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REAAA Technical Report

Report on FEHRL Scanning Tour to South Korea and Japan: Infrastructure Resilience

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REAAA Profile

REAAA is the Road Engineering Association of Asia and Australasia. The association promotes the science and practice of road engineering and related professions in the Asia-Pacific region through the development of professional and commercial links within and between countries in the region. REAAA Chapters have been set up in Australia, Brunei, Korea, Malaysia, New Zealand and the Philippines. REAAA is also active in Indonesia, Japan, Singapore, Taiwan and Thailand.

REAAA was set up in June 1973 with a permanent secretariat in Malaysia. It has more than 1,500 members in 37 countries. It holds regular events including an annual Heads of Road Authorities (HORA) meeting, a triennial international conference, technical visits and study tours, trade exhibitions, seminars, forums and workshops. It also publishes a Journal and a Newsletter. The most recent initiative is a series of technical reports addressing issues of concern in the region.

REAAA Technical Reports

This is the tenth in the series of REAAA Technical Reports since the first report was published in 2008. The following Technical Reports have been published to date.

TC-1 Guide to privatisation of expressways and highways

TC-2 Disaster risk management

TC-3 Efficient operation of the road network

TC-4 Road safety – make it happen

TC-5 Pavement durability

TC-6 Guide to the public-private partnership of road and highway projects

TC-7 Incorporating Japanese pavement design practice for a community road in Mongolia

TC-8 Pavement maintenance and rehabilitation practices

TC-9 Compendium on pavement recycling

TC-10 Report on FEHRL scanning tour to South Korea and Japan: infrastructure resilience

REAAA 2018
Kuala Lumpur, Malaysia

Forum of European National Highway Research Laboratories (FEHRL)

The Forum of European National Highway Research Laboratories (FEHRL) was formed in 1989 in the United Kingdom by the Directors of road research institutes of 13 countries in Europe. Since then its primary objective has been to provide opportunities for identifying research priorities and to create a positive climate for cooperation between its institutes. Its current membership consists of 30 European countries – including members throughout the EU states, EFTA countries, Eastern and Central European countries – as well as international affiliates from the USA, South Africa, Australia and Israel. FEHRL became an international association, with its registered office in Brussels, in 2000.

In 1993, FEHRL developed an on-going Strategic Road Research Programme (SERRP) that is defined by a series of detailed implementation plans. It was published to ensure that many of FEHRL's research topics were pursued with the assistance of the European Framework Programmes for Research and Technological Development (RTD) and the EU COST Programme. Following early successes, FEHRL then established a network of Research Coordinators in the member Institutes to provide effective and expert communication routes within the organization. This was followed by the development and adoption of a five-year Development Plan, and the preparation of SERRP II in consultation with the Conference of European Directors of Roads (CEDR) – one of FEHRL's main client bodies – and industry. The latest version of the program (SERRP V) for the years 2011-2016, was published in 2011.

FEHRL coordinates the publication of research results from its projects; for example, in final reports and media articles. It also publishes its own semi-annual magazine, the *FEHRL Infrastructure Research Magazine* (FIRM) which is distributed to some 2000 key road and infrastructure stakeholders.

Further details can be obtained at: http://www.fehrl.org/.

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- Korea National Committee
- Korea Expressway Corporation Research Institute
- Korea Expressway Corporation
- Korea Road Association
- Ministry of Land, Infrastructure and Transport, Korea
- Hanshin Expressway, Japan
- Honshu-Shikoku Bridge Expressway Company, Japan
- NEXCO West, Japan
- NEXCO East, Japan
- NEXCO Research Institute, Japan
- National Institute for Land and Infrastructure Management (NILIM), Japan
- Public Works Research Institute, Japan
- Railway Technical Research Institute, Japan.

FEHRL Delegation at Akashi-Kaikyo Bridge

SUMMARY

This report presents the details of a FEHRL Scanning Tour to Korea and Japan in November/December 2016, on the topic of 'Resilience of the Infrastructure'. The locations visited were Seoul, Korea, and Osaka, Kobe and Tokyo, Japan. Based on existing connections with the Asia region, the Australian Road Research Board (ARRB) was appointed as Program Manager to develop this tour in cooperation with FEHRL.

The report provides an outline of the research priorities in Korea and Japan, and key approaches and learnings to enhance infrastructure resilience. It is structured according to the key principles underpinning the concept of resilience, using a collation of presentations and case study examples from the Scanning Tour.

The successful conduct of the Scanning Tour resulted in:

- the establishment of a dialogue regarding challenges for implementing more resilient infrastructure
- the establishment of mechanisms to share information and experiences regarding the management of resilient infrastructure
- the identification of practical applications of resilient infrastructure
- the identification of opportunities for future collaboration.

Currency conversion (approximate, July 2018):
1 AUD: 0.74 USD = 0.63 EUR = 1.01 BND = 10,740 IDR = 82.4 JPY = 838 KRW = 1.09 NZD = 39.7 PHP = 1.01 SGD = 20 TWD = 24.7 THB.

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1 INTRODUCTION

The Forum of European National Highway Research laboratories (FEHRL) has organised several Technical Scanning Tours to the USA since 2010. The tours are intended to facilitate the exchange of knowledge and partnership building between international organizations and the participating members of FEHRL. Previous tours have comprised teams from Europe, Israel, South Africa, the USA and Australia. These teams have previously included experts from FEHRL institutes, as well as road directorate experts from the Conference of European Road Directors (CEDR).

FEHRL identified the opportunity to broaden exchanges with other parts of the world, in particular, and for the first time, with Japan and South Korea. As a result, a Scanning Tour was conducted from 23rd November to 1st December 2016, on the topic of 'Resilience of the Infrastructure'. The locations which were identified were Seoul, Korea, and Osaka, Kobe and Tokyo, Japan. Based on existing connections with the Asia region, the Australian Road Research Board (ARRB) was appointed as Program Manager to develop this tour in cooperation with FEHRL. The participants were representatives from FEHRL and FEHRL institutes and PIARC. The Project Team comprised Thierry Goger (FEHRL), Caroline Evans (ARRB), Jean-Bernard Kovarik (IFSTTAR), Boerre Stensvold (NPRA), Jürgen Krieger (BASt), Fabien Palhol (CEREMA) and Maria Van den Hark (RWS).

The report provides an outline of the research priorities in Korea and Japan, and key approaches and learnings to enhance infrastructure resilience. It is structured according to the key principles underpinning the concept of resilience, using a collation of presentations and case study examples from the Scanning Tour.

2 DEFINITION OF RESILIENCE

The Intergovernmental Panel on Climate Change (IPCC) has defined resilience as ‘a system’s ability to anticipate, absorb and recover from a hazardous event in a timely and efficient manner’. The need for infrastructure to be resilient is of fundamental importance globally. In the face of natural disasters, climatic challenges and security threats, the resilience of infrastructure – and the wider implications for transport, planning and emergency relief – are critical components which decision-makers need to address. Resilience also plays a key role in maximising the economic, social and environmental aspects of transport infrastructure and network operations.

According to the Realising European RESILiencE for Critical INfraStructure, EU (European Union) research project, ‘resilience’ is defined as ‘the ability to survive in the face of a complex, uncertain and ever-changing future’. It is a way of thinking about both short-term cycles and long-term trends. ‘Resilience’ means to plan and prepare for minimising disruptions in the face of shocks and stresses, recover rapidly when they do occur, and adapt steadily with an optimal economic allocation of resources. Within the context of critical infrastructure, the resilience process offers a cyclical proactive and holistic extension of risk management practices. Similarly, it was agreed that the terminology needed to be consistent, and ‘resilience’ should be understood as the capability of the community, authorities and expert groups to minimise the total life-cycle consequences of hazards. It was also noted that many different definitions and metrics exist, and that there is a need to define these appropriately depending on object, purpose and hazard.

A resilient system should encompass the notion that the disaster-resilience of society equals the society’s ability to reduce:

- failure probabilities of (infra)structure
- direct or indirect consequences of failures, in terms of lives lost, damage, and negative economic and social consequences
- the time to recover (restoration of a specific system or set of systems to their ‘normal’ level of functional performance) (sourced from Bruneau et al. 2003).

It is recognised that there are several levels encapsulated in the definition of ‘resilience’. It spans the ability of road infrastructure to plan/prepare, withstand, recover and adapt according to a cyclical, proactive and holistic risk management system, as highlighted in Figure 2.1. Important aspects to consider in quantifying disaster-resilience include:

- robustness – the inherent strength, or resistance, to external damage without degradation or loss of functionality
- redundancy – system priorities that allow for alternative options, choices, and substitutions under stress
- resourcefulness – the capacity to mobilise needed resources and services in emergencies
- adaptability and ability to recover quickly – the speed with which disruption can be overcome and safety and services restored (Bruneau et al. 2003).

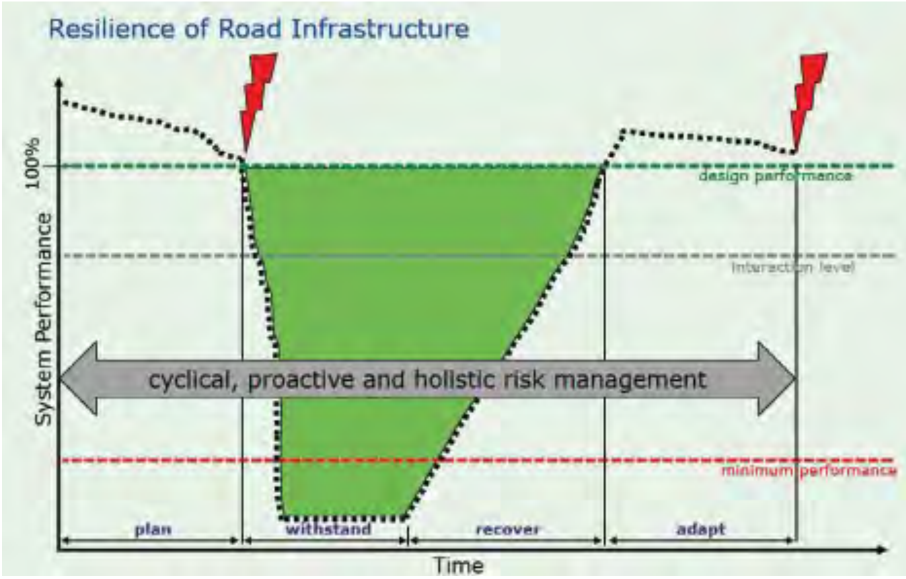

Figure 2.1: Resilience of road infrastructure

Source: J. Krieger – Resilience, climate change adaptation and related PIARC TC E.1 activities – FEHRL Scanning Tour on Infrastructure Resilience presentation.

In this sense, an integrated resilience cycle can be formed comprising mitigation, preparedness, response and recover, as reflected in Figure 2.2.

Figure 2.2: Integrated resilience cycle

Source: J. Krieger: Resilience, climate change adaptation and related PIARC TC.E.1 activities – FEHRL Scanning Tour on Infrastructure Resilience presentation.

3 RESILIENT ROADS AS AN ELEMENT OF THE FOREVER OPEN ROAD PROGRAMME

3.1 Resilient Road as an Element of FOR Programme

FEHRL initiated the FOR Programme as the core of its Strategic European Road Research Programme V (SERRP V), which ran from 2011 to 2016. The FOR Programme works towards a next generation of advanced and affordable smarter, connected and resilient roads that can be adopted both for maintaining the existing network and building new roads. This will enable future road operators to adopt emerging innovations, whilst overcoming the increasing constraints on capacity, sustainability, reliability and integration. It will also enable the whole sociotechnical system (e.g. road operators/managers/stakeholders) to adapt for climate change and extreme weather events and prevent/minimise social and economic costs. FOR will also contribute substantially to the way the road transport sector addresses societal challenges.

The next generation of roads will require high levels of adaptation, automation and resilience. These three elements will define the following next generations of road:

- adaptable road – focusing on ways to allow road operators to respond in a flexible manner to changes in road users demands and constraints
- automated road – focusing on the full integration of intelligent communication technology applications between the user, the vehicle, traffic management services and the road operations
- resilient road – focusing on ensuring service levels are maintained under extreme weather conditions and man-made events.

Additionally, the EU has launched, within the Horizon 2020 (H2020) Programme, several initiatives associated with the development of cross-modal transport infrastructure. Three European H2020 coordination and support actions, namely the REFINET, FOX and USE-iT projects, have been established to support this work.

The aim of the FOX (Forever Open Infrastructure across (X) all transport modes) project is to develop a highly-efficient and effective cross-modal research and development (R&D) environment and culture which meets the demanding requirements associated with the transport and connectivity of people and goods. The FOX project involves a network of researchers and practitioners from the different modes. It sets the agenda for the further improvement of cross-modal research development innovation, as well as the demonstration and implementation of the results. Another project under H2020 – Next generation transport infrastructure: resource efficient, smarter and safer – is USE-iT (Users, Safety, security and Energy and carbon in Transport Infrastructure). This project is connected to FOX. The aim of the USE-iT project is to seek a better understand of the common challenges experienced across transport modes and to develop a set of common research objectives.

In addition to this work, the overarching aim of the REFINET (Rethinking Future Infrastructures Networks) project is to create a sustainable network that integrates relevant stakeholders' representatives of all transport modes (road, rail, maritime, aviation) and transport infrastructure sectors in order to obtain a shared European vision of how infrastructure should be specified, designed, built or renovated, and maintained according to a multimodal European transport infrastructure network of the future. In order to address the different levels of development of the transport infrastructure in the European countries, REFINET is considering two complementary scenarios: the maintenance and upgrading of already exiting transport infrastructures; and the development of new transport infrastructures (multimodal infrastructure). All of these projects complement the objectives of the Scanning Tour.

4 DETAILS OF SCANNING TOUR

As discussed in Section 2, it is recognised that the term 'resilience' can be interpreted in a range of contexts; hence the focus of the FEHRL Scanning Tour 2016 was on infrastructure resilience as a whole process. This entails taking consideration of:

- methodologies for decision-making in a climate of great uncertainty
- the development and application of technologies
- assessment frameworks for measuring progress
- methodologies/approaches to the design and measurement of resilience, including the contribution of rescue services
- implementation of 'resilience' into the planning, design and operation of road and bridge infrastructure.

Accordingly, the purposes of the Scanning Tour were to:

- establish a dialogue on challenges for implementing more resilient infrastructure
- establish mechanisms to share information and experiences regarding the management of resilient infrastructure
- identify practical applications of resilient infrastructure
- explore opportunities for future collaboration.

The desired outcome of the tour was an improved understanding of how roads and associated infrastructure in Japan and South Korea are managed in terms of:

- the provision and maintenance of a resilient network
- innovative solutions for technology, governance, and customers for adaptable, resilient and automated infrastructure.

This was achieved through visits to a range of multi-modal research facilities and companies responsible for the management of the road, rail and bridge networks, as well as site visits to outstanding construction projects/programs.

The successful conduct of the Scanning Tour would also contribute to the sharing of knowledge and the implementation of solutions to other modes (for example the Use-iT FOX project), and assistance in the drafting the needs for further research proposals managed by the EU.

This tour, the program of which was managed by ARRB, also represented the first cooperation of FEHRL within the Asia region. Additionally, and in order to maximise the opportunity for cross-fertilisation of knowledge, invitations were sent to representatives from PIARC (see Section 4.1) for the first time.

The tour commenced in Seoul with an information exchange meeting between PIARC Technical Committee E.1, FEHRL and the Korea Expressway Corporation Research Institute (KECRI). This included a visit to the ICT Centre located within KECRI, site visits to the Seohae Bridge and the KEC Traffic Information Centre, and an International Joint Seminar on Climate Change Adaptation and Resilience jointly hosted by the Korea Expressway Corporation, Korea Road Association and the Ministry of Land, Infrastructure and Transport, Korea. The tour continued to Osaka, Japan, where a Workshop on Infrastructure Resilience was jointly hosted by Hanshin Expressway, Honshu-Shikoku Bridge Expressway Company and NEXCO West, followed by site visits to the Ikuno Bridge, Akashi Bridge and the Hanshin Expressway Earthquake Museum. In Tokyo, the FEHRL delegation visited the NEXCO Research Institute, National Institute for Land and Infrastructure Management (NILIM), Public Works Research Institute (PWRI), and the Railway Technical Research Institute. A site visit was also conducted to the Tokyo Bay Aqua-line.

Details of the visits, technical tours, meetings, presentations and testing facilities are presented in the following Appendices:

Appendix A: Institutes/companies visited and details of technical tours

Appendix B: Summary of testing facilities.

4.1 Synergies with PIARC Technical Committee E.1: Adaptation Strategies and Resilience

The World Road Association (PIARC) was formed in 1909. It fosters and facilitates global discussion and knowledge sharing on roads and road transport. The Association comprises 121 government members worldwide and retains consultative status to the Economic and Social Council of the UN.

Within the PIARC Strategic Plan exists Strategic Theme E: Climate Change, Environment and Disasters. The goal of this Strategic Theme is to increase resiliency and protect investments in transportation infrastructure from the impacts of climate change events while lessening the impact of road transportation on the environment. This Strategic Theme includes three Technical Committees, one of which is PIARC Technical Committee E.1 (Adaptation Strategies and Resilience).

Dealing with transport strategies for climate change adaptation to increase the resilience of the road infrastructure is an issue being studied by Technical Committee E.1. Due to its close relationship to the topic of the FEHRL Scanning Tour, it was agreed that the tour would commence in Seoul directly after the PIARC Technical Committee E.1 meeting.

Of the eight Scanning Tour participants, Jürgen Krieger (Chair, PIARC Technical Committee E.1, Caroline Evans (Leader of Working Group 1, PIARC Technical Committee E.1) and Fabien Palhol (Co-leader of Working Group 1, PIARC Technical Committee E.1) attended the PIARC meeting.

5 MACRO ECONOMIC COMPARISON

It was considered that an economic comparison was necessary to provide context to the information received during the Scanning Tour. A comparison of the economic indicators used by the countries which participated in the Scanning Tour revealed that the economic indicators used varied. These indicators have been summarised in Table 5.1a and Table 5.1b and grouped into the following categories: GDP, employment, infrastructure and urbanisation.

In summary:

- Korea has the second shortest road network, the third smallest land area, and the median population. It has a higher GDP purchasing power parity than Belgium, Norway and the Netherlands but the lowest GDP per capita overall.
- Japan has the highest population, a high level of urbanisation, the highest GDP purchasing power parity and a low level of unemployment; however, it has a lower per capita GDP than its European and Australian counterparts. Japan also has by far the longest road network length – approximately 200,000 km more than France (which has the longest road network in Western Europe). Additionally, it has the highest labour force (65.93 million).
- France has the second largest land area and the second longest road network. Currently 79% of the French population live in urban areas, with a rate of change of people moving into urban areas of 0.84% annually.
- Australia has the largest land area – more than 20 times greater than Japan – but a road network approximately 400,000 km shorter than Japan's. Currently 89% of the Australian population live in urban areas. Australia has the highest annual rate of change of people moving into urban areas (1.47%).
- Belgium has the second smallest land area – only one-third of that of Korea – yet their road network is approximately 50,000 km longer than Korea. Due to its small area, Belgium has the highest level of urbanisation (97% of their total population) and the lowest population.
- The length of road network in the Netherlands is lower than Japan, Australia and France. Its GDP per capita is $50,800, the second highest compared to the other countries.
- Norway has the shortest road network and the lowest GDP purchasing power parity; however, they have the highest GDP per capita (USD69,300).
- Germany's road network length, land area and GDP per capita sit in the middle range of the eight countries compared. However, they have the lowest level of urbanisation, with 75% of their population living in urban areas, and only a 0.16% annual rate of change of people moving into urban areas. It has the second highest labour force compared to the other countries.

Table 5.1a: Comparison of key economic indicators: Germany, France, Belgium, Korea

Country		Germany	France	Belgium	Korea
Population (2016 estimate)		80,722,792	62,814,233	11,409,077	50,924,172
Area (sq km)		357,022	551,500	30,528	99,720
Gross Domestic Product (GDP) (USD: 2016 est.)	Purchasing power parity	$3.979 trillion	$2.737 trillion	$508.6 billion	$1.929 trillion
	Per capita	$48,200	$42,400	$44,900	$37,900
Employment	Unemployment rate (2016 est.)	4.3%	9.7%	8.4%	4%
	Labour force (2016 est.)	45.3 million	30.48 million	5.272 million	27.25 million
	Labour force by occupation	agriculture: 1.6% industry: 24.6% services: 73.8% (2011 est.)	agriculture: 3% industry: 21.3% services: 75.7% (2013 est.)	agriculture: 1.3% industry: 18.6% services: 80.1% (2013 est.)	agriculture: 5.7% industry: 24.2% services: 70.2% (2015 est.)
Infrastructure	Length of road network (km)	645,000 (2010)	1,028,446 (2010)	154,012 (2010)	100,428 (2016)
Urbanisation	Urban population (% of total population – 2015)	75.3%	79.5%	97.9%	82.5%
	Rate of urbanisation (annual rate of change – 2010-2015 est.)	0.16%	0.84%	0.48%	0.66%

Note: Statistics for France are based on Metropolitan France and do not include the overseas regions of French Guiana, Guadeloupe, Martinique, Mayotte, and Reunion.

Sources:

- *US Central Intelligence Agency (CIA), The World Factbook, https://www.cia.gov/library/publications/the-world-factbook/*
- *Organisation for Economic Co-operation and Development (OECD), 2016, Transport – passenger transport – OECD Data, https://data.oecd.org/transport/passenger-transport.htm – indicator-chart*
  TomTom, TomTom Traffic Index, http://www.tomtom.com/en_gb/trafficindex/list.

Table 5.2b: Comparison of key economic indicators: Japan, Australia, Norway and Netherlands

Country		Japan	Australia	Norway	Netherlands
Population (2016 estimate)		126,702,133	22,992,654	5,265,158	17,016,967
Area (sq km)		377,915	7,741,220	323,802	41,543
Gross Domestic Product (GDP) (USD: 2016 est.)	Purchasing power parity	$4.932 trillion	$1.189 trillion	$364.7 billion	$865.9 billion
	Per capita	$38,900	$48,800	$69,300	$50,800
Employment	Unemployment rate (2016 est.)	3.2%	5.8%	4.8%	6.2%
	Labour force (2016 est.)	65.93 million	12.63 million	2.794 million	7.919 million
	Labour force by occupation	agriculture: 2.9% industry: 26.2% services: 70.9% (2015 est.)	agriculture: 3.6% industry: 21.1% services: 75.3% (2009 est.)	agriculture: 2.7% industry: 18.3% services: 79% (2015 est.)	agriculture: 1.8% industry: 17% services: 81.2% (2013 est.)
Infrastructure	Length of road network (km)	1,218,772 (2015)	873,573 (2015)	93,870 (2013)	139,124 (2016)
Urbanisation	Urban population (% of total population – 2015)	93.5%	89.4%	80.5%	90.5%
	Rate of urbanisation (annual rate of change – 2010-2015 est.)	0.56%	1.47%	1.35%	1.05%

Sources:

- *Central Intelligence Agency (CIA), The World Factbook, https://www.cia.gov/library/publications/the-world-factbook/*
- *Organisation for Economic Co-operation and Development (OECD), 2016, Transport – passenger transport – OECD Data, https://data.oecd.org/transport/passenger-transport.htm – indicator-chart*
  TomTom, TomTom Traffic Index, http://www.tomtom.com/en_gb/trafficindex/list.

6 SUMMARY OF POLICIES AND MASTER PLANS IN KOREA AND JAPAN

6.1 Convergence Research Centre for Disaster-Hazard Resilience (CRC-DHR), Korea

It is recognised in South Korea that there is a need for 'convergence research' to understand and attain disaster-resilience of urban communities. Efforts for making communities more disaster-resilient are recognised under the 'Making Cities Resilient' campaign of the UN Office for Disaster Risk Reduction (UNISDR). Toolkits are available to make 2,998 cities 'ready', including guidance documents, assessment tools, risk mapping and planning for resilience (UNISDR January 27, 2016)[1]. Additionally, the 'Communities resilience' program of the US National Institute of Standards and Technology (NIST) focusses on research, community planning and guidance, and stakeholder engagement[2].

The *Convergence Research Centre for Disaster-Hazard Resilience* (CRC-DHR) was created with a budget of USD12 million over seven years, funded by the Ministry of Science, ICT and Future Planning. It includes 12 core researchers from universities and research institutes (56 in total). Its goal is to develop sustainable convergence research infrastructure to provide cutting-edge solutions and to maximise disaster-hazard resilience of urban societies in the areas of:

- pre-disaster – predict to prepare
- peri-disaster – monitor and respond
- post-disaster – recover quickly and completely.

6.2 Strategic Innovation Program (SIP)

The Strategic Innovation Program (SIP) involves infrastructure maintenance, update and management technology. The program is directed by Professor Yozo Fujino at Yokohama National University; its budget is approximately 3.5 billion Yen per year. The program consists of the research and development in areas such as:

- inspection, monitoring and diagnostic technology
- structural materials, including deterioration mechanisms, repair and reinforcement technology
- information and communication technology
- robot technology
- asset management technology.

Other programs being conducted include:

- the development of technology for concrete bridge inspection by high-power x-ray sources
- X-ray tomography
- 3.95 MeV x-ray source (Linac)

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1 The 'Making Cities Resilient' campaign addresses issues of local governance and urban risk while drawing upon previous UNISDR Campaigns on safer schools and hospitals, as well as on the sustainable urbanizations principles developed in the UN-Habitat World Urban Campaign 2009-2013.

Readers are also referred to 'United Nations plan of action on disaster risk reduction for resilience: towards a risk-informed and integrated approach to sustainable development', January 2017' http://www.preventionweb.net/files/49076_unplanofaction.pdf.

2 <https://www.nist.gov/topics/community-resilience>
https://www.nist.gov/news-events/news/2017/08/nist-funds-12-projects-make-communities-more-resilient-disasters.

- tomography imaging by 3.95 MeV x-rays.

6.3 Research Association for Infrastructure Monitoring Systems (RAIMS)

RAIMS was established in October 2014 to develop a monitoring system to determine the damage and deterioration of social infrastructure. This not only includes the development of a monitoring system but also field tests of a robot for the maintenance of bridges. Key members of RAIMS include: NEXCO-East, NEXCO-Central, NEXCO-West, Kajima Maeda, Nippon Koei, Kokusai Kogyo, Hitachi, Fujitsu, NEC, Oki, Kyoma and Nohmi.

Monitoring technology within RAIMS has five key goals:

- be notified immediately after the damage has occurred
- know the places where damage is likely to occur
- know the deterioration that cannot be identified using visual inspection
- know the effect of the repair of reinforcement
- know the safety of bridges which have restricted load limits.

For further details, refer to: http://www.raims.or.jp/en/inquiry.html.

6.4 Railway Technical Research Institute Master Plan

The aim of the Railway Technical Research Institute (RTRI) is to develop innovative technologies to enhance the rail mode to ensure that railways can contribute to society. Its masterplan is a medium-term action plan embodying the strategy to implement the vision. Its objectives are as follows:

- Improvement of safety – the promotion of research projects to develop measures to prevent railway accidents and to mitigate natural disaster damage. This includes undertaking tests for earthquake conditions and rolling stock, the safety of railway vehicles in cross-winds, and the development of prevention technologies associated with various natural disasters.
- Cost reduction – reduction of the costs of facilities, rolling stock and railway system maintenance using cost-effective design and construction methods, and efficient methods of inspection, diagnosis and evaluation. This includes the efficient monitoring and maintenance using ICT and sensor networks, applying image processing technology to infrastructure diagnosis, reducing track maintenance costs, and the development of low-cost disaster-resistant structures and innovative structure replacement technology.
- Harmony with the environment – RTRI are investigating energy saving by utilising energy-efficient rail networks, reducing aerodynamic noise associated with the Shinkansen (high-speed) trains, and noise reduction using innovative material technology.
- Improvement of convenience – to achieve more comfortable and convenient rail travel, RTRI is improving methods to evaluate ride comfort, measures to predict and evaluate the impact of high-speed trains on the trackside environment and measures to enhance mobility around the stations, including innovative power supply systems for trains.

7 FINDINGS OF STUDY TOUR

The findings of the Scanning Tour are now presented under the following general headings:

- preparedness
- robustness
- recovery
- adaptation.

7.1 Preparedness

7.1.1 Development of Smart Roads

In both South Korea and Japan, the use of big data for smart roads, smart systems and smart data was found to be widespread. This relates to resilience in terms of ensuring that infrastructure and the community are prepared for natural and man-made events as much as possible, and then can respond effectively.

The Korea Expressway Corporation Research Institute (KECRI) is a leading research agency of technology and policy for roads. It covers road pavements, structures, the construction of bridges, road and bridge maintenance, GIS pavement management, toll collection management, ITS and methods to enhance and improve the traffic environment. It actively manages private/public partnerships (PPP's) and provides both domestic and private infrastructure solutions, as well as long-term investigations of road projects, and the global transfer of knowledge and technologies. There are four National Flagship projects funded under KECRI's budget of US$44 million, two of which were relevant to the Scanning Tour):

- *Carbon neutral road* project.
- The *Super long-span bridge research* project (commenced in 2008) – includes a core technology-type test bed that assesses the practicality of detailed technologies and an integrated technology-type test bed to verify and commercialise the developed technologies. One aim is to develop self-sufficient core technologies for a long-span bridge and expand the relevant industry to the global market using its technological advantage. The *Super Long-Span Bridge R&D Center* has a 'convergence' strategy that divides the entire research period into three different stages for implementation. The pursuit stage can be categorised as:
  - CONcentration stage to develop various core technologies
  - VERification stage to assess the economic efficiency of the developed technologies
  - GENeralization, or realisation, stage to commercialization.

  Research topics include wind resistance and structural systems, concrete with improved workability, super low-heat casting technologies, total test beds using all the developed technologies, and integrated solutions for disaster risk assessment and resilience.

  It is expected that the *Super Long-Span Bridge R&D Center* will serve as a medium for industry, university, research institutes and government by taking advantage of Korea's long-span bridge market to: pursue fully-localised construction technologies, secure the world's best long-span bridge technologies, and contribute to the expansion of Korea's bridge construction companies into the global markets
  (source: www.ingentaconnect.com/content/iabse/report/2012/00000098/00000016/art00001?crawler=true).
- SMART Highway Research Project (2007-2014) – the aim is to realise the 'intelligent highway' using ICT, WAVE Communications, road infrastructure technologies and non-stop smart tolling wireless/multi-lane systems. This also involves the Cooperative Automated Driving Highway System (C-ARS) which will be developing a roadway system than supports automated driving from 2015-2020. A demonstration Smart Highway is to be developed during the 2018 Pyeongchang Winter Olympics. The new expressway with the Smart Highway (Seoul-Sejong Expressway) will be completed by 2015.

- Road Safety Facility Project (information can be obtained from KECRI).

KECRI is also involved in a three-year cooperative collaboration program with UNESCAP.

7.1.2 Big Data for Improved Resilience

During the Study Tour, the participants took part in a Technical site visit (sponsored by KEC) to the KECRI ICT Centre. The Centre provides integrated management of tolling, traffic, construction, and maintenance, including 'ICT operations and maintenance' of servers, storage, and network facilities. It also provides an integrated monitoring systems operation room in real time for 'Cyber security'. Events are collected, analysed, responded to, and then documented. It also provides 'big data analysis and use' where raw data (VDS, Hi-Pass, DSRC and accident) is gathered, analysed, shared and utilized for the public. Here, traffic problems can be solved by using big data; this can assist in traffic forecasting and enhancing traffic safety and flow. This also enhances the resilience of the infrastructure, because information can be quickly transferred to road asset users in the event of a natural or man-made (e.g. security) event.

7.1.3 KEC Traffic Information Centre: Korea

The KEC Traffic Information Centre is a direct interface between data and the road users. Data is collected in real time, processed (via the ICT Centre in KECRI) and disseminated to the public in the form of call centres, broadcasting rooms, and directly to vehicles (via mobile phones or on-board smart devices) in less than 2 minutes. Information transferred directly to drivers includes accidents. Weather information is transferred directly to drivers without filtering or editing in an attempt to prevent accidents or delays before they occur. The on-board smart devices are regulated in all new vehicles and subsidised for installation in older vehicles (all vehicles are yet to be standardised). Emergency vehicle notifications are sent to the smart devices to advise drivers on vehicle breakdowns, wildlife on roads, fallen obstacles, and vehicle malfunctions. Vehicles are also installed with break detection devices to notify drivers of distances. Vehicle-to-vehicle communications (V2V) and vehicle-to-infrastructure technologies (V2I) are utilised, as well as ICE detection systems, whereby radar detects icy roads, fog, wind (WAVE technology) and snow in real time and relays the information to road users. The radar is located within a 1-kilometre radius.

The KEC Traffic Information Centre also uses 20 years of historical traffic data to predict where and when congestion may occur. It provides detour mapping in real time, ramp metering systems, lane-controlled systems, and bus-only lanes.

Weather and Traffic Broadcasting Studio: KEC, Korea

The Traffic Information Centre at KEC is equipped with a weather and traffic broadcasting studio. Traffic and weather information generated via big data within KEC is broadcasted to the community. This assists in ensuring that road users are able to prepare and have as much information as possible before they travel and whilst they are travelling.

7.1.4 Bridge Surveying and Monitoring Techniques

For disaster resilience of complex infrastructure systems such as cable bridges, it is desirable to build big-data platforms so that data, information and knowledge of the bridge can be processed and utilised for decision-making purposes. A five-year research project, funded by the Ministry of Land, Infrastructure and Transport in Korea, on the maintenance of cable bridge systems based on disaster-hazard resilience commenced in September 2016. Details are provided in Figure 7.1.

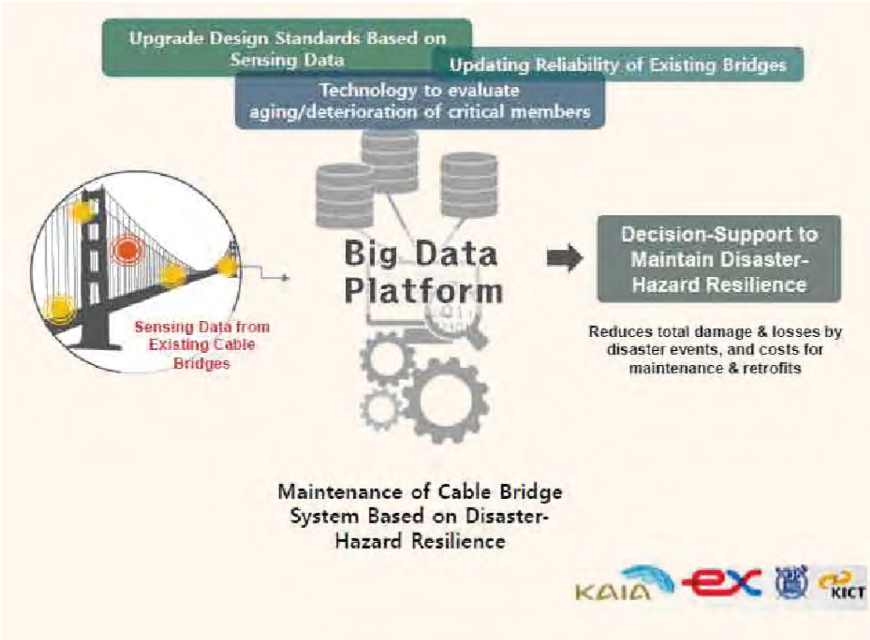

Figure 7.1: Details of research project on disaster hazard resilience of cable bridge systems

Source: Junho Song, Professor Department of Civil and Environmental Engineering Director, Convergence Research Center for Disaster-Hazard Resilience Seoul National University.

As an example, the Seohae Grand Bridge has 96 sensor which collect ten types for data, including the stress levels on the cables and movement of the bridge in real time. A centralised control room monitors fog, rain and wind, and the state of the cables using CCTV technology and motion analysis; emergency broadcasting is applied when necessary. The 24-hour monitoring system and automatic warning system provides safe driving information during incidents and inclement weather conditions (when the wind velocity is over 14 m/sec, and visibility due to fog is below 250 metres.

7.1.5 Maintenance, Wind Resistant Design and Monitoring of Long-span Bridges

The Akashi-Kaikyo Bridge (Honshu-Shikoku Bridge Expressway Company) is the longest suspension bridge in the world (3,911 m). It links the city of Kobe on the Japanese mainland of Honshu to Iwaya on Awaji Island. It was opened to traffic in 1998. It comprises six lanes, and a three-span, two-hinged stiffened girder system.

Inspection of long-span bridges involves annual surveillance, main inspections (every two years), precise inspections (every five years), inspection after extraordinary events (evaluation of bridge behaviour and soundness) and special inspections. It involves dynamic monitoring via a series of monitoring sensors, including wind velocity, displacement, earthquakes, accreditation and GPS, as outlined in Figure 7.2.

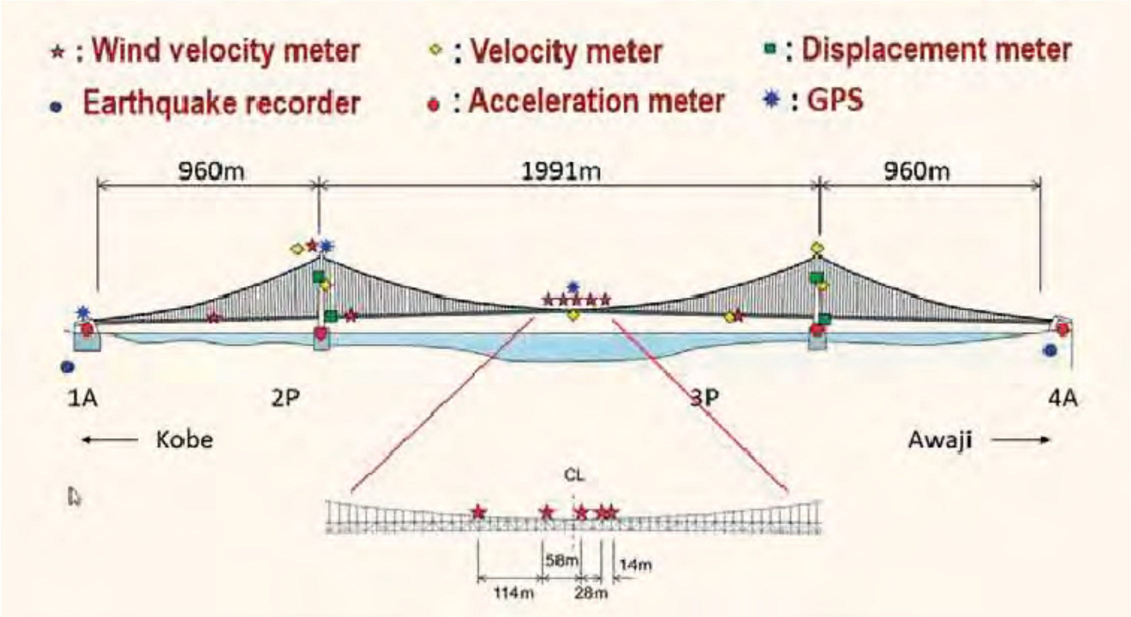

Figure 7.2: Monitoring sensors on Akashi-Kaikyo Bridge

Source: Kiyohiro Imai, Deputy Director of Planning Division, Honshu, Shikoku Bridge Expressway Company.

The GPS sensors are arranged to maximise the assessment of potential horizontal displacement, and wind data, particularly following Typhoon 9807 in September 1998. A comparison of observed and analytical data for the displacement of the horizontal girder is shown in Table 7.1.

The bridge was constructed to an earthquake resistant design and with monitoring systems in the event of a disaster. Appropriate seismic design procedures for the foundations specified in the Japanese Bridge Standard are in place. Dynamic interactions between the foundation and ground, and verification of stability checks, ensure effective seismic designs for the superstructure.

Table 7.1: Comparison of observed and analytical data – displacement of horizontal girder at middle of centre span

	Observed displacement (m)	Predicted displacement (m)	
		Case 1	Case 2
Average displacement [1]	5.17	5.43	5.43
Dynamic displacement [2]	0.78	2.62	0.68
Total displacement [1] + [2]	5.95	8.05	6.11

Note: Average wind speed: 32 m/s.

Case 1: designed power spectrum and spatial correlation.

Case 2: observed power spectrum and spatial correlation.

A dry-air injection system developed by the Honshu-Shikoku Bridge Expressway Company protects the bridge's main cables. The cable can be protected from corrosion if the relative humidity is kept to less than 60%. The dry-air injection system is managed to keep the relative humidity in the cables to less than 40%. In 2007, nine years after completion, a cable opening inspection was undertaken which revealed no rust. Dry-air injection systems have now been implemented in 15 other bridges in Japan, four bridges in Korea, three bridges in the UK, China and Turkey, two bridges in Denmark and Sweden and one bridge in France, Norway and the USA. In order to continue to improve the dry-air injection system, research is being conducted towards the reduction of operation units, reduction in air pressure, and the installation of pre-cooling units.

7.1.6 Earthquake Early Warning Systems: Railway Transport Research Institute (RTRI)

Japan is one of the highest seismic regions in the world. The Railway Transport Research Institute (RTRI) incorporates seismic design and reinforcement into its rail operations to maximise the resilience of the infrastructure and the safety for users.

The Shinkansen Earthquake Early Warning (EEW) System is a system which combines front-detection and on-site warnings. Warnings are issued based on single-station seismic data.

The EEW successfully controlled trains during the 2011 Great Tohoku Earthquake. The system can also receive Japan Meteorological Agency information. The EEW acts to stop the Shinkansen (high-speed train) and the flow of all train operations at the time of an earthquake by:

- controlling the train before an earthquake
- controlling the train during an earthquake (the train is stopped to reduce potential damage)
- inspection after the earthquake (the train restarts).

A combination of front-detection (located on coastlines to detect earthquakes) and on-site warning seismic station systems are used as highlighted in Figure 7.3.

Both the Japan Meteorological Agency (JMA) and the railway EEW system information is used to stop the train and power supply in the event of an earthquake. It uses both S-wave (or secondary waves, the motion of the particles is perpendicular to the propagation axis of the wave, thus inducing shear stresses) and P-wave (or primary waves, the particles move along the propagation axis of the wave, thus inducing compression stresses) warning systems (depending on the size of the earthquake). This is illustrated in Figure 7.3: .

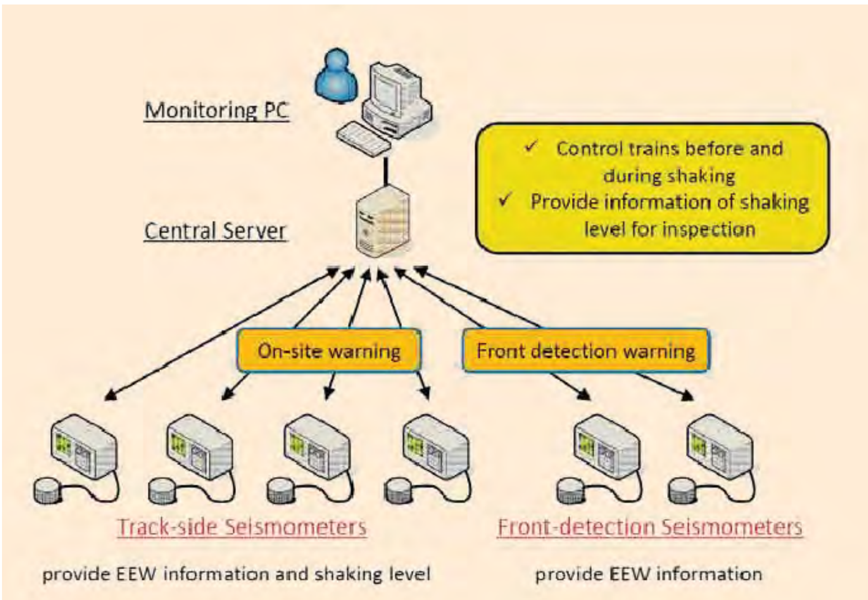

Figure 7.3: Combination of front–detection and on-site warning

Source: Earthquake Early Warning Systems for Railways (RTRI).

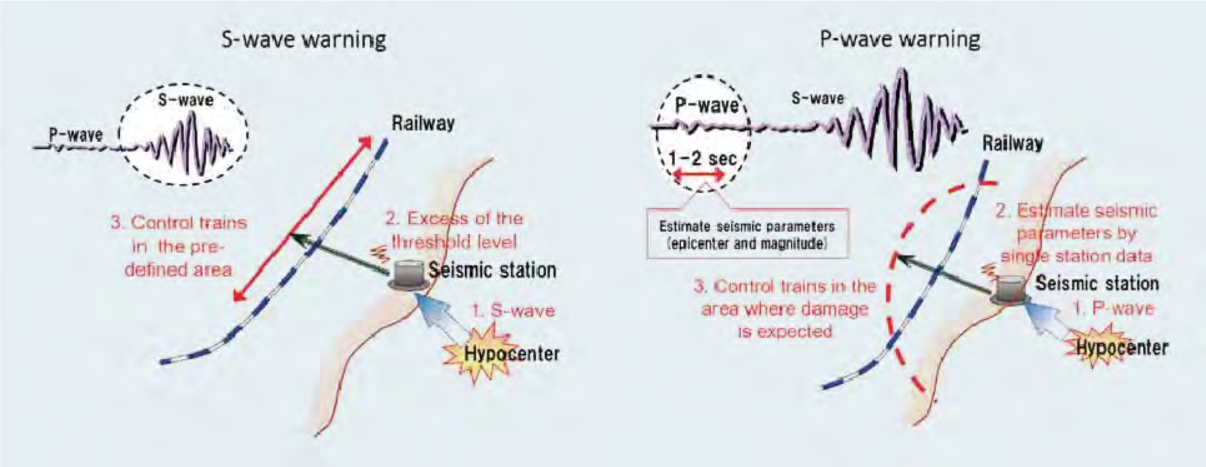

Figure 7.4: S-wave and P-wave warning systems

Source: Earthquake Early Warning Systems for Railways (RTRI).

During the 2011 Great Tohoku Earthquake (magnitude of 9.0, epicentre near the east coast of Honshu), it took 90 seconds to stop the Shinkansen line. The closest part of the line to the epicentre was 170 km away, and the closest station to issue the EEW was 130 km from the epicentre. There were 19 trains running on the line and all were successfully controlled before large shaking occurred. The seismic signal was detected first and then an EEW control signal was issued. The control signal was then received by all operators within seconds of the initial detection.

Areas for further investigation include the issuing of pre-defined rescue areas for the trains to stop, evaluation centres along the tracks, the use of these early warning systems for tunnels, and consistent communication of emergency information to the community.

7.1.7 Response to Effective Disaster Prevention and Disaster Mitigation Measures: NILIM

It is acknowledged that the threat of future large-scale earthquakes, such as the Nankai Trough Earthquake and earthquakes directly under Tokyo, is a high possibility. NILIM noted that, over the past 30 years, rainfall throughout Japan had become more localised and more intense. Sedimentation disasters, e.g. Hiroshima City in 2014, and the fear of super typhoons and volcanic eruptions are carefully considered.

In order to prepare for these events, NILIM conducts research on effective dam flood control, flood forecasting methods, and the advanced planning of evacuation. This includes the following:

- Countermeasures against sediment disasters and urban floods and the provision of information for safe evacuation, including:
  - the development of danger detection systems using big data and smart phones
  - the identification of debris flow precursors
  - the development of rapid inundation warning information systems for users in underground infrastructure
  - the development of rainfall and inundation prediction information provision systems using compact X-band MP radars.
- Countermeasures for river flood inundation, including the preliminary release from dams to reduce peak flow, accurate flood forecasting systems and the development of evacuation plans and countermeasures against inundation.
- The development of technologies to evaluate storm surge risk and support evacuation, including methods for determining large-scale storm surge external forces, and the development of tsunami and storm surge evaluation simulation technologies.

Additionally, NILIM is ensuring the safety of the community by improving the accuracy of real-time observations of tsunamis and storm surges. This is achieved through improved observation technologies, such as the installation of short-wave marine radars along the coast where populations and assets are concentrated, and the development of technologies for the observation of tsunamis and storm surges. Other research is being conducted to provide technical support for damage risk evaluations and evacuation plan enactment for coastal regions. This includes the development of technologies to evaluate storm surge inundation risk, the evaluation of the strength of seawalls, and the development of tsunami/storm surge evacuation simulation technologies.

7.1.8 Early Warning Against Floods: PWRI

Under the auspice of the Public Works Research Institute (PWRI) Japan is the International Centre for Water Hazard and Risk Management (ICHARM). Its objective is to serve as the Global Centre of Excellence to provide and assist in the implementation of best practice strategies to manage the risk of water-related hazards, including floods, droughts, landslides, debris flows and water contamination. It works towards reducing water-related risks and promotes research into flood risk assessment. ICHARM provides higher education training in disaster management and develops technologies to assess real time hazard mapping, flood forecasting, and the evaluation of the river basin.

SOUSEI project

A key project being undertaken is the *Program for generation of climate change risk information* (SOUSEI Project). Collaborative organisations include Kyoto University, Yamanashi University and the Governments of Pakistan, Thailand, Cambodia, Indonesia and the Philippines. This project seeks to develop a methodology for the local application of the predicted values of flood/drought hazard. It provides:

- local customised hazard assessment
- uncertainty assessment
- socio-economic impact assessment (flood and drought)
- a vulnerability monitoring system.

The development of the basic technology for the socio-economic risk assessment is based on:

- the development of a response framework to assess hazard and socio-economic impact
- assessment of the socio-economic impact, including uncertainty
- the provision of necessary information for local adaptation.

The flood risk assessment involves an assessment of various experimental scenarios and basin scale rainfall information; this is downscaled on a regional basis with a bias correction. Hydrological models (e.g. IFAS/BTOP/RRI) are also used to carry out flood evaluations and projections for present and future climates according to projections of variations in discharge, water level and water depth. Based on this uncertainty assessment, a socio-economic assessment is undertaken. This risk assessment simulation can also be used to estimate agricultural damage (Pampanga river basin), drought risk and water utilisation. It can also assist in the prediction of the impacts of salinity on pavements.

Probabilistic streamflow forecasting utilising regional Ensemble Prediction Systems (EPS)

Methods for forecasting weather predictions (NWP) have been improving in recent years, as has the accuracy of the data being inputted into regional models. ICHARM has developed an ensemble flood forecasting system which utilises regional ensemble prediction systems (EPS). Downscaling is undertaken using mesoscale data assimilation. It is then compared to European flood forecasting systems utilising EPS.

Using the example of the Kinu River flood in September 2015, the time evolution of rain systems (radar composite rainfall data collected by the JMA) and streamflow forecasts, it was concluded that, while the EPS assessed the probability of flood occurrence and predicted some of the flooding quantitatively, it was outperformed by the JMA operational deterministic forecasts. Rainfall distributions were predicted by the EPS in less than 18 hours, while predicting the possibility of flooding involved a lead time of greater than 24 hours.

This early warning system is closely connected to the flood warning information provided by the JMA. It is used by NILIM, PWRI and ICHARM. PWRI is responsible for developing the models, techniques and tools for application to regional needs.

7.1.9 Emergency Escape Facilities

The Tokyo Wan Aqua-Line is a toll road with a length of 15.1 km. It crosses the middle of Tokyo Bay along the coastal cities of Tokyo, Tokohama, Kawasaki, Chiba, and Kisarazu, and forms part of National Route 409 (see Figure 7.5).

The road cost 1.44 billion yen to construct, with the costs shared between the Japan Highway Public Corporation and the Trans-Tokyo Bay Highway Corporation. The project was completed in 1987. It comprises a 4.4 km long bridge and a 9.6 km long tunnel underneath the bay; it is the longest underwater tunnel in the world. After completion, the property was handed over to the Japan Highway Public Corporation (JHPC) and the Japan Expressway Holding and Debt Repayment Agency according to the privatisation policy of the JHPC.

Figure 7.5: Tokyo Wan Aqua-line

Source: East Nippon Expressway Company Limited (NEXCO East).

The East Nippon Expressway Company Limited (NEXCO) is responsible the daily maintenance work; it entrusts the operation and maintenance tasks to the Trans-Tokyo Bay Highway Corporation. It is responsible for observation and the control of equipment, and the provision of traffic information using CCTV cameras, vehicle detectors, emergency telephones and meteorological stations. NEXCO is also responsible for traffic regulation (15,000-20,000 vehicles per day), including obstacle and snow removal and accident transaction and repair works in response to accidents, disabled vehicles, fire, fallen objects, extreme weather events, earthquakes, etc.

The Aqua-line is equipped with advanced emergency escape facilities to ensure the safety of transport uses, as well as to ensure that the infrastructure is resilient. A network of communication facilities is spread throughout the tunnel and bridges, including:

- speed control signs – to control the speed in the tunnels or on the bridge in the event of an emergency, including accidents or disasters
- roadway information boards – to indicate the condition of the road at the tunnel inlets and inside the tunnels

- electrostatic precipitators and booster fans installed on the ceiling boards of the roadways – to remove soot and dust from the air, and to act as ventilators
- ventilation station (located at the mid-point of the tunnel) –installed on the Kawasaki man-made island following wind tunnel experiments; during tunnelling, the island provided a work base for the shield tunnelling construction
- fire extinguishers, hydrants and alarms
- emergency telephones – to contact the NEXCO control rooms in the event of accidents or disasters in the tunnel and bridges
- escape facilities – to escape onto roads located under the floor slabs (normally used by maintenance vehicles) if escape onto the roadway is dangerous (Figure 7.6)
- escape guiding facilities (every 300 meters) – to guide road users to emergency exits when necessary
- seismic controls in the bridge joints – for resistance against earthquakes.

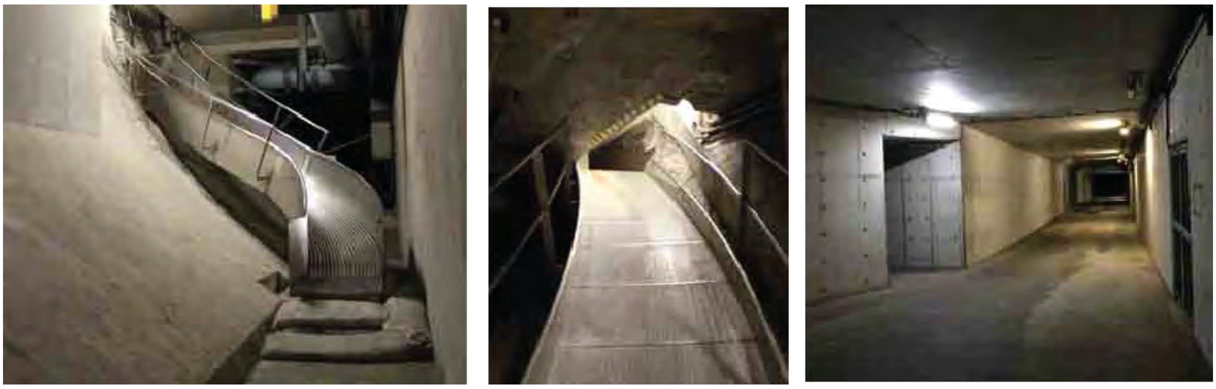

Figure 7.6 Escape facilities within the Tokyo Wan Aqua-line tunnel and wind towers (ventilation system)

Source: East Nippon Expressway Company Limited (NEXCO East).

7.2 Robustness

Robustness is defined as the inherent strength, or resistance, of a system to withstand external demands without degradation or loss of functionality (Bruneau et al. 2003).

7.2.1 Disaster-Resilience of Cable Stay Bridge Systems

Seohae Grand Bridge

The Seohae Grand Bridge was the first composite cable-stayed bridge constructed in Korea. It is a multi-strand stay cable bridge that connects Pyongtaek and Dangjin. Construction commenced in 1993 and was completed in 2000 at a cost of 6777.7 billion Won. Its main features are:

- main-span length of 470 m (total span length of 990 m)
- 144 cables
- pylon height of 182 m
- stiffened steel girder with a precast slab
- designed to withstand winds of 65 m/s and earthquakes of a magnitude of 6.0 on the Richter scale.

Bridges in Korea are susceptible to deterioration, collision, typhoons, earthquakes and fires. On 3rd December 2015 a lightning strike resulted in one cable rupture, two partial failures, and casualties of one dead and four injured. The bridge was closed for repairs resulting in the re-routing of 90,000 vehicles per day. It was re-opened on 19th December 2015 after a visual examination, field measurements, driving tests and structural analysis.

It was recognised that there was a need to analyse, monitor and manage resilience based on knowledge of the existing bridge system. As a result, lightning protection systems (LPS) and fire-protection systems were installed, including horizontal conductors on the pylons, lightning wires, fire hydrants, nozzles at the top of the pylons for fire trucks, and radio transmitters inside the pylons. Additionally, the design codes were revised for cable-supported bridges to check for lightning risk and, if necessary, install LPS, and cable replacement. These improved design codes now form the basis for other bridges in Asia and worldwide.

In terms of disaster resilience, the lessons learned included built-in robustness and redundancy, and quick mobilisation of resources (stay cables, equipment, engineers and technicians). Additionally, the importance of investment in disaster risk reduction, management, and preparedness for resilience was recognised as being essential.

A new project on cable-stayed bridges has been developed to strengthen global competitiveness of the technology. The project, which is running from 2016 to 2021, includes integrated solutions for cable-stayed bridge projects which highlight their economic and technological advantages, disaster risk assessment and resilience, disaster management guidelines, reliability-based design for substructures, and suction pile foundations for offshore bridges. Details of the project are shown in Figure 7.7.

Figure 7.7: Strengthening global competitiveness of cable-stayed bridge technology

Source: Heungbae Gil, Research Director, Korea Expressway Corporation.

7.2.2 Standards and Scoring

Hanshin Expressway scoring techniques

The FEHRL Scanning Tour delegates visited the Hanshin Expressway Earthquake Museum which displays structures damaged by the Great Hanshin-Awaji Earthquake. Its purpose it to promote further research into disaster prevention for future generations. It provides extensive information on innovative methodologies used in reconstruction and seismic strengthening technologies based on the lessons learned as a result of the earthquake.

Details are summarised as follows, together with the major standards applied:

- Specification for highway bridges 1990
  - — buckling of upper lateral brace and deformation of the end of the cross-beam in long arch bridges
- Design and fabrication specifications for highway steel bridges 1964
  - — deformation of central support members of continuous steel box girder bridges
  - — buckling of continuous steel box girders
  - — local buckling of stiffened plate of steel piers
  - — cracks in circular steel piers
  - — local buckling and cracking in circular steel piers
  - — local buckling and tension cracks in circular steel piers
  - — buckling of stiffeners in steel piers
  - — cracking at the base of steel piers
- Design guidelines for highway bridge substructures 1966
  - — flexural shear failure around the base of a reinforced concrete piers
  - — flexural shear failure around the base of a reinforced concrete piers
  - — flexural failure around the base of the reinforced concrete piers
  - — flexural shear failure of reinforced concrete piers at cut-off position of the main reinforcements
  - — shear damage of reinforced concrete piers
  - — flexural shear failure around the base of reinforced concrete piers
- fracture of pivot bearing supporting large arch bridges
- damage to bearings.

Further information regarding the restoration of each structure is presented in Section 7.3.

Hanshin Expressway has developed an effective classification of expressway damage, which was used in the determination of the extent of recovery and restoration required following the 1995 Great Hanshin-Awaji earthquake. The infrastructure classifications include: reinforced concrete piers, steel piers, steel girders and bearings.

Damage was assessed according to the damage level criteria shown in Table 7.2. The categories AS and A indicate complete collapse or significant damage to the infrastructure.

Table 7.2: Damage level criteria

Category	Definition
AS	Collapse or toppling, or equivalent damage
A	Damage affecting load-carrying capacity is significant; risk of life-threatening secondary disasters
B	Damage is affecting load-carrying capacity but allowance for temporary use provided it does not worsen during aftershocks or under live load
C	Damage, but no adverse effects on short-term load-carrying capacity
D	Damage, but no specific effects on load-carrying capacity

Source: Adapted from Hanshin Expressway Earthquake Museum Brochure 2009.

NEXCO-West renewal projects

The former Japan Highway Public Corporation (JHPC), a government-backed organisation, was established in 1956. JHPC was privatized in October 2005 and separated into three private companies: NEXCO-West, NEXCO-Central and NEXCO-East. The West Nippon Expressway Company Ltd (NEXCO-West) is located in Osaka; it is responsible for the construction and operation of expressways in western Japan.

NEXCO-West is currently undertaking expressway renewal projects (rehabilitation/preservation), including bridge rehabilitation, to extend the life of expressways and make them safer and more reliable. The condition of a bridge is assessed in terms of the progress of deterioration, the performance of the structure and deterioration factors developed by NEXCO-West. The level of structural health, including the condition of reinforced concrete bridge decks, is assessed according to five stages of grading as shown in Figure 7.8. The deterioration factors considered include: fatigue (increase in heavy vehicle traffic, overweight vehicles), salt damage (high floating salinity environment, concrete composed of sea sand which was insufficiently desalinised and constructed before chloride regulations were introduced), and de-icing salts (influence of the ban on spiked tyres).

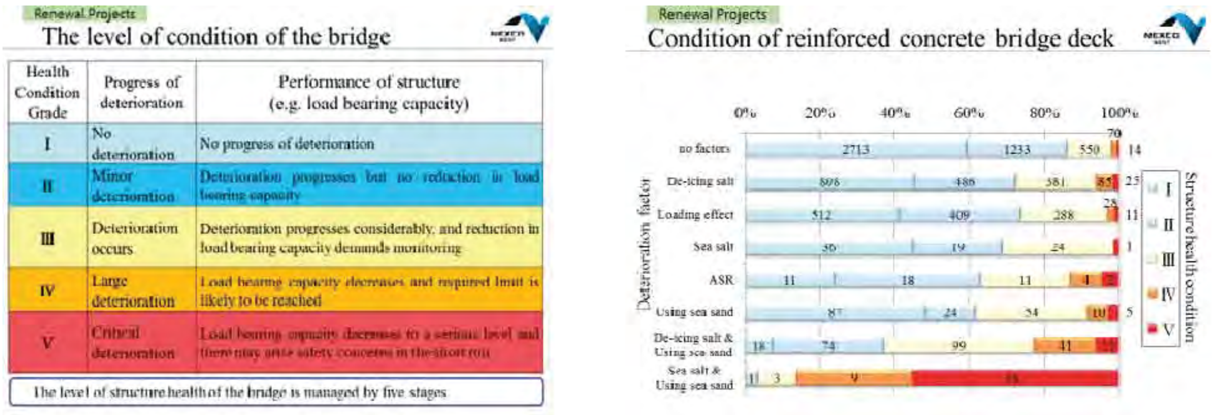

Figure 7.8: Guidelines for assessing the condition of bridges

Source: Presentation by Takatoshi Tomita, Deputy Manager, NEXCO West.

A number of other rehabilitation and preservation activities are being undertaking using these assessments, including:

- replacement of bridge decks and girders (rehabilitation activity)
- repairing and reinforcing of the main structure to return it to its original performance level
  - preservation of the bridge deck, e.g. partial repair of damaged steel reinforced concrete deck and deck overlays
  - reinforcement of bridge girders, installation of tunnel inverts, reinforcement of tunnel lining concrete, additional installation of ground anchors and the installation of draining off boring.

Bridge management and classifications – PWRI

PWRI noted that many bridges were constructed in a high economic growth period and are now 50 years of age and older. As a result, the maintenance of these bridges is of critical importance. Maintenance costs for transport infrastructure in 2014 were 2.5 billion Yen, of which 950 million Yen was spent on bridges. The classification of bridges with span lengths greater than 2 metres is shown in Figure 7.8: . A total of 680,000 bridges are maintained by local government.

Bridges in Japan are susceptible to a range of corrosion-related failures due to geographical and weather events (airborne salts from waves, de-icing salts used on roads, and chloride-induced deterioration), including:

- corrosion and fracture of truss members
- corrosion at embedded truss bridge bracings
- corrosion of steel bridges (lower flange, girder ends, stagnant water).

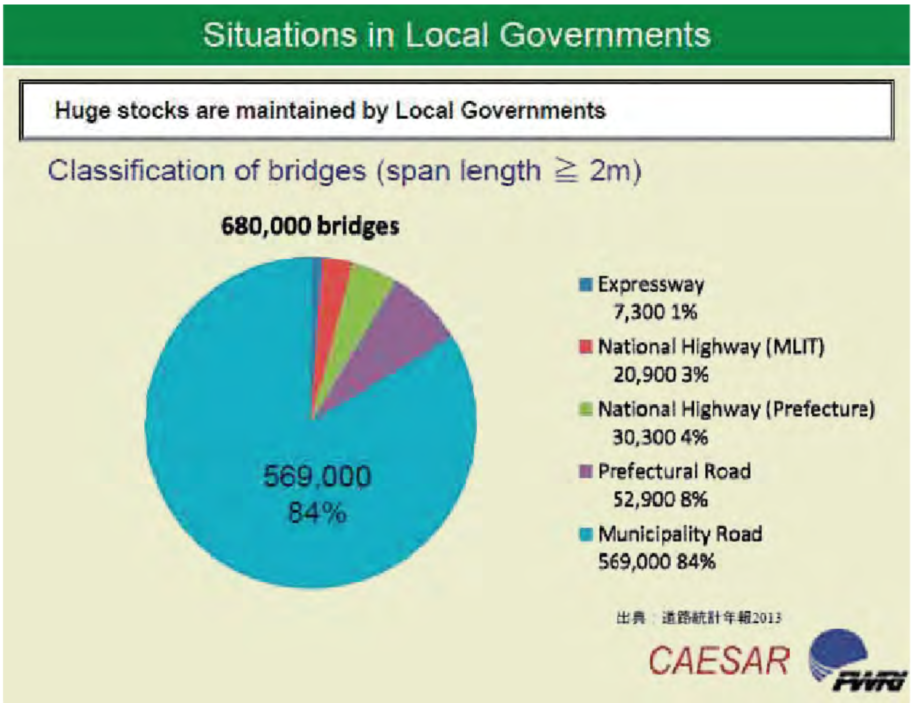

Figure 7.9: Classification of bridges (span length greater than 2 meters)

Source: Masahiro Ishida, Center for Advance Engineering Structural Assessment Research (CAESAR), Public Works Research Institute.

Following accidents at the Sasago Tunnel in December 2012, and the collapse of an I-girder bridge in Okinawa, the following was mandated from July 2014 by law and regulations:

- visual inspection of all tunnels and bridges of 2 metres or more in length every five years
- all tunnels and bridges to be classified into the four stages shown in Table 7.3
- the results of diagnostics and all measurements to be stored at the Masahiro Ishida, Centre for Advance Engineering Structural Assessment Research (CAESAR), PWRI.

Additionally, the following recommendations relating to the full-scale implementation of the aging measures of road structures (April 2014) include:

- subsidy system for local government
- enhancement of training for local government engineers and private companies
- a licencing system for engineers to ensure knowledge and skills diagnosis.

Table 7.3: Classification of bridges (by regulation)

	Classification	State of the structure
I	Healthy	There are no problems with the function of the structure
II	Preventive maintenance	There are no problems in terms of the function of the structure: however, measures should be taken from the viewpoint of preventive maintenance
III	Early measures	There is a possibility that there are problems with the function of the structure and preventative measures should be undertaken as soon as possible
IV	Urgent measures	There are problems with the function of the structure and preventative measures should be undertaken urgently

Source: Masahiro Ishida, Center for Advance Engineering Structural Assessment Research (CAESAR), Public Works Research Institute.

Risk-based inspection strategy for Hanshin Expressway

A risk-based inspection strategy has been developed for the Hanshin Expressway structures. Hanshin Expressway is responsible for 259.1 km of the road network in the Osaka metropolitan area. The traffic volume on the expressways in 2015 was 745,000 veh/day, which generated a daily income from tolls of 0.5 billion Yen. Almost all of the Hanshin Expressways structures are bridges, with 52% of them over 30 years old. These structures are being maintained using a periodic inspection and evaluation strategy.

Periodic inspection of the Hanshin Expressway has been carried out in five-year cycles and damage is classified into five key categories:

S – urgent repair needed

A – repair needed

B – observation

C – minor

OK – no damage.

Hanshin Expressway Engineering is a subsidiary company of Hanshin Expressway, its role being to carry out specific maintenance roles. The process that the Hanshin Expressway Engineering team uses to inspect and evaluate the Expressway structures is shown in Figure 7.9: .

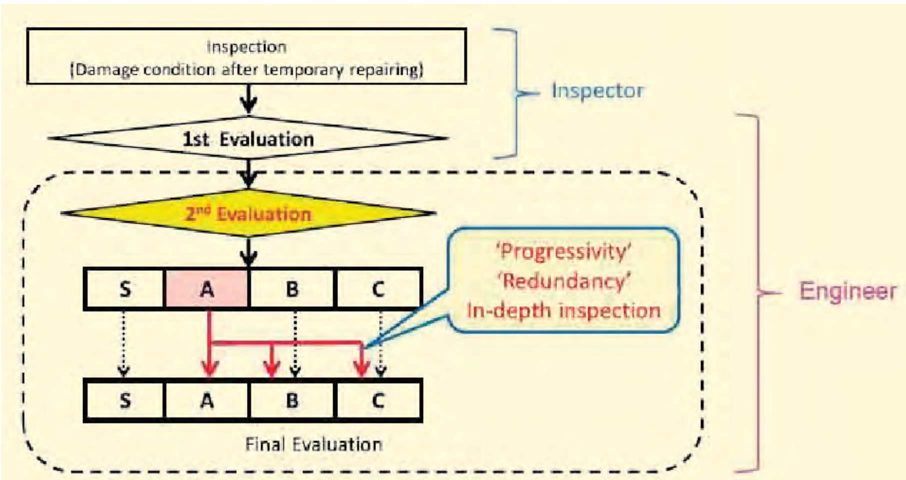

Figure 7.10: Process for inspecting and evaluating Hanshin Expressway structures

Source: Eiichi Tsujimoto, Engineer, Hanshin Expressway.

Initially, the focus is on individual apparent damage. Inspectors carry out bridge inspections based on the inspection manual and evaluate any damage. They then decide if repairs are necessary. However, sometimes using the Manual can result in over-evaluation. The need for extensive repairs has been identified in the past, resulting in the budget and human resources available for damage repair being insufficient and repairs having to be delayed until the next inspection term. As a result, a new inspection method was implemented based on 'soundness-based evaluation', a more risk-based inspection approach. The concept of structural soundness and assessment using 'progressivity' and 'redundancy' is summarised in Figure 7.10: , along with a sample of progressivity and redundancy.

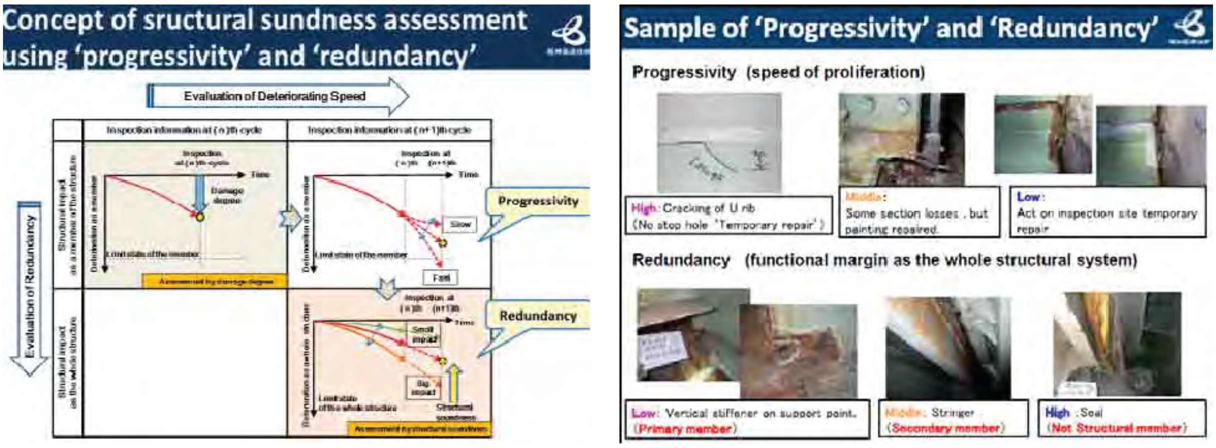

Figure 7.11: Concept of structural soundness assessment

Source: Eiichi Tsujimoto, Engineer, Hanshin Expressway.

In the second evaluation, the structure is reassessed by an engineer. The preferred method of soundness evaluation (risk assessment) is conventional inspection using progressivity and redundancy. There is a strong relationship between the first and second evaluations. The evaluation matrix is shown in Figure 7.11:

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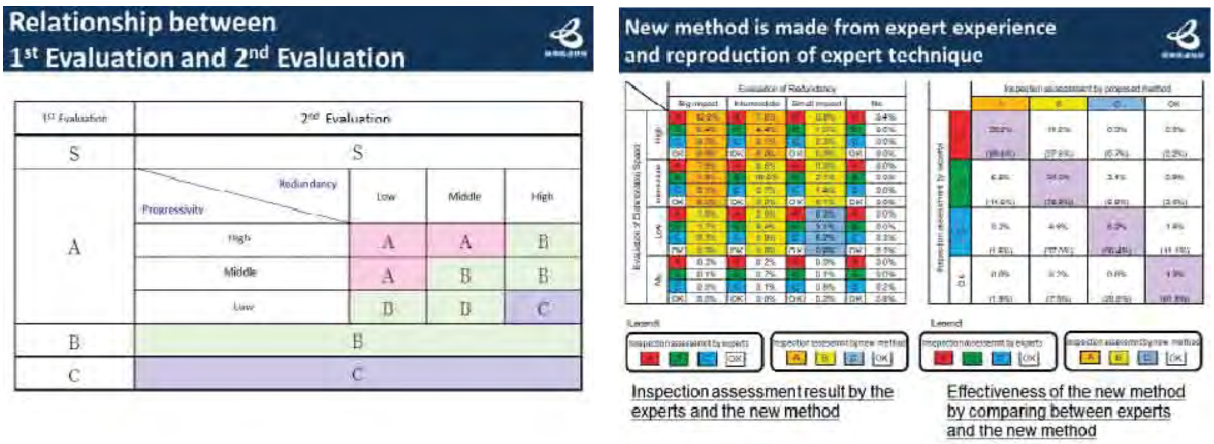

Figure 7.12: Evaluation matrix

Source: Eiichi Tsujimoto, Engineer, Hanshin Expressway.

This new (risk-based) inspection strategy is based, as far as possible, on 'on-site temporary repairing'. It is an effective method because it uses an on-site 'arm's length' strategy which is based on a progressive and soundness-based evaluation which makes full-use of the engineer's skills. The first evaluation is currently no different to an inspector using a manual whereas the second evaluation requires the necessary accumulation of knowledge and experience with field evaluations.

7.2.3 Intensive Maintenance Work: Closure of All Lanes

Hanshin Expressway outlined options for conducting intensive maintenance works through the closure of traffic lanes. Lane closures provide a method for minimising impacts on traffic in a central city area. Hanshin Expressway's major work in this area focusses on the road pavement and flexible joints. It commenced in 1973 (including work with single-lane closure) and has been carried out approximately every year since 1985. Hanshin Expressway gain public cooperation through publicity campaigns informing the public about the work they are carrying out.

There are several advantages to intensive maintenance works requiring all lanes to be closed as opposed to regular maintenance works with traffic control. These include: adequate work space, a shortened work period, and an improvement in the quality of work by securing a path for work vehicles in and out of the work space. The effects of closing all lanes for intensive maintenance works compared with regular maintenance works using traffic control is shown in Table 7.4.

Table 7.4: Comparison of maintenance works with traffic control and all lanes closed

	(a) Regular maintenance with traffic control	(b) Intensive maintenance with all lanes closed	(b)/(a)
Necessary days	approx. 190 days	Approx. 8 days	–
Total traffic congestion factor *	approx. 5,400 km/h	Approx. 540 km/h	0.10
Monetary value of time loss**	approx. 12.8 billion yen	Approx. 2.2 billion Yen	0.17

* Only amount of congestion caused by the works.

** Including major surfaced roads.

Source: Kunihiro Hayashi, Deputy Manager Hanshin Expressway: Intensive maintenance work using all-lane closure.

The program preparation for maintenance work consists of the following four key steps:

1. Estimate traffic impact during the work: undertaken by predicting congestion and impacts on the traffic during the work and consulting with the traffic administrator regarding traffic control.
2. Establish a consultation framework with relevant public institutions: based on the congestion prediction results (Step 1), Hanshin Expressway consult with other related road administrators, or traffic administrators (e.g. Police) to reach a consensus regarding the work, including the timing of the work, and to determine detour routes and guidance methods.
3. Public relations activities: how to reduce problems with relevant parties and the public is fundamental; this is undertaken through various public relations campaigns asking for cooperation of the public/drivers.
4. Planning of work schedule: coordination with contractors is a key success factor. This process should consists of the following four key steps:
   (a) define the work quantity
   (b) organise staff, subcontracting systems, etc.
   (c) secure path, waiting areas, and entering point/procedures for work vehicles
   (d) develop a work schedule based on priority of the work, prepare a map that indicates the location of the maintenance work, and prepare a timetable for each event.

The work schedule is coordinated using daily meetings with contractors to: check work progress and the consequent work schedule, identify problems and their coordination, report safety supervision results, remind everyone about safety, and report complaints and coordinate accordingly. The work is always undertaken on a 24 hour basis in cooperation with the local residents and the Police. Hanshin Expressway prepare for unforeseen situations during the work by:

- preparing backup vehicles/machines to use in case of a breakdown
- having an optional extra day in the work schedule to account for rain

- preparing optional extra materials and workers for repair work, e.g. if a floor slab is damaged when the pavement is removed.

The procedure for lane closure, and timeline, when intensive work is to be conducted is summarised in Figure 7.11: . Pavement repairs can involve pavement cutting, work on the adhesive layer, paving of the base layer and paving of the surface layer.

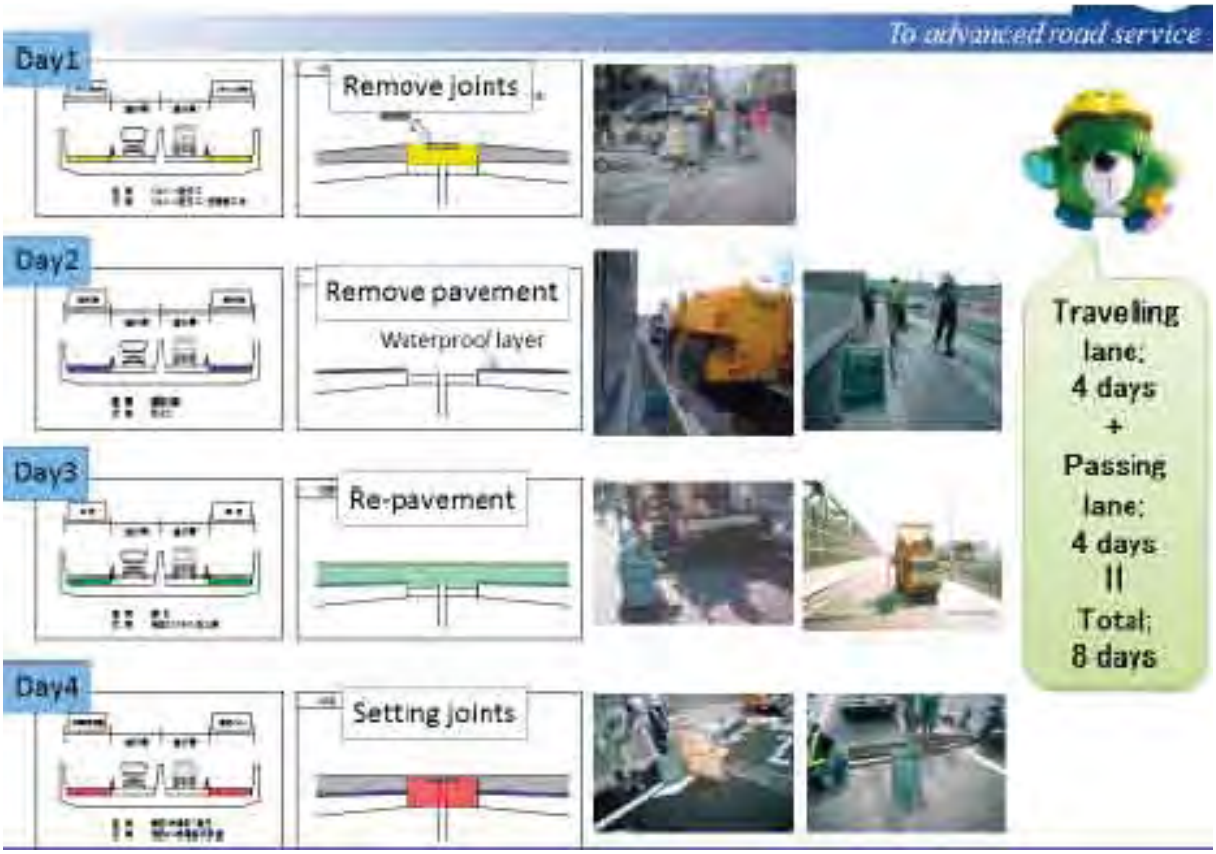

Figure 7.13: Procedure for lane closure when intensive work is to be conducted

Source: Kunihiro Hayashi, Deputy Manager Hanshin Expressway.

Effective public communications

The lane closure program has been recognised and accepted as an efficient maintenance methodology in the Kansai region. Hanshin Expressway have developed a trusted relationship with key stakeholders through repetition of implementation and the lessons learned throughout the process. Consensus from the transport industry and motorists has been enhanced through intensive public relations efforts. Additionally, all sites are determined by supervisors on a case-by-case basis and communicated to the public.

Unexpected problems often occur despite the thorough preparation; thus timely work supervision is very important. Hanshin Expressway share these problems when training their supervisors; they also continually update their manuals to take account of lessons learned manuals of accumulated knowledge for continuous implementation.

7.3 Recovery

Recovery represents the speed at which disruptions can be overcome and safety and services are restored. This section outlines key examples of recovery following natural and man-made events identified throughout the Scanning Tour.

7.3.1 2011 Great East Japan Earthquake

The Great East Japan Earthquake occurred on 11th March 2011. It caused widespread damage to the infrastructure. It reached a magnitude of 9.0 (Japan's maximum seismic scale was 7.0), off the coast of Sanriku. The fault was 450 km long and 200 km wide – a much wider seismic area than previous earthquakes in Japan. Large aftershocks caused further secondary and extended damage.

The traffic control at East NEXCO when the earthquake occurred is shown in Figure 7.13: . Initially, all the routes (2,310 km of road) were closed. The proportion of the network opened 20 hours later was 34%, with the rapid urgent restoration resulting in 98% of the network being opened 13 days later.

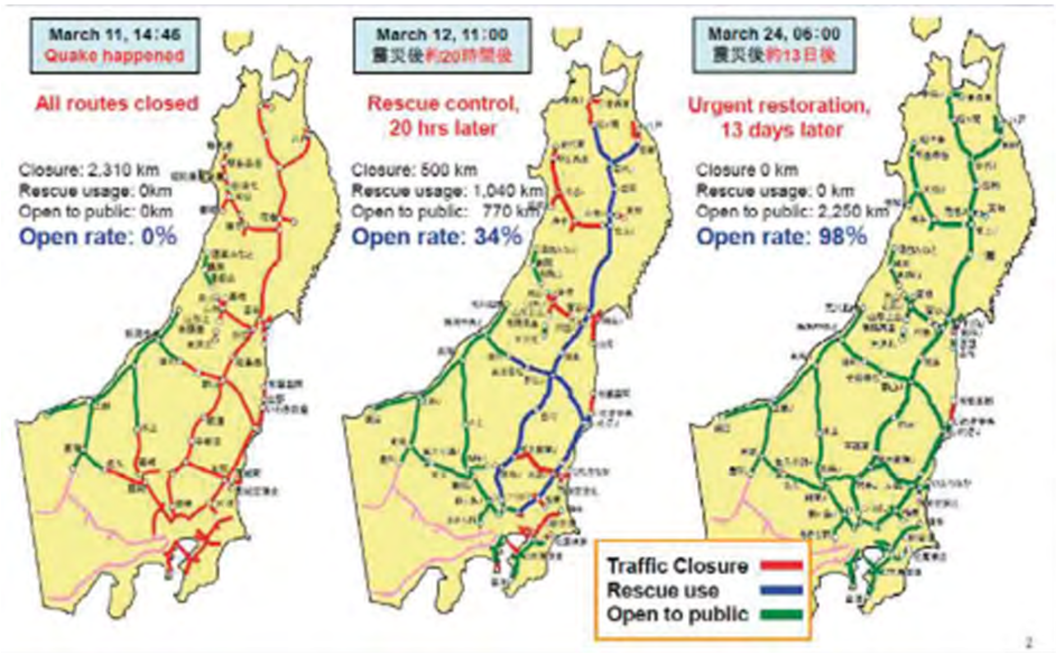

Figure 7.14: Traffic control at East NEXCO

Source: Takeshi Hirose, Bridge Division Chief (NEXCO Research Institute).

In terms of expressway control, 20 routes, or 854 km, of road were closed for inspection. Damage to the expressways was significant, including:

- cracking (longitudinal, curvature and divided shoulders)
- structural division
- swollen banks
- embankment and ground slides, rupture and deformation.

The proportion of roads returned into service 20 hours after the earthquake is shown in Figure 7.14: . About half of the network had returned to service one week later; significant sections of the network were by that stage open to rescue traffic.

Figure 7.15: Return of NEXCO expressways back into service after the Great East Japan earthquake

Source: Seiya Yokota, Chief Researcher for Geohazards (NEXCO Research Institute).

Assessment of urgent repair

Following the 2011 Great East Japan Earthquake, the *Urgent Repair Operation Standard* was implemented by NEXCO. Details of the urgent repair assessment are shown in Figure 7.14: . According to NEXCO standards, in the event of an earthquake, the road is closed if the magnitude of the earthquake is greater than 5. Urgent inspections are undertaken by NEXCO maintenance companies, followed by a detailed inspection by NEXCO engineering companies, and detailed design (if required) using consultants.

The following three-staged repair restoration of roads and bridges was enacted:

1 Tentative repairs so that rescue vehicles can travel pass on Tohoku, Joban and other expressways (within 20 hours).

1 Urgent repairs – lifting almost all closures (in 13 days). This included urgent repairs of bearings using vertical supports sustained by saddles; side blocks by setting horizontal movable limits; and expansion joints by covering steel plates with asphalt.

2 Main repair – the network was back to normal in 21 months.

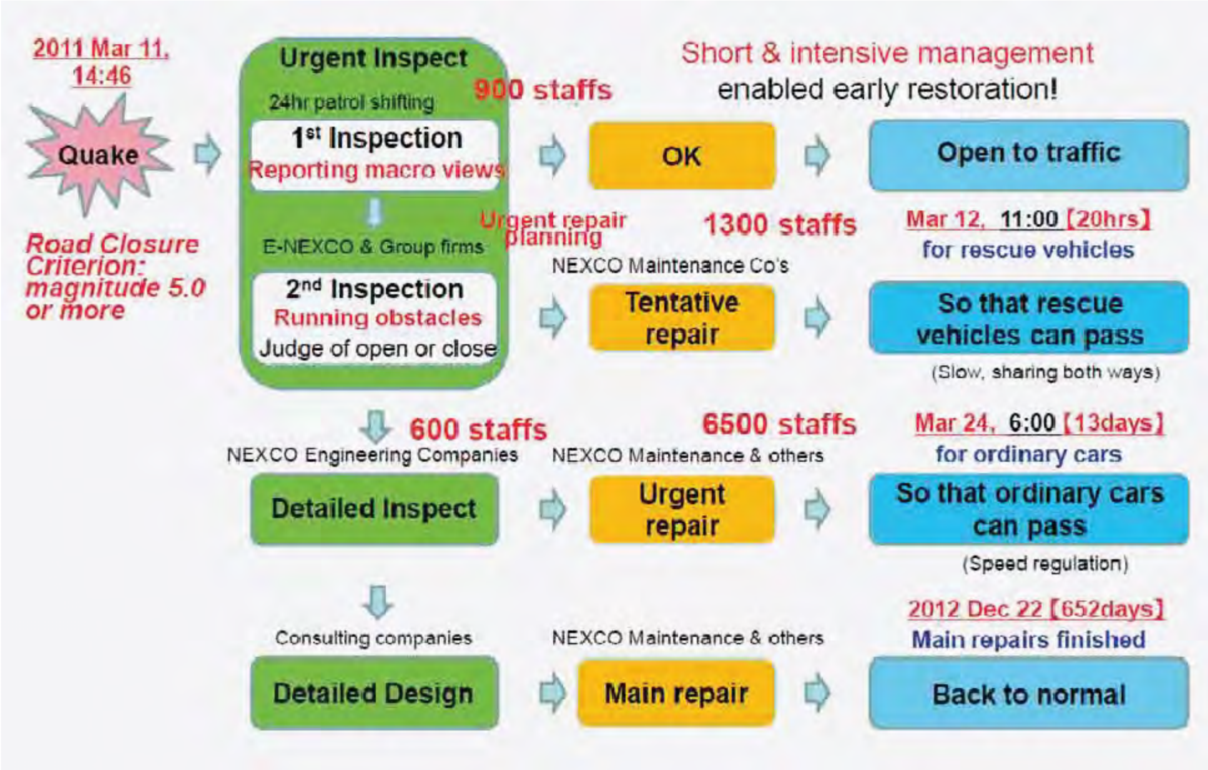

Figure 7.16: Details of urgent repair assessment

Source: Takeshi Hirose, Bridge Division Chief (NEXCO Research Institute).

In terms of communications, following the March 2011 earthquake, the Emergency Traffic Control Directory was followed as shown in Figure 7.15: .

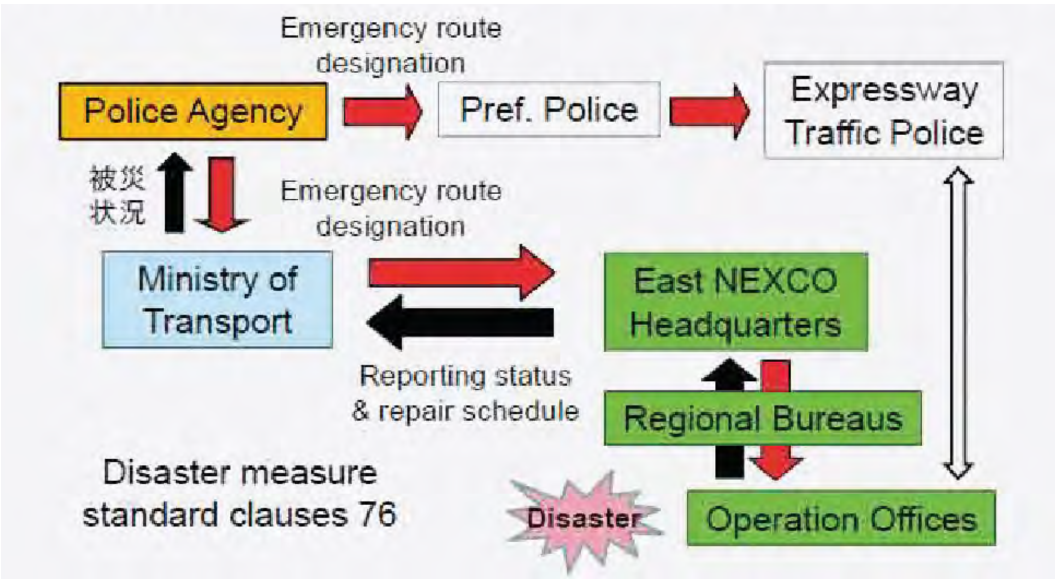

Figure 7.17: Emergency Traffic Control Directory

Source: Takeshi Hirose, Bridge Division Chief (NEXCO Research Institute)

7.3.2 *Great East Japan Earthquake*

An example highlighting the rapid rate of recovery required to support high populations was highlighted when 130 meters of traffic lane collapsed in Naka, Japan; the mid-upper embankment collapsed, commencing from the longitudinal paving joint area. While the repairs were taking place emergency vehicles were only allowed to pass on the Tokyo-outbound two lanes, as the repairs occupied the inbound two-lanes. The Tokyo-outbound two lanes therefore had to share both directions of traffic.

The emergency restoration included road base and subgrade construction (gravel course aggregates were used), paving, the installation of guard cables, and the inclusion of drainage at the foot of the slope. This emergency restoration took place only six days after the severe damage (see Figure 7.16:).

Figure 7.18: Recovery example – Naka repair

Source: Seiya Yokota, Chief Researcher for Geohazards (NEXCO Research Institute).

In the wake of the March 2011 earthquake further research was conducted on the compilation of experiences on the relationship between the scale of damage and amount of repair required. Urgent personal management involved all East NEXCO groups: of the order of 6,500 staff and 258,000 person hours.

Bridge rescue recovery following Great East Japan Earthquake

As a result of the 2011 earthquake, a total of 250 bridges, 944 embankments, and 2,829 road surfaces were damaged. According to assessments, the greatest damage to the bridges, in order f extent, was:

1 bearings – steel bearings (side blocks broken, shoe roller pins derailed, upper shoes damaged), elastomeric bearings (designed to withstand earthquakes, however, they failed)

2 joints – expansion joints (face plates detached, skewed bridges twisted)

3 girders –transverse flanges deformed, edges crashed

4 pillars (almost no damage) – damage to side blocks for movable limits and some loss of paint

5 faulting of the bridge edges, and faulting over culvert boxes.

Overall, there was not extensive damage to the bridges related to vibration, confirming the effectiveness of existing standards and earthquake proof-measures. There was almost no damage to the elastomeric bearings, and only conventional damage to the steel joints.

Using the Sendai-Tobu Expressway as an example, there were problems with only two bridge pillar segments. There were some broken elastomeric bearings, moved bearings, deformed girders and stiffness plates above the bearings, faulting side blocks, damaged expansion joints and the loss of paint on some steel pillars. Tentative repairs were undertaken on the vertical supports using saddles. Follow-up urgent repairs involved strengthening the supports for jack-up, the removal of rubber bearings, changing the main girder's supports, the repair and setting of side blocks and changing rubber bearing supports.

7.3.3 Great Hanshin-Awaji Earthquake, Osaka

The Great Hanshin-Awaji Earthquake in January 1995 (magnitude of 7.3) affected the densely-populated areas of Kobe and its adjacent cities causing extensive damage to the Hanshin Expressway which was running along the fault line. Major damage included a complete collapse of a 635 metre long stretch of the viaduct structure and four fallen girders in the Kobe Route and a fallen girder in the Wangan Route. About 50% of the supporting piers and four bridge spans collapsed. Additionally, 90% of the railway fleet was lost as a result of this disaster.

The entire Hanshin Expressway route was fully recovered and reopened in September 1996, only 623 days after the earthquake. Full restoration included:

- Emergency strengthening for the prevention of aftershock-induced secondary disasters. Seriously damaged structures were strengthened to support the girders and pier beams so that emergency strengthening could be carried out on the piers.
- Removal work was carried out using special technologies to achieve faster removal of damaged structures in confined spaces with various restrictions. For example, the pier columns and beams to be removed were cut into blocks with a rotary diamond wire saw, and large self-powered carriers were used to remove pier beams in large blocks.
- Procedures for reconstructing reinforced concrete piers included a reinforced concrete column and a steel beam.

7.3.4 Akashi-Kaikyo Bridge

The Akashi-Kaikyo Bridge was only half completed when damaged by the Kobe (Great Hanshin Earthquake) earthquake of 1995. This earthquake caused major havoc, with many houses, buildings, roads and railways suffering considerable damage. The earthquake caused a new fault to form in the seabed below the bridge, but no damage was reported to the bridge structure itself because only the towers had been built. Although no damage occurred, the earthquake generated so much movement in the supporting towers that they shifted: the two towers were originally 1,990 metres apart, but after the shift the span had increased by 1 metre. This was attributed to:

- the inherent suppleness of the suspended structures
- the selection of an appropriate site based on thorough geological surveys to avoid active faults
- the seismic design techniques adopted in the details of suspended structures.

In line with the policy of rapid recovery, the implementation of disaster recovery mechanisms was immediate. The shift was recalculated rapidly, and the recovery was fully government funded. The dampening systems were adapted to ensure that they were more accurate to prevent vibrations to the bridge supports, and the construction and design rules were made stricter. The bridge was designed to withstand large-scale earthquakes (as high as 8.5), only 150 km from the bridge site. In order to consistently monitor road conditions and to provide up-to-date information quickly to road users, the Kobe-Awaji-Naruto Expressway is managed by a control system located at the Tarumi Traffic Control Centre.

The Akashi-Kaikyo Bridge has designed for a 200 year life, which differs to the 100 design life generally adopted in Europe. In addition, construction in Japan is life-cycle orientated, reflecting both traditional and innovative design approaches. This contrasted to Korea, where technologies and communications are a key driver for network operations and infrastructure design.

7.3.5 Earthquake and Tsunami Restoration Research by NILIM

NILIM conducts research into the development of buildings to achieve sustainable use immediately after an earthquake. This includes:

- the use of wing walls to improve the stiffness of reinforced concrete buildings
- reducing cracks in beam-column connections in reinforced concrete buildings
- realising damage control design at lower costs than the base isolation systems.

Research is also undertaken into the long-term earthquake ground motions, e.g. response reduction effects, and predicting ground motion amplification. Research is also conducted towards creating disaster-resilient cities, including the planning for disaster-resilient cities in the context of tsunamis, improving tsunami evacuation simulators and improving city fire evacuation simulators. Research also includes preparing for smooth reconstruction of houses following earthquakes in terms of technical support for the construction and reconstruction of houses.

7.3.6 Summary

Following the 2011 Great East Japan Earthquake there was a very large focus on quick recovery in a cost-efficient manner – within the scope of what was required for immediate repairs to return the infrastructure to a useable functionality for a large population of transport users. This was based on existing standards, personal expertise and approaches to repairs. The dissemination of information was found to be different to Europe, particularly in the way that inspections were carried out, largely on a case-by-case basis.

Experience has shown that using a large workforce (e.g. for East NEXCO in the order of 6,500 staff and 258,000 person-hours) resulted in the rapid recovery of infrastructure within a minimum of 0-7 days. This was found to differ to the European and Australian approach to recover infrastructure to full capacity in a short space of time, where more detailed inspections following an event may occur.

Examples of rapid recovery post-disaster are:

- Great Hanshin-Awaji Earthquake in January 1995 – the entire route was fully recovered and reopened within a period of 623 days after the earthquake
- Great East Japan Earthquake in 2011 – 98% of roads were reopened to the public after 13 days
- Seohae bridge fire in Korea – the bridge was re-opened to traffic 16 days after the event.

The difference in recovery rates was also due to the way in which assessments are carried out. For example, NEXCO Research Institute used in-house expertise to undertake the assessments, whereas this may not occur in Europe and Australia due to different response frameworks and management configurations.

The Scanning Tour delegates noted that the Akashi-Kaikyo Bridge had been constructed with a 200 year perspective, which differs to the 100 year timeframe typically adopted in Europe. Additionally, following the Great Hanshin Earthquake, the implementation of disaster recovery mechanisms was immediate. The resulting shift of the Akashi-Kaikyo bridge during construction as a result of the earthquake resulted in the dampening systems being adapted so the response to future earthquakes could be more immediate and effective. In addition, construction in Japan is life-cycle orientated, reflecting both traditional and innovative design approaches. This was in contrast to Korea, where technologies and communications are a key driver for network operations and infrastructure design.

7.4 Adaptation

The final identified pillar of resilience is the ability to adapt to events and/or implement technologies to minimise future impacts. Some examples of these technologies during on the Scanning Tour are now presented.

7.4.1 Eco-friendly pavement technologies – NILIM

Recycling

The recycling of pavement wastes commenced in Japan the 1970s. It is one of the most effective methods to reduce CO_2 emissions associated with pavements. Currently, almost 98% of asphalt is recycled, with about 70% recycled as new asphalt applications. Almost 100% of concrete pavement is also recycled concrete is also close to 100%, almost all of it as basecourse material. A summary of the pavement recycling methods used in Japan is presented in Figure 7.17: .

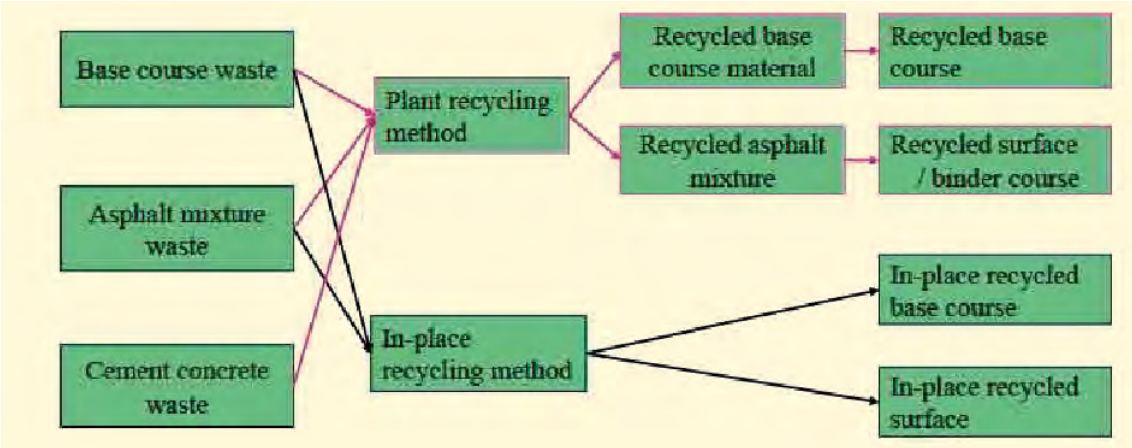

Figure 7.19: Pavement recycling methods used in Japan

Source: Kazuyuki Kubo, Head, Pavement and Earthworks Division, NILIM.

Plant recycling is the most popular method of recycling used in Japan; there are more than 1,200 asphalt plants in Japan with most located in close proximity to each other. The recycled of asphalt is promoted according to the *Promoting Green Purchasing Law*, which was enacted in 2000. In-place basecourse recycling is also undertaken, mainly applied to local roads. This technology has been trailed in Vietnam and other Asian countries.

In-place surface recycling was largely used in the past for expressway applications; however, there are environmental issues associated with the influence of hot air on roadside vegetation. Other waste (such as wood, molten slag made from municipal waste, glass, steel slag, tyre rubber, fly ash from power plants, etc.) is also recycled, and these have been found to be successful in terms of environmental safety (no seeping of harmful materials), durability (equal strength with natural aggregate in terms of hardness and wear-resistance), economics, stable supply (can be supplied with constant quality and uniform quality), and sustainability (can be recycled in several ways).

Warm mix asphalt (WMA)

Warm mix asphalt (WMA) technologies have been developed since 1997. They are considered to be one of the most useful technologies in terms of reducing CO_2 emissions. Technologies include:

- Type A: foaming additive
- Type B: viscoelasticity adjustment additive
- Type C: surfactant additive.

Similarly to Europe and Australia, the benefits include reductions in CO_2 emissions and improvements to construction quality in cold weather. However, the costs of the additives and the reduction in motivation due to work zone safety concerns is affecting its widespread use in Japan.

Innovative pavements

As a result of heavy rainfall, and increased heat island effects (due to increasing artificial land surface area, decreasing water surface area, and heat generated from infrastructure) in Japan, a number of innovative pavement technologies have been adopted over the last 10 years, mainly in urban areas. These include:

- Water retention pavements (to store water inside the pavement utilising the mechanism of latent heat).
- Porous asphalt is currently used in expressways and bridges, and its durability is between 3-10 years. Further research is being conducted into the performance of porous asphalt pavements..
- Heat shield pavements, which require surface paint and the reflection of infrared rays. These pavements can reduce the surface temperature by 10°C and improve the urban heat island effects. A trial section of heat shield pavement has been implemented in the Ginza district of Tokyo.

7.4.2 Adaptive approaches to road maintenance – Hanshin Expressway

In order to undertake maintenance works as effectively as possible, maintenance on the Hanshin Expressway is undertaken by:

- repaving high functional-performance pavements
- replacing expansion joints
- using low-noise construction methods
- providing driving safety counter-measures.

The high functional-performance pavement is repaved with a permeable surface layer to allow for the quick discharge of rainwater through the surface. This process also decreases the noise levels generated between the wheels and the road surface. Damaged expansion joins are replaced with a new type of joint that minimises the height difference between two sections of pavement, thus lowering roughness levels. Various low-noise construction methods are also applied to minimise noise levels during joint replacement. Examples of the public driving the wrong way on Hanshin Expressways has been increasing recently. In order to improve driver safety, road markings on the surface now have a high reflection sheet on the side wall indicating the correct direction to drive.

7.4.3 Risk reduction adaptive measures

Hanshin Expressway applies adaption techniques to reduce risk and ensure efficient and effective inspection of the infrastructure. The technological methods to reduce risks that are currently under implementation include:

- Digital binocular – equipped with high resolution photography and video technology, as well as night vision and 25 times zooming power, this device allows for visual access to inaccessible structures.
- Video scope – this technology can fit into narrow and sealed off spaces to provide visual assistance.
- Cable inspection robot for cable staid bridges.
- 3 dimension laser scanner – can be used for visual assistance in tunnels, slopes, pavements, etc.
- Detecting patrol car – data can be obtained at a normal driving speed to study pavement deterioration, expansion joints, noise barriers, etc. It uses a line scanning infrared camera. It has synergies with the USE-iT FOX, Inspection Work Package.
- Mitsukeru-kun K – detect fatigue cracks in pavements.

Another techniques currently used to inspect steel bridges is the three-step inspection method for steel bridges orthotropic deck plates. The method is summarised in Figure 7.19: .

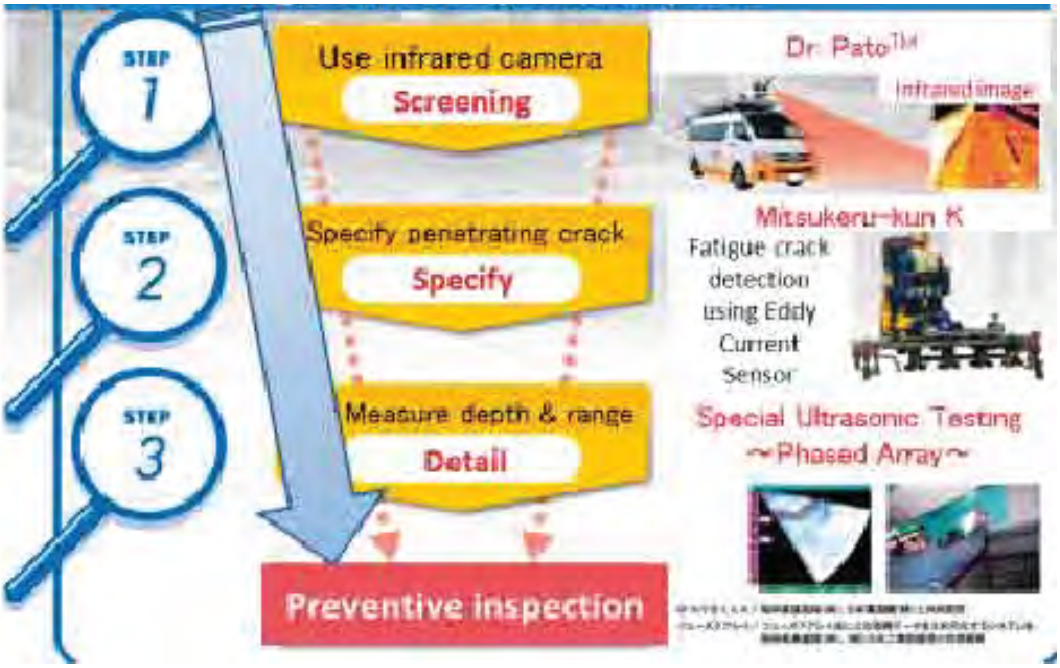

Figure 7.20: Three-step inspection method for steel bridge orthotropic deck plates

Source: Eiichi Tsujimoto, Engineer, Hanshin Expressway Presentation.

Technological methods to reduce risk currently under development include:

- continuous slip resistance measuring vehicle – can be used to collect data on pavements in curved sections
- wall-moving inspection robot – can move along a wall to access otherwise inaccessible structures.

7.4.4 Lessons Learned from Great Hanshin-Awaji Earthquake

Bridge structures are subject to deformation through temperature change and live loads. Bearings are designed to absorb these deformations and prevent excessive inertial force from being transmitted from the pier to the superstructure in the event of an earthquake. During the 1995 Hyogo-ken Nanbu earthquake, it was discovered that most of the conventional bearings could not withstand the applied forces and were severely damaged.

As a result of the earthquake, a 18-span prestressed concrete bridge (635 m long) in Kobe collapsed. The girders fell, and 17 reinforced concrete piers collapsed at their mid-height. In the rebuilding of the structure, the piers and girders are no longer connected to each other, and base isolators have been installed to reduce the seismic load. The dual box girders with steel decks are light in weight, and the reinforced concrete piers have expanded widths in the transvers direction.

The Benten Viaduct at Kobe was also severely damaged. Multiple reinforced concrete piers failed in shear, causing the bridge to fall and the main girders to buckle. The existing pile foundation was reused for faster restoration, with base isolators placed at the bottom of the piers so that no strengthening of the existing foundation was required. Seismic performance is achieved in this new 19-span continuous rigid fame bridge with a steel deck.

Considerable effort is being put by Hanshin Expressway in preventing and mitigating further disasters through seismic retrofit projects. New seismic isolation control technologies applied to long-span bridges include:

- Strengthening bridge piers and girders – steel structures are filled with concrete and concrete structures are jacketed with steel plates to prevent future collapse due to earthquakes.

- Ensuring adequate seating of girders – the beams of bridge piers have been made wider to keep the girders from falling during an earthquake. Girder connection devices have been included, as well as a girder connection and replacement of metal bearings with seismic isolation rubber bearings, e.g. coupling of girder to girder and pier to pier.
- Improving bridge restrainers – connections between adjacent girders or between girders and piers have been improved using cables and devices so that the bridge will not fall by displacement between a pier and girder due to a seismic motion.
- Changing base indicators – base isolators made of laminated rubber absorb seismic forces by attenuating the energy and reducing the ground motion transmitted to the bridge girders.
- Making girders continuous to prevent them from being unseated – this structure also reduces noise and vibrations.
- Sliding seismic isolation systems and buckling-restrained braces (Minato Bridge) – this is the third longest truss-bridge, now equipped with a sliding seismic isolation bearing system; it is suspended by cables not trusses, and the use of laminated rubber reduces swing.
- Shear panel dampers (Tenpozan Bridge)
- Laminated rubber dampers of a vertical sandwich structure with cables (Higashi-Kobe Bridge).

Since the 1996 Great Hanshin-Awaji earthquake, and the 2011 tsunami associated with the Great East Japan earthquake, standards have been revised to take account of earthquake-resistant technologies and seismic reinforcement. Modifications have also been fed into these standards. A great deal has been learned from these events, and new techniques to mitigate, or reduce, the economic cost of recovery (the recovery cost is estimated to be half the cost of new construction) have been introduced in Japan.

8 OTHER OBSERVATIONS

Other observations from the Scanning Tour include the following.

- An informative presentation was provided on an Intermodal Transfer Complex in Korea. It covered the importance of transfer systems in public transport, Korea's experience and best practices and lessons learned and recommendations. The presentation had synergies with the intermodal characteristics of FEHRL USE-iT FOX.
- At NILIM, an overview of the environmental issues of roads in Japan was provided. In order to accelerate road development, a Five-Year Road Development Program has occurred every four to five years since 1954. Two financial systems were introduced using revenue from toll roads, and a tax revenue system which earmarks funding for roads. Since the program commenced, the total length of expressways in Japan has reached more than 100,000 km.
- Road administrators have implemented various countermeasures to improve the roadside environment in the areas of noise barriers, regulations for nitrogen oxide emissions, the preservation of habitat through avoidance (i.e. moving the route away from habitats or changing the structure of the tunnel or bridge to avoid habitat loss), minimisation (in the absence of avoidance, the influence is minimised), and compensation (in the absence of avoidance, or minimisation, endangered species are moved to new locations.
- An evaluation model of transport CO_2 emissions was developed as a result of work conducted by a joint OECD/ITF transport research committee in 2009. NILIM is also researching the integration of data from moving vehicles (driving route and speed) which is collected automatically to monitor CO_2 emissions from road traffic, and estimating CO_2 reduction effect of various road projects.
- In terms of economic assessments, evaluations are undertaken largely on a qualitative basis. There are opportunities for knowledge exchange on the valuation of environmental externalities and their integration into existing guidelines.

9 SUMMARY OF FINDINGS AND RECOMMENDATIONS

The main findings and recommendations are presented under the four pillars of: preparedness, robustness, recovery and adaptation. Opportunities for international collaboration are also briefly discussed.

9.1 Preparedness

- Definitions of ‘Resilience’ seem consistent between Europe and Korea and Japan. Korea and Japan are working to ensure that both the infrastructure and the community are prepared for natural and man-made adverse events as much as possible, and have an opportunity to respond effectively.
- The use of ‘Big Data’ for smart roads, smart systems and smart data communications between the road and the user, vehicles and infrastructure is widespread in Korea and Japan. Using Big Data, information such as accidents and weather conditions is transferred directly to drivers without filtering or editing to try and prevent accidents or delays before they occur. Data can also be used to reduce traffic disruption, providing resilience at the network level.
- The legal/practical framework regarding data privacy seems to be less difficult compared to Europe: it is openly transferred to road users in real time.
- In Korea, smart bridges and highways means that there is a great deal of real-time sensory data, which provides increased resilience of infrastructure. Data is transferred using V2V and V2I technologies, and there is common use of sensors within the infrastructure.
- Further areas for investigation include the behaviour/training of GPS for users, and data privacy, e.g. the use of random numbers/colours instead of number plates? The question was also raised as to the need for sensors on roads, and whether this can be achieved by V2V only. Whilst vehicles will contain ever increasing levels of information, will users require their own system to own the data?
- The wider use of warning systems against earthquakes, floods and droughts could be particularly useful in Europe and Australia. There is the potential to apply these systems and technologies to other infrastructure such as tunnels, and implement countermeasures against sediment disasters and urban floods as well as information for safe evacuation. This includes developing danger detection systems using Big Data and smart phones, the identification of debris flow precursors, the development of rapid inundation warning information systems for users in underground infrastructure, and the development of rainfall and inundation prediction information provision systems using compact X-band MP radars.
- Big Data is used across a range of institutes and government agencies to ensure that they all are informed as quickly as possible, e.g. early warning systems against floods is closely connected to flood warning information (extensive data is collected and processed) from JMA. It is also used by NILIM, PWRI and ICHARM.
- Cross-fertilisation of knowledge between Korea, Japan, Europe and Australia can occur in the area of the inspection of the long-span bridges, including techniques such as annual surveillance, main inspections (every two years), detailed inspections (five years), inspection after extraordinary events (evaluation of bridge behaviour and soundness) and special inspections. Dynamic monitoring using a series of monitoring sensors, which measure wind velocity, displacement, earthquakes, accreditation and GPS can be considered.
- It was observed that the Tokyo Wan Aqua-line is equipped with advanced emergency escape facilities to ensure the safety of transport users, as well as to ensure that infrastructure is resilient.

9.2 Robustness

- Japan has an extensive network of expressways intersecting with city centres; this is considerably different to Europe and Australia. The major focus is on reducing the impacts of disasters and maintaining the aging infrastructure. There are opportunities for further knowledge sharing with regards to inventory and the deterioration rate techniques adopted.

- In the case of the fire on the Seohae Grand Bridge, the lessons learned included built-in robustness and redundancy, quick mobilisation of resources (stay cables, equipment, engineers and technicians).
- Similar classifications of bridges are adopted by Hanshin Expressway and PWRI. Hanshin Expressway has developed an effective classification of expressway damage, which was used in the determination of the extent of recovery and restoration required following the 1995 Great Hanshin-Awaji earthquake. Similarly, NEXCO West is undertaking expressway renewal (rehabilitation/preservation) projects, including bridge rehabilitation, to extend the life of safe and reliable expressways. The condition of the bridge is assessed according to the progress of deterioration, the performance of the structure and deterioration factors. PWRI also has bridge management classifications, adopted according to regulations.
- Hanshin Expressways has developed a risk-based inspection strategy where structures are maintained through a periodic inspection and evaluation strategy every five years. Intensive maintenance works are also in place. This has advantages associated with traffic control, including: adequate work space, a shortened work period, and an improvement in the quality of work by securing a path for work vehicles in and out of the work space.
- Effective maintenance at Hanshin Expressway includes establishing a trusted relationship with stakeholders. Trust with the traffic management entity has been deepened after the implementation of lessons learned. The sharing of failure experiences, the training of skilled supervisors and the development of manuals are critical for the continuous improvement of the infrastructure. Consensus from transport industries and car users has been enhanced through intensive public relation efforts
- Economic evaluations concerning environmental externalities are undertaken largely on a qualitative basis. There are opportunities for further knowledge exchange on the valuation of environmental externalities and integration into existing guidelines.

9.3 Recovery

- Following the 2011 Great East Japan Earthquake there was a very large focus on quick recovery in a cost-efficient manner (within the scope of what was required for immediate repairs to return the infrastructure to a useable functionality for a large population of transport users). This was based on existing standards, personal expertise and repair approaches. The dissemination of information was found to be different to Europe in that inspections were carried out largely on a case-by-case basis.
- It was shown that the experience from a large workforce (e.g. East NEXCO of the order of 6,500 staff and 258,000 person-hours) led to the rapid recovery of infrastructure within a minimum of 0-7 days. This was different to European and Australian approaches to recover infrastructure to full capacity in a short space of time, where more detailed inspection following an event may occur.
- Examples were provided of rapid recovery post-disaster, e.g. Great Hanshin-Awaji earthquake on 17 January 1995: the entire route was fully recovered and reopened within a period of 623 days after the earthquake. Similarly, following the 2011 Great East Japan earthquake, 98% of the roads were reopened to the public after 13 days. Similarly in Korea, following the fire, the Seohae bridge was re-opened to traffic only 16 days after the event.
- The difference in recovery rates was observed to also be due to the way in which assessments are carried out. For example, NEXCO Research Institute used in-house expertise to undertake the assessments; this may not occur in Europe and Australia due to different response frameworks and management configurations.
- The FEHRL Scanning Tour delegates noted that the Akashi-Kaikyo Bridge has been built with a design life of 200 years, which differs to the 100 year life normally adopted in Europe. Additionally, following the Great Hanshin earthquake, the implementation of disaster recovery mechanisms was immediate. The resulting shift of the Akashi-Kaikyo bridge during construction was quickly recalculated and dampening systems were further adapted in the event of future earthquakes.

- It was observed that Japanese construction is life-cycle orientated, reflecting both the traditional and innovative design approaches. This contrasted to Korea, where technologies and communications are a key driver for network operations and infrastructure design.

9.4 Adaptation

- There is potential to consider the technology approaches of water retention pavements and heat shield pavements in real life applications, as adopted in Japan. Similarly, there are opportunities to share initiatives such as roll-out pavements, solar roads associated with Forever Open Roads, and knowledge transfer on these technologies.
- A range of mechanical and robotic road maintenance and inspection techniques have been adopted, e.g. Hanshin Expressway apply adaptation techniques to reduce risks and ensure efficient and effective inspection of infrastructure. A vehicle which continuously measures skid resistance can be used to collect data on pavements in curved sections, and wall-moving inspection robots can move along the wall to access otherwise inaccessible structures.
- Considerable effort for preventing and mitigating further disasters is taking place with on the Hanshin Expressway and new seismic isolation control technologies applied to long-span bridges. Since the 1996 Great Hanshin-Awaji earthquake, and the 2011 tsunami associated with the Great East Japan earthquake, standards have been revised to take account of earthquake resistant technologies and seismic reinforcements. Modifications have been fed into the appropriate Standards.
- New techniques have been implemented in Japan to reduce the economic cost of recovery (the recovery cost is estimated to be half the cost of new construction) in future.

9.5 Opportunities for International Collaboration

The successful conduct of the Scanning Tour resulted in:

- the establishment of a dialogue regarding challenges for implementing more resilient infrastructure
- the establishment of mechanisms to share information and experiences regarding the management of resilient infrastructure
- the identification of practical applications of resilient infrastructure
- the identification of opportunities for future collaboration.

The possibility of Korea and Japan becoming members of FEHRL was discussed. Further discussions are required in this regard. Continued cooperation opportunities in the area of resilience will occur as a result of the networks built between Korea and Japan and within the FEHRL representative institutes. Some possible opportunities include:

- The further integration of big data and smart roads by way of enhancing V2V and V2I technologies.
- Rapid recovery post natural and man-made disasters.
- Early warning systems for earthquakes, floods, storm surges and drought, and how to ensure that infrastructure and society are provided with information as quickly as possible.
- Awareness of ISO standards, and the importance of improving international standards. For example, the RTRI's Railway International Standards Centre (RISC) was established in 2010 to review international rail standards; it is acting strategically to incorporate Japanese technical specifications and design concepts into international standards. This addresses the areas of strategic planning for international standardisation of railways, participation in the drafting and review of activities for international standards, and co-operation with overseas international standards experts.

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United States, Central Intelligence Agency (CIA), The world factbook <https://www.cia.gov/library/publications/the-world-factbook/>

Also numerous information brochures provided by the agencies, institutes and companies visited.

APPENDIX A SUMMARY OF VISITS AND TECHNICAL TOURS

A.1 Korea

Contacts:

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A.1.1 Korea Expressway Corporation

The Korea Expressway Corporation (KEC) was founded in 1969 and its headquarters are in Gimcheon. It has over 4,500 employees.

The KEC constructs expressways, tunnels, and bridges; it also provides expressway maintenance services, such as routine and periodic maintenance, emergency response and structural rehabilitation, and real-time, three-dimensional road management services. The company offers various traffic management services, including traffic information; congested area management services, including: shoulder lane systems, bus-only lane systems, and ramp metering system services; and traffic safety management services, including safety patrol services.

It also offers ITS services, including: expressway traffic management systems, toll collection systems, and tunnel traffic management systems; operation services including disaster, traffic, pavement, and structure management services; and bridge load rating/testing technology for determining a bridge's real load carrying capacity.

The company leases service areas and gas stations; offers research services; and provides services to the government, including supervision of government construction projects at various locations adjacent to the expressways.

A.1.2 Seohae Bridge

The Seohae Bridge is a cable-stayed bridge that connects Pyongtaek and Dangjin. It is 7.31 km long, 34 metres wide and 470 metres high. Construction commenced in 1993 and was completed in 2000 at a cost of 677.7 billion Won. It carries six lanes of traffic.

Figure A 1: Seohae Bridge

Source: https://en.wikipedia.org/wiki/Seohae_Bridge.

A.1.3 Gyeongbu Expressway

The Gyeongbu Expressway is the second oldest and most heavily-travelled expressway in Korea. It connects Seoul to Suwon, Daejeon, Gumi, Daegu and Busan. It is Route Number 1, signifying its role as Korea's most important expressway. The entire length from Seoul to Busan is 416 km and the posted speed limit is 100 km/h, which is mainly enforced by speed cameras. Construction commenced in 1968 and was completed in 1970. In December 1987, work began to widen it to six lanes in selected areas. Some areas were widened to eight or ten lanes by 1996. In February 1995, a bus-only lane was established between the northern terminus and Sintanjin.

In December 2002, the Korea National Expressway Corporation passed control of the northern-most 9 km stretch of the expressway to the City of Seoul.

Bus lane enforcement between Seoul and Osan (Sintanjin) on weekends became daily between 6 am and 10 pm on 1 July 2008. On 1 October this was adjusted to 7 am to 9 pm weekdays and 9 am to 9 pm weekends.

In August 2001, all expressways in South Korea were re-organised based on the US Interstate Highway System model. The Gyeongbu Expressway's Route Number 1 was the only one not to change; however, its kilometre markers changed from a north-south progression to south-north.

A.2 Japan – Osaka

Contacts:

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Dr Hideki Kaji, Manager, General maintenance engineering division West Nippon Expressway Co., Ltd (h.kaji.aa@w-nexco.co.jp), NEXCO West.

A.2.1 Hanshin Expressway

The Hanshin Expressway consists of 239.3 km of expressways surrounding Osaka, Kobe and Kyoto. Opened in 1962, it is operated by the Hanshin Expressway Company Limited. It has played an important role in the transport infrastructure of the region, supporting the community and the economy. The Hanshin Expressway network is three times as efficient as other general roads in the Hanshin metropolitan area in terms of traffic volume carried. The volume of goods carried through the Hanshin Expressway accounts for 50% of the total volume in the area. Elevated structures account for 80% of the network, while 10% of the network is located underground.

Portions of the expressway (about 400 m east of Fukae Station) collapsed during the Great Hanshin Awaji Earthquake on 17 January 1995. This was a 7.3 magnitude earthquake which directly affected the densely-populated areas of Kobe and adjacent cities. The earthquake caused a great deal of damage to the expressway as it is located along an activated fault line. These sections had been rebuilt by 1996, and the entire route was fully recovered and reopened 623 days after the earthquake. A seismic retrofit and new seismic-based designs were implemented based on the lesson learnt following the disaster, including pier strengthening, a girder connection device, and replacement of metal bearings with seismic isolation rubber bearings.

Hanshin Expressway's business domain branches into several areas that are fundamental to providing safe and secure road services. These include planning, construction management, land acquisition, inspection and maintenance, business, environmental considerations, international experience and traffic management. The Hanshin Expressway Co. Ltd fulfils its social responsibility as a road operator by implementing various strategies to minimise negative environmental impacts and to harmonies its structures with roadside communities. These strategies include noise and vibration reduction measurements and aesthetic considerations.[3]

A.2.2 NEXCO West

NEXCO-West was established in October 2005. Their predecessor was the government-backed organization Japan Highway Public Corporation (JH). Since the establishment of JH in 1956, the company has been contributing to the development of Japan's expressway network for more than half a century. JH was privatized in 2005 and split into three private companies. The West Nippon Expressway Company Limited (NEXCO-West) and the East Nippon Expressway Company Limited (NEXCO-East) operate a number of expressways in Western and Eastern Japan. They are not only responsible for the construction and operational management of expressways, but also the broad and ever-expanding range of services for expressway users, such as rest areas, restaurants and petrol stations.

NEXCO West's Missions is to provide logistics, access to airports and harbours, tourism, regional revitalisation, medical support and inter-regional exchange. Its business area includes 24 prefectures in West Japan (Fukui and Shinga to Okinawa). In west Japan, there are regions with an abundance of historical and tourist sites. The potential of these regions to expand in terms of logistics, tourism, culture and life is achieved by linking these diverse regions together through the use of expressways.

The main elements of the operation of the expressways is structural retrofitting, maintenance, traffic control/traffic safety and facility control, toll collection and disaster prevention. To prepare for large-scale earthquakes, NEXCO-West are taking comprehensive anti-disaster measures, including the promotion of anti-seismic reinforcement of bridge piers and measures to prevent bridge collapses, as well as having a system for quickly re-opening roads. NEXCO-West are also working to reduce the duration of road closures caused by snow and fog. In order to contribute to regional development and improvement in regional living standards, NEXCO-West continues to construct safer and more accessible expressway networks and refine existing expressways.

NEXCO-West are aiming to become a growing business group that is trusted by society, by performing thorough risk management, raising customer satisfaction and contributing to regional development.

A.2.3 Honshu-Shikoku Bridge Expressway Company

The Honshu-Shikoku Bridge project is a system of bridges connecting the islands of Honshu and Shikoku across the inland Sea of Japan, which were previously only connected by ferry. The system consists of three expressways and their respective bridge systems. All the bridges are now controlled by the Honshu-Shikoku Bridge Expressway Company and the Japan Expressway Holding and Debt Repayment Agency.

The eastern expressway was completed in 1998. Crossing the Akashi Strait, this connection links Hyogo Prefecture on Honshu with Tokushima Prefecture on Shikoku, using Awaji Island for most of its length. The route connects to the Sanyo Expressway at its northern terminus, allowing traffic to connect to Himeji, Kobe and other major cities on Honshu.

This connection consists of three suspension bridges, with the most well-known being the Akashi-Kaikyo Bridge, the world's longest suspension bridge. It connects Kobe to Awaji Island. The others are the Onaruto Bridge, connecting Awaji to Oge Island across the Naruto Strait, and the Muya Bridge, which connects Ōge Island with Shikoku. Although the connection was initially designed to accommodate railway services as well as road traffic, economic considerations meant it is only used for road traffic.

These bridges use highly-sophisticated bridge technologies including: the evaluation of bedrock, seismic design, pavements for steel deck plates, railway movement joint systems, hybrid PC-steel girder systems, steel buffer systems and vibration testing conducted on an actual bridge. In the case of the Akashi-Kaikyo

[3] Another interesting fact about the Hanshin Expressway is that portions of the Osaka Highway are featured in Tokyo Extreme Racer 3 (among other games).

Bridge, the new seismic design standard introduced new ideas involving non-linearity bearings as well as dynamic interaction between the ground and the foundation.

When designing and constructing bridges, the motion of each bridge structure as well as that of the ground on which it stands is carefully analysed. This is achieved by analysing the earthquake motion likely to hit the area. The Akashi-Kaikyo Bridge was only half completed when damaged by the Kobe earthquake of 1995. The survival of the bridge was attributed to: the inherent suppleness of suspended structures, the selection of an appropriate site based on thorough geological surveys to avoid active faults, and the seismic design techniques adopted in the details of suspended structures.

A.2.4 Shin-Meishin Expressway Construction

The Shin-Meishin Expressway at Osaka is 19.3 km long, comprising 8.9 km (46%) in earthworks, 5.6 km of bridges (29%) and a 4.8 km long tunnel (25%). The Expressway construction includes Inagawa Town, Takarazuka City (bridge and tunnel construction) and a rest area in Takarazuka.

Figure A 2: Shin-Meishin Expressway

A.2.5 Ikuno Bridge

The Ikuno Bridge is located in Ikuno, Dojo, Kita-ku, Kobe, Hyogo Prefecture (https://goo.gl/maps/2LThH3PeMyQ2). It is currently being constructed by NEXCO West. It comprises a three-span butterfly web bridge, a four-span box girder. It will be 606 meters in length when construction is completed.

Figure A 3: Ikuno Bridge

Source: *http://corp.w-nexco.co.jp/activity/branch/kansai/shinmeishin/situation/situation01.*

A.2.6 Akashi Bridge

The Akashi-Kaikyo Bridge is located at 1873-1 Iwaya, Awaji, Hyogo-Prefecture (https://goo.gl/maps/AGf3yD4aQKw). It is the longest suspension bridge in the world. It links the city of Kobe on the Japanese mainland of Honshu to Iwaya on Awaji Island. The bridge consists of three spans and is 3,911 m long. The bridge was constructed as part of the Honshu-Shikoku Bridge project, which is one of the greatest projects in Japan, connecting Honshu with Shikoku by both highway and railway. Construction commenced in May, 1988 and was completed in April 1998.

Figure A 4: Akashi Kaikyō Bridge

Source: www.jb-honshi.co.jp/english/bridgeworld/index.html.

The bridge was designed with a two-hinged stiffening girder system which allows the structure to withstand winds of 286 km/h, earthquakes measuring up to magnitude 8.5 on the Richter scale and harsh sea currents.

A.2.7 Earthquake Museum of Hanshin Expressway

The Earthquake Memorial Museum is located at Fukaehama, Higashinada-ku, Kobe, Hyogo Prefecture (https://goo.gl/maps/8hx97yFVNX22). It is part of the Disaster Reduction and Human Renovation Institution, which opened in 2002 to commemorate the tragic Kobe earthquake in 1995 and to educate visitors about earthquakes and disaster prevention. The museum includes a large-screen theatre with realistic images of the earthquake's destructiveness, a documentary film about the recovery process, and information about the earthquake and disaster prevention.

Further details are available at:
www.tech-center.or.jp/hokanko/display.html, and museumchick.com/2011/01/hanshin-awaji-earthquake-museum-kobe-japan.html.

A.2.8 NEXCO Research Institute

The NEXCO Research Institute was established in April 2007 to contribute to the growth of the three NEXCO Companies – NEXCO-East, NEXCO-West and NEXCO-Central – by centralising the best expressway technologies at one location, to conduct investigations and high-level research efficiently, and to develop new technologies. NEXCO's role in managing the Japan's expressway system is shown in Figure A 5.

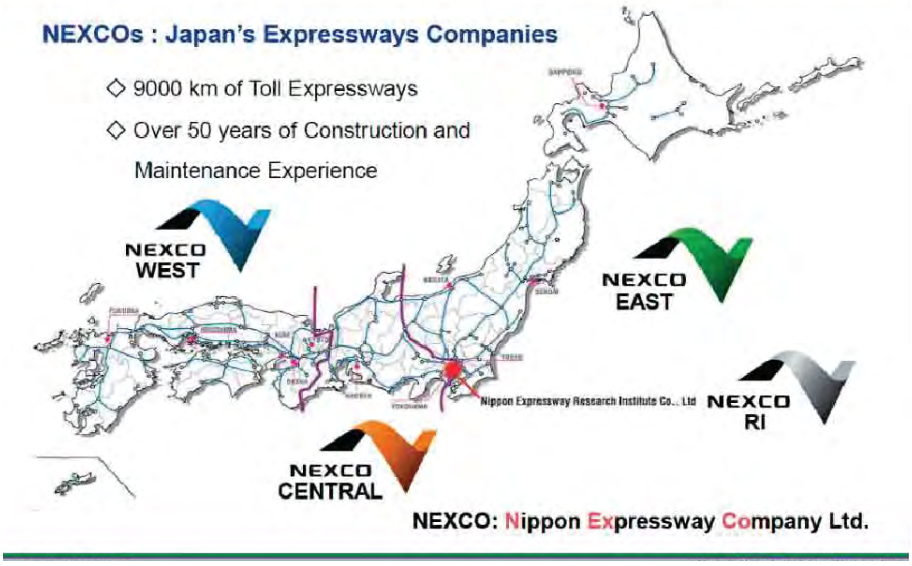

Figure A 5: NEXCO expressway network in Japan

Source: Keizo Kamiya, Chief Researcher for Pavement, NEXCO Research Institute, Japan

The role of the Research Institute is to contribute to the well-being of society through the development and application of expressway technologies. This is undertaken through: research and development, the drafting of technical standards, the provision of technical support, training sessions and lectures, and improving recognition and value of NEXCO's technologies. The Institute consists of six major working groups, including: general affairs and accounting, research planning, infrastructure development, traffic and environmental research, facilities research and road research. The Road Research Department includes a geotechnics division who undertakes research on earthworks design, maintenance and disaster prevention.

NEXCO technical support team provides support for disaster relief; for example, the Great East Japan Earthquake of 2011 and the Makinohara earthquake. It provides technical advice and proposals for fast recovery through the conduct of field surveys, and referencing to construction data and disaster relief operations kept since the 1970s.

A.2.9 National Institute for Land and Infrastructure Management (NILIM)

The NILIM conducts research to help the Ministry of Land, Infrastructure, Transport and Tourism to achieve the its goal of creating 'beautiful, safe and vigorous national land'. It is the only national research organization in Japan which is publically funded. It develops the results of its research so it can contribute to society now and in the future, by preventing and mitigating disasters and by utilizing, maintaining, and improving roads, bridges, and airports. Its priority research fields are: infrastructure maintenance; disaster prevention and disaster mitigation, and crisis management; intelligent utilization; innovative work execution method development; and regional revitalization and liability improvement.

The NILIM selects and defines priority challenges and concentrates its effort on their resolution. The top three priorities are: ensuring safety and security, forming sustainable and vigorous national land and regions and stimulating its economy, and creating and developing common fundamental technology. Ensuring safety and security refers to: disaster prevention and disaster mitigation, deterioration counter measures, safety of cities and residential environments, and enhancing the reliability of transportation.

Further details can be found at: www.nilim.go.jp/english/about/outline.htm.

A.2.10 Public Works Research Institute

The Public Works Research Institute (PWRI) was established with the aim of efficiently developing public works technologies and quality social capital by conducting research and development in public works, technological instruction and distribution of its research results, at the same time as contributing to the promotion of development of Hokkaido. In April 2006, the PWRI – whose parent organization had been Road Materials Laboratory, Public Works Bureau, Department of the Interior (established in 1921), and the Hokkaido Civil Engineering Institute, whose parent organization had been Public Works Department Laboratory, Hokkaido Government, Department of the Interior (established in 1937) – were integrated.

The PWRI consists of four institutions – Tsukuba Central Research Institute, Civil Engineering Research Institute for Cold Regions, International Centre for Water Hazard and Risk Management and Centre for Advanced Engineering Structural Assessment and Research.

The PWRI's research and development program consists of three main elements: contribution to the realization of a safe and secure society, contribution to strategic maintenance of public infrastructure, and contribution to the realisation of a sustainable and vibrant society. Examples of projects conducted include:

- The development of design techniques for disaster prevention and risk management related to intense water hazards.
- The development of technology to prevent or mitigate damage related to sediment-related disasters.
- The development of seismic technology for strengthening the resilience of infrastructure facilities to earthquakes.
- The development of technology for the mitigation of snow and ice disasters caused by extreme weather.
- The development of more efficient and reliable maintenance cycles.
- The development of technology for public infrastructure construction to achieve sustainable construction recycling.
- The development of river channel management technology that satisfies both flood control and environmental sustainability.
- The development of sustainable sediment management technology.
- The development of water quality management and control techniques for regional water use and aquatic ecosystem conservation
- The development of safer and more reliable road transport services in winter.
- The efficient use of infrastructure for attractive local development.
- The maintenance and management of agricultural infrastructure in cold regions contributing to improving food supply.

Further details can be found at: www.pwri.go.jp/eindex.html.

A.2.11 Railway Technical Research Institute (RTRI)

The Railway Technical Research Institute (RTRI) was incorporated in December 1986, just before the privatization and division of the Japanese National Railways (JNR). It took over the research and development activities of JNR when the Japan Railway (JR) Companies were established on 1 April 1987.

Activities include:

- research and development into railway technologies and labour
- the preparation of the drafts of railway technology standards
- the collection and distribution of railway-related documents, materials and statistics
- diagnosis, advice and guidance on railway technologies and sciences
- the drafting of plans and proposals for standardization with respect to international railway standards
- the authorization of qualifications with respect to railway-related science and technology.

A.2.12 Railway Technical Research Institute, Tokyo

Tokyo Bay Aqua-Line

The Tokyo Bay Aqua-Line, also known as the Trans-Tokyo Bay Highway, is a bridge-tunnel combination across Tokyo Bay. It has an overall length of 14 km, including a 4.4 km long bridge and a 9.6 km long tunnel under the bay, the fourth-longest underwater tunnel in the world.

Tokyo Bay plays a vital role in terms of marine traffic, which accounts for 1,400 ships per day. The Aqua-line was constructed to enable the passage of large ships (Kawasaki side), with the bridge taking account of height restrictions associated with Tokyo International Airport. As marine traffic is less frequent in the shallows of the Kisarazu coast, the bridge structure was a more economical option rather than continuing the shield tunnel structure the full length.

Figure A 6: Tokyo Bay Aqualine

APPENDIX B SUMMARY OF TESTING FACILITIES

B.1 Korean Accelerated Loading and Environmental Simulator (KALES)

The Korean Accelerated Loading and Environmental Simulator (KALES) is operated by the Korea Expressway Corporation Research Institute (KECRI). KECRI's three strategic goals are to: contribute towards sustainable growth, create future core technology, and offer customer-orientated technology services. KALES consists of three loading vehicles (each 36 tonnes) with dynamic/static measurement systems, a temperature chamber and an underground moisture level control unit. Further details of the simulator can be found at: www.ex.co.kr/research/eng.

There are four main applications of KALES:

- evaluate structural performance – evaluate structural capacity and performance of pavement structure systems
- simulate traffic load and environment – evaluate traffic load and environment during design periods
- material testings – engineering characteristics of pavement materials
- constitute and validate the pavement models – construct performance models and evaluate the responses of pavement structures.

B.1.1 Advantages of KALES

The advantages of KALES are:

- fast evaluation of pavement performance based on scientific methods
- evaluate pavements under the simulated field conditions
- evaluate pavements under controlled traffic loads and environmental conditions
- verify construction techniques and materials before application to the field.

B.2 Collision Test Facility (NILIM)

In order to address road traffic accidents and reduce pedestrian fatalities, NILIM has developed new guard fences for residential roads. Collision testing of guard fences for residential roads is conducted, where test conditions are set based on the situation of vehicles travelling on residential roads (medium-sized vehicle: 8 tonne, collision speed 40 km/h, collision angle 10°).

The results of the test include analysis of the amount of deformation in the guard fence, speed after collision and the angle after collision. The vehicles are remote controlled, with a series of cameras showing the damage to barriers. This assists in guiding the technical standards to determine the maximum height of guard rails.

B.3 30 MN Large Structural Members Universal Testing Machine (NILIM)

The 30 MN Large Structural Members Universal Testing Machine is operated by the Centre for Advanced Engineering Structural Assessment and Research at the PWRI. The machine is used for compressive, tensile, and bending testing of full-scale or reduced-scale bridge members/components to evaluate the ultimate strength and future performance. It was constructed in 1978 with the control unit updated in 1991 and 2002 to improve safety and the usability for operation.

Three examples of the use of this machine are as follows

- Buckling strength for stiffened plate girders – testing the combined shear/bending strength of a plate girder with horizontal stiffeners to evaluate the ultimate strength and post-buckling behaviour.

- Slip strength of high-friction bolted joints with high strength bolts, when inorganic zinc rich paint was painted on the surfaces.
- Bending, shear strength of PC/RC girders using CFRP as PC tendons.

B.4 Railway Technical Research Institute (RTRI) Testing Facilities

The RTRI's test facilitates include a rolling stock test plant, a large-scale tunnel lining model testing machine, brake test stands, a large-scale low-noise wind tunnel, a large-scale vibration testing system, and a train vibration and acoustic simulator. The Railway International Standard Centre and the Railway Technology Promotion Centre is also located at the site.

Brief details are as follows:

- Rolling stock test plant – capable of reproducing speeds of up to 500 km/h, using an actual vehicle.
- Large-scale tunnel lining model testing machine –reproduces the lining structure of a tunnel to a 1/5 scale; this enables the deformation of tunnels to be simulated.
- Brake test stands – testing of disc brakes and tread brakes under various conditions.
- Large-scale low-noise wind tunnel – located in Maibara-shi, in Shiga, it was built for the purpose of studying aeroacoustics and aerodynamic phenomena for high-speed trains; the wind tunnel can be used for not only railways but also automobiles and other modes.
- Large-scale vibration testing system – this machine can simulate ground vibrations with a seismic intensity of 7 and also apply two-dimensional horizontal acceleration onto an actual bogie; this is the first of its kind in the world.
- Train vibration and acoustic simulator – generates vibrations and acoustic environments of a rail vehicle in order to study passenger comfort characteristics.
- Railway International Standards Centre – established in 2010 to review international railway standards. Its role is to incorporate Japanese technical specifications and design concepts into international standards.
- Railway Technology Promotion Centre – established in 1996 to provide a forum where railway engineers and researchers can cooperate, and learn about new developments.

B.5 PWRI Pavement Test Field and Driverless Trucks

THE PWRI Pavement Testing Field is operated by the Pavement Research Team at the PWRI. The team operates within the Road Technology Research Group which also includes the Tunnel Research Team. The team conducts research on pavement technologies by conducting performance evaluations of pavement and design methods, analysing the economic management of pavements, improving the roadside environment and promoting new energy conservation and recycling.

The serviceability efficiencies of pavement deteriorate gradually because they are exposed to repeated traffic loading. PWRI believe that newly-developed materials and structures should be evaluated before being applied to pavements of highways and roads, not only in the laboratory but also in the field with 'real' vehicles used to test 'real' pavements. The PWRI's pavement testing field can conduct 2,000 cycles per hour with four loaded vehicles, which corresponds to 10-year loading in road classified into category C with 1,000 to 3,000 one-way daily heavy vehicle traffic volumes. The facility includes a circular test rack with a diameter of 200 metres and heavily-loaded driverless vehicles to traffic the test pavements (Figure B.1). The vehicles are equipped with GPS and other sensors (Kawakami and Kubo 2009).

Figure B 1: Driverless vehicles used to track test pavements at PWRI research facility

Source: Kawakami, A & Kubo, K, 2009, 'Accelerated Loading Tests on the Durability of Cool Pavement at PWRI', Third International Conference on Accelerated Pavement Testing.
www.coolrooftoolkit.org/knowledgebase/accelerated-loading-tests-on-the-durability-of-cool-pavement-at-pwri.

INFORMATION RETRIEVAL

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Keywords:

REAAA / FEHRL / technical report / scanning tour / infrastructure resilience / Korea / Japan / road / bridge / rail / technology transfer / evaluation & assessment / future collaboration

Abstract

This report presents the details of a FEHRL Scanning Tour to Korea and Japan in November/December 2016, on the topic of 'Resilience of the Infrastructure'. The locations visited were Seoul, Korea, and Osaka, Kobe and Tokyo, Japan. The report provides an outline of the research priorities in Korea and Japan, and key approaches and learnings to enhance infrastructure resilience. It is structured according to the key principles underpinning the concept of resilience, using a collation of presentations and case study examples from the Scanning Tour. The successful conduct of the Scanning Tour resulted in:

- the establishment of a dialogue regarding challenges for implementing more resilient infrastructure
- the establishment of mechanisms to share information and experiences regarding the management of resilient infrastructure
- the identification of practical applications of resilient infrastructure
- the identification of opportunities for future collaboration.