

## Innovative Maintenance and Asset Management for Urban Expressway Structures

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### ABSTRACT

The Hanshin Expressway Company Limited (here in after HEC) manages about 250km on the three major urban areas of Kyoto-Osaka-Kobe and carries out construction, operation and maintenance. In order to contribute to keep safe and smooth urban vehicle transportation, HEC has maintained highway infrastructures in fair condition and to upgrade load capacity against various natural disasters, especially earthquake which is more likely to occur in Japan. 90% of structures in HEC consist of Viaducts, and 50% of those have been place in service over 20 years, which results in implementing various countermeasures against the aging structures. In Addition, HEC launched systematic inspection-works and countermeasure-implementations in the early stage, and has been operating Hanshin Expressway Bridge Management System, highway asset management system. On this lecture HEC will introduce the maintenance of urban highway structures based on our experience.

**Keywords.** Highway, Viaduct, Maintenance, Upgrade, Asset Management



**Figure 1. Hanshin Expressway in Central Business District**

## **About Hanshin Expressway**

Since Hanshin Expressway Company (here in after HEC) has started its expressway operation services in 1964, its networks lengths of over 250 kilometres and a daily traffic of vehicles are counted more than 700 thousands of trips, thus the Hanshin Expressway Network plays important role for socio-economic activities of Kansai Region as an arterial highway of Kyoto-Osaka-Kobe Urban Area. After the privatization of Japanese Highway Public Agency in October 2005, HEC is engaging actively with spirits of the challenges to realize of our Corporate Identity, which is “Aiming to Achieve More Advanced Expressway Services”.

## **Experience 1: Facing to Various Deteriorations of Expressway Structures**

It should be naturally said that bridge structures are not immediately detracted their various performances, there are many instances which retain long durability and their performances as public infrastructures by the proper use and the appropriate maintenance that include the replacement of bridge parts/members.

It is generally said that the serviceability of structures is determined by the maintenance of operation stage, rather than not the premier design condition and the quality management of construction stage. In other words, probably, every public structure must not be free from maintenance, even though a large amount of construction cost is expended in very high consideration for maintenance whoever wishes to set up “Maintenance Free”. Every public infrastructure asset managers, probably all around the world, must be involved in the following missions from owners/users of those public assets and must keep sustainably conducting with high passion.

- To specify those public structures should be needed both of the service level and various performances of structures.
- To conduct daily maintenance works to detect signs of deterioration and defects on each structure which will become RISK that leads to decline service level and also to hinder necessary functions of each structure or members.
- To exert maintenance works to repair or retrofit by recovering performances of structures, mitigation and avoidance for RISK.

Following topics are highly important for the highway structure maintenance that HEC experienced.

- 1970s Frequent occurrence of defects of road surface and expansion joint due to a rapid increase of daily traffic volume, and complaints from highway side residents have been urged that are for traffic noise and house vibration.
- 1972 Punching shear failure of reinforced concrete highway slabs
- 1980 Delayed failure of high tension bolts
- 1981 Fatigue cracks at a notched part of steel plate girder
- 1982 Early deterioration of concrete pillars which were caused by Alkali Silica Reaction

In 1982, HEC compiled a series of booklet namely “Deterioration and Repair of Bridge Structure in Hanshin Expressway”, “Manual of Maintenance of Concrete Bridge Structures” and “Manual of Maintenance of Steel Bridge Structures”. On those two manuals, HEC has focused on necessary aspects which should be considered on the upstream stages of construction projects like as planning and detail-design, the reason why new construction project was a high priority issue, so it could not say that our business mind was insufficient

for existing structures however HEC had started to maintain viaducts after determining “Structure Inspection Manual” in 1971 by ourselves

### **Fatigue Damages of Steel Structures**

Presently the provisions of fatigue damages on steel superstructures become one of important maintenance issues because Hanshin Expressway consist viaducts which share of 90 percentages of the network of Hanshin Expressway, and the steel superstructures share 70 percentages of the viaducts. Fatigue damages on the steel structures of Hanshin Expressway have gradually occurred since 1980s. Fatigue damages were observed as cracking at various bridge members, which were supporting points of girders and between diaphragm and girders and decks and damages were also observed at corner of steel pier. Those fatigue damages have proactively investigated under the research framework of a research group of industry-government-academia to identify premiere causes and effective measures. HEC is conducting inspection/diagnosis for those damages and often taking appropriate measures. From the early 2000s, the fatigue damages on orthotropic steel deck which were designed and fabricated using trough-shaped rib plate have been detected by Structure Inspection. Although it is quite difficult and complicated to perfectly solve fatigue deterioration of bridges. Periodic inspection and special diagnosis are currently applied as the practical maintenance methods to mitigate various RISKS for highway users. To be more precise, measures for fatigue damages which HEC adopted as repair and retrofit to mitigate fatigue crack growth like as making a stop hole at fatigue crack toe, attaching steel plate parts by high-tension bolts and paving rigid steel fibre mixed concrete pavement on the surface of orthotropic deck. All of these measures were investigated and evaluated by HEC and steel structure experts.

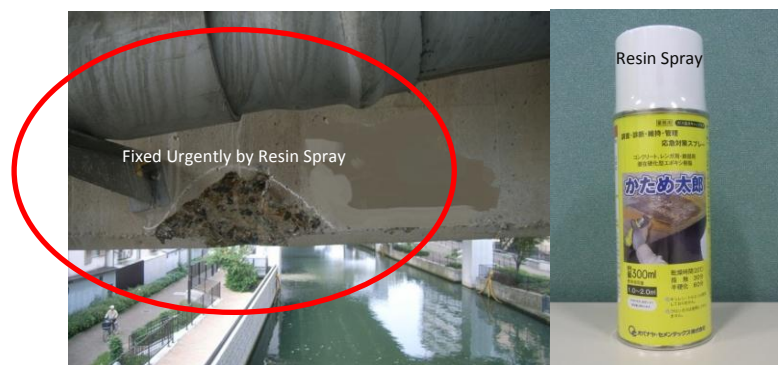


**Figure 1. Fatigue Damage on Orthotropic Deck**

### **Defects/Deteriorations of Concrete Structures**

The Concrete defects which frequently occurred are surface cracks, abrasions and cavities. These defects are recognized generally on existing structures as results of concrete deterioration which is carbonation and chloride damage; however those may have been probably caused by a lack of concrete covering depth to reinforcing bars and by shoddy concrete casting in construction stages. As the Hanshin expressway is urban expressway, the Right-Of-Way of the Hanshin Expressway is being utilized at multiple levels, like as city-roads, public-parks, parking-spaces and commercial-buildings. It is therefore an important requirement to prevent public damages which are resulted with concrete pieces falling. HEC conducts Daily Patrol for visible structures like as road surfaces, various facilities, super-structures and sub-structures, and as the main object of Daily Patrol is to detect

obvious defects or signs of deteriorations and to repair/remove defects urgently, HEC also carry out Periodic Inspection for all visible structures by visible check at closely and inspections by touch. HEC requires that all structural inspectors shall check condition of defects and if the defects may have a possibility that concrete pieces will fall down and then will injure third party persons; inspectors shall remove defects urgently and shall fix defect area urgently by using resin surface treatment.



**Figure 2. Typical Defects of Concrete Structure**

### **Deterioration caused by Alkali Silica Reaction**

The deterioration of Alkali-Silica-Reaction (ASR) on actual highway structures in Japan might have been first verified as very extensive surface crack of an unknown cause at Hanshin Expressway. HEC studied with experts from both of academic and private sectors to specify the mechanism and factors of the deterioration, and to develop countermeasures against both of prevention for construction stages and maintenance method for existing deteriorated structures. Presently HEC has being monitoring and sometimes repairing by surface coatings for these structures affected by ASR. In 2000s, HEC checked reinforcement bar inside of concrete pile caps which was seriously deteriorated by ASR and its maximum crack width extended to almost 10mm, and then the fracture of reinforcing bars were confirmed at bending corner of reinforcement. HEC implemented immediately Urgent Inspection for ASR affected structures which were specified through the former maintenance records, and then same fractures were detected at bending corners of other reinforcement bars. HEC decided to rehabilitate some pile caps that were assumed as seriously deteriorated applying steel-plate/ continuous fibre reinforcement method. In 2006, HEC published “Maintenance for ASR affected Structures” to share our experience for thirty years.



**Figure 3. Typical Damage caused by Alkali Silica Reaction**



## Experience 2: The 1995 Hyogoken-Nambu Earthquake and Restoration Project

Hanshin Expressway suffered enormous damage from The 1995 Hyogoken-Nambu Earthquake. Major Damage included a complete collapse of a 635m stretch of viaduct structure and four fallen girders in Kobe route and one fallen bridge in Wangan route. HEC undertook the restoration project of devastated routes and had completed the project for almost 20 months.



**Figure 4. Viaducts Seriously Collapsed and After the Restoration**

### Seismic Capacity Upgrade Project

HEC implemented a seismic capacity upgrade project for the viaducts which were not seriously damaged by the earthquake. Based on the damage experience and knowledge HEC revised the Technical Standards for the Seismic Design of Highway Bridge Structures. Table - 1 shows the typical methods of seismic capacity upgrade for highway viaducts.

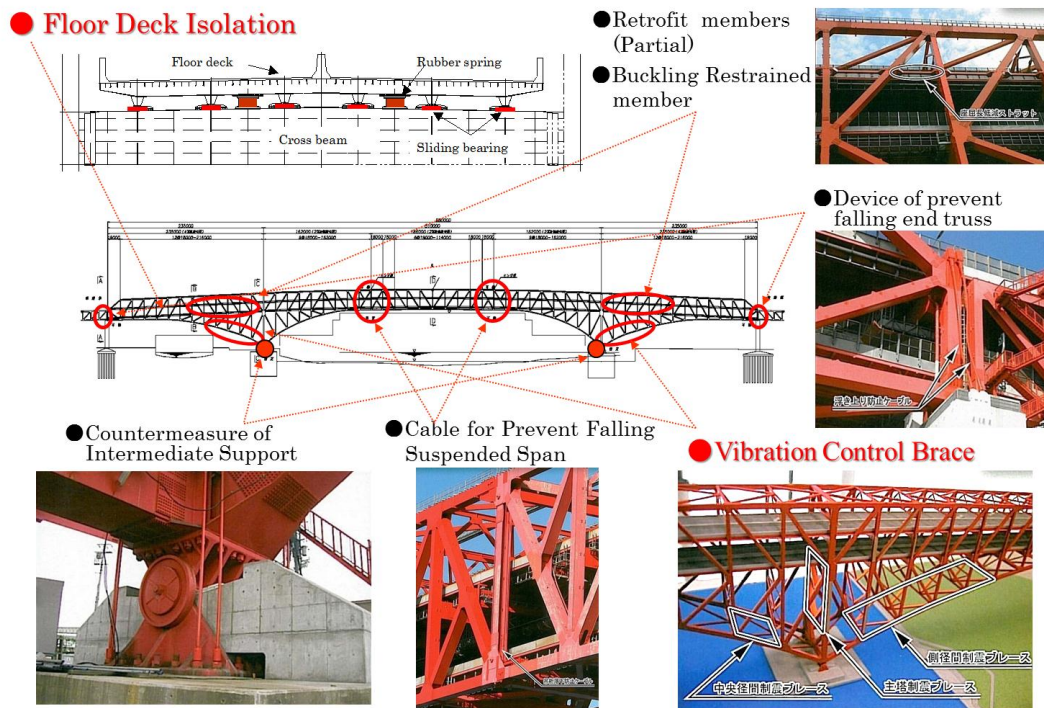
**Table - 1 Typical Method for Seismic Capacity Upgrade**

Steel Fabricated Pier	<ul style="list-style-type: none"> <li>➤ Concrete Filling</li> <li>➤ Vertical Reinforcing Rib-plate Addition</li> <li>➤ Additional Anchoring at Pier Base to Footing Foundation</li> </ul>
Concrete Pier	<ul style="list-style-type: none"> <li>➤ Steel Plate Jacketing</li> <li>➤ Reinforced Concrete Jacketing</li> <li>➤ Continuous Fiber Reinforcement Jacketing</li> </ul>
Super-structure	<ul style="list-style-type: none"> <li>➤ Base isolator installation to girder bearing</li> <li>➤ Modifying simple girder to continuous girder</li> <li>➤ Sufficient Girder Sitting Space on Pile Cap</li> <li>➤ Installation of New Type Bridge Restraints</li> <li>➤ Displacement Restraints for Girders after Bridge Bearing Collapse</li> </ul>

### Seismic Retrofit of Special-type Bridges

HEC adopted Damage-controlled Design to upgrade long spanned and special-type bridges. This is because of the huge dimensions of bridge members and its design procedure is more complex than conventional viaducts. And another reason is HEC needed to secure the optimum balance between the seismic capacity upgrade and an economic performance. Minato Bridge (980m span-length) is the third largest in the world as Truss Type Bridge. HEC defined damage scenario and mode for this special-type bridge, and decided that main object of design is to keep “Main Truss Members” in fair condition.

- 1) Sliding Base Isolation Bearing System was adopted to reduce seismic force of dead load of floor which is utilized as expressway lanes.
- 2) Vibration Control Brace (VCB) was adopted to absorb seismic force energy and to reduce seismic force of main truss. Existing lateral structures were replaced to VCB at both side of Main Truss Support Point, and VCB was designed as secondary members and allowed partially damage occurring some buckling to a certain extent.



**Figure 5. Seismic Retrofit of Minato Bridge**

### Experience 3: Optimization of Maintenance Budget under a Budget Constraint

HEC developed Hanshin Expressway Asset Management System, called “H-BMS”, originated from a maintenance data management system in 1986, because it became an important issue to manage an enormous data of from construction records to maintenance results.

In October 2005, as the Japanese Government Policy for the privatization of Highway Public Corporations, HEC was newly established. As well as other Highway Companies, HEC is being required to operate and maintain the Hanshin Expressway Network appropriately under budget constraint according to the agreement of highway asset lease and operation with “Japan Expressway Holding and Debt Repayment Agency (JEHDRA)”

Therefore, after the privatization, HEC are held fully accountable for explain not only detail items of maintenance works and the amount of expended cost but also how the expended cost contribute to the asset of Hanshin Expressway, furthermore to the upgrade of service level for all users of Hanshin Expressway. In addition to that, it became an important mission that is to explain how much the future cost of maintenance is necessary for the implementation of effective maintenance and for the achievement of the corporate identity of HEC which is “SAFE, SECURE and COMFORTABLE”.

## Development for Operation and Maintenance Logic Model

HEC started the systematic inspection and diagnosis of viaducts in the early years, and developed the DATA MANAGEMENT SYSTEM which can assist the integrative data management of “Construction Data”, “Inspection Data” and “Maintenance Results”. HEC is presently developing our own “Maintenance Logic Model” which configures as following;

- 1) Assuming final goals of maintenance works in consideration of a great deal of “Effectiveness”
- 2) Setting up “Quantitative Indicators” for “Input: Resources and Activities”, “Output: Maintenance Results” and “Outcome: Achievements that a maintenance result brought” as our own “Logic Model”
- 3) Signifying necessary issues to achieve our own “Logic Model”
- 4) Optimizing “Management Level” through the sustainable improvement of maintenance management cycles while collecting “Quantitative Indicators”

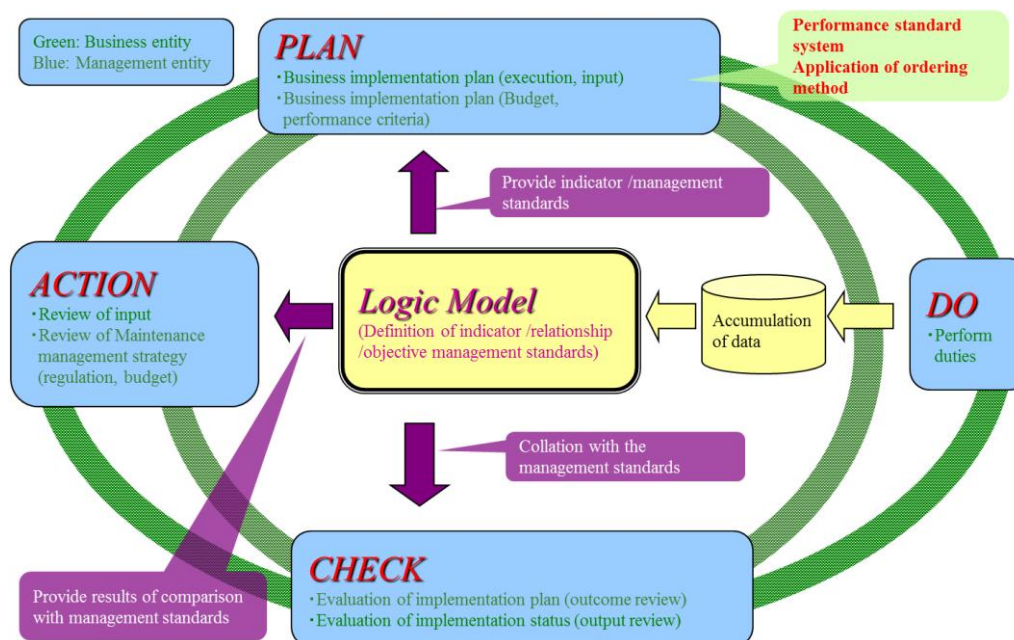


Figure 6. Maintenance Management Cycle of Hanshin Expressway

## Effective Implementation of Repair and Retrofit Projects

The maintenance of road surface is one of the most important tasks due to 700,000 trips of average daily traffic, therefore it is required to secure both of comfortable driving/safety driving, and to mitigate or improve the environmental impacts on the roadside residents. In the case of emergency, by all means, HEC implements replacement of pavement for the small section and renewal of some bridge expansion joints. Since road surface maintenance works makes often the serious traffic congestion requiring a lane restriction for long hours, in principal, HEC shall plan and implement those maintenance works on every weekend when a daily traffic volume can be expected relatively small.

In order to replace the pavement exceeding several tens of thousands square meter, however, a conventional rule is not effective for the time of large scale replacement of pavement, and thus it must be needed to be implemented for every weekends. Probably these maintenance



works on every weekend will affect to both of the total cost, which is estimated to increase the cost of repeated lane restrictions and lose social benefit due to traffic congestion. Therefore to solve this problem, HEC adopted the intensive maintenance by closing isolated section of Hanshin Expressway. The full lane closure will be usually scheduled for 8 days. HEC promotes that the traffic closure for several days is a most effective way for the large scale replacement of pavement and expansion joints.

HEC regularly implements the traffic lane closure since 1982 with coordinating various stakeholders like as local officials, expressway users and roadside residents.



**Figure 7. Full Lane Closure Maintenance Works**

## **Conclusion**

Know-how of the social infrastructure management, including expressway maintenance, cannot possibly be achieved overnight. Long term experience and knowledge enable us to develop know-how for maintenance and operation of social infrastructures includes expressways. A failure case can be a great knowledge, so it is necessary to enhance the human resource development with intentional effort for establishing maintenance experts/strategists. For maintenance experts/strategists who are facing to asset management, to optimize the balance of restricted budget and service level, it is highly important to develop know-how for the provisions of future expenditures of maintenance and deterioration process.

However this sort of know-how is still under developing, it can be said that the best way to develop know-how is to collect and evaluate more data of structure conditions and to break down those bedside deterioration data because there are always the uncertainties in those defects and deterioration process. These efforts will be necessary to build sharing system not only for one highway maintenance experts/strategist like as HEC but also for sharing between similar highway maintenance management entities. As one of our efforts, HEC is coordinating and the Maintenance Engineers Committee where we can share information about Asset Management of road and bridge with different local official persons who are in charge of maintenance affairs of local road/bridges. Moreover asset management of road/bridges is common issue all over the world. HEC is making contribution to solve issues of road/bridge operation and maintenance, so that HEC is dispatching staff of HEC to administrative departments in developing countries as technical assistances.