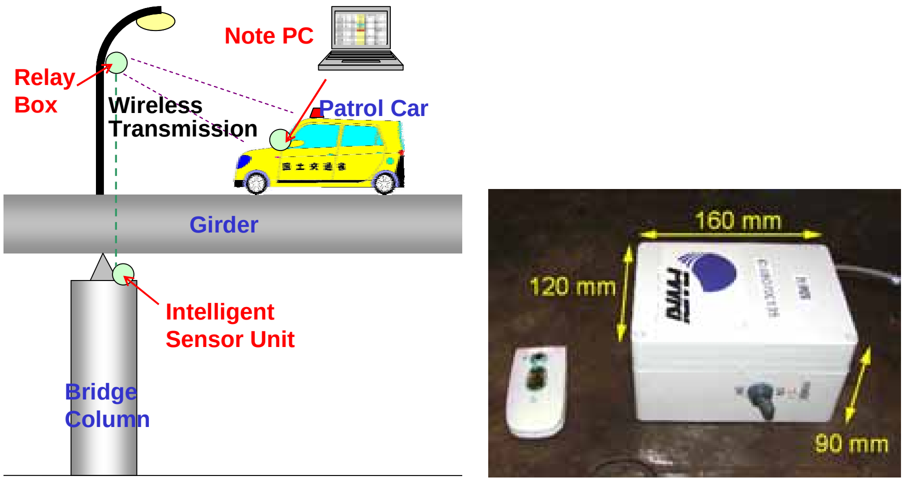


Figure 14 Quick repair methods just for emergency traffic service



(a) Damage detection system (b) Intelligent Sensor Unit

Figure 15 An example of new damage detection systems and its intelligent sensor unit

Figure 16 Tests for deck plate fatigue durability (left) and bridge pier ductility (right)