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The Current Situation and Maintenance of Expressways in Japan

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ABSTRACT

The number of bridges currently managed by NEXCO is 18,000 bridges. The current average years-of-service is about 26 years, and those bridges that have been in service for over 30 years take up about 37%. The environment which the bridges are placed under is also becoming severer, with the number and the size of the vehicles, and the amount of de-icing salt used in winter increasing, further accelerating aging.
It is expected that aging of the structures will further progress and inspection frequency and the number of structures which need to be repaired or reinforced will increase in the future, increasing maintenance costs. It will, therefore, be necessary to upgrade inspection, repair and reinforcement technologies, and work out maintenance schedules for preventive maintenance, including the rebuilding of bridges, planned based on the concept of asset management and in consideration of LCC.

Keywords, expressway bridge, aging of bridges, increasing maintenance costs, preventive maintenance, asset management, bridge management system

INTRODUCTION

Today, the maintenance of infrastructures has become a major issue for countries around the globe. Bridges alone add up to a huge number and, therefore, economically, socially and technically, maintaining the health of all bridges is not an easy task. As you may all know, Japan's current economic situation does not allow sufficient funding for maintenance. In addition, the importance of maintenance operations is not recognized by all and there also remain many technical issues that hinder effective maintenance.

NEXCO (NEXCO-East, NEXCO-Central, NEXCO-West) is a group of three companies founded by splitting and privatizing the former Japan Highway Public Corporation in 2005. From the founding of its predecessor, it has built, operated, maintained and provided expressway services in Japan for over 50 years. NEXCO's responsibility and mission is to maintain the expressway network, which serves as the main artery that support industrial activities and everyday life of the people, now and in the future, and secure safety of expressway structures so that it may carry out its vital role. Many years have passed since the expressways were constructed, and aging of bridges, tunnels, and earthworks are becoming evident. Currently, there is a pressing need to study and develop technologies for preventive maintenance to guard against damages and conduct large-scale repairs and reconstruction.

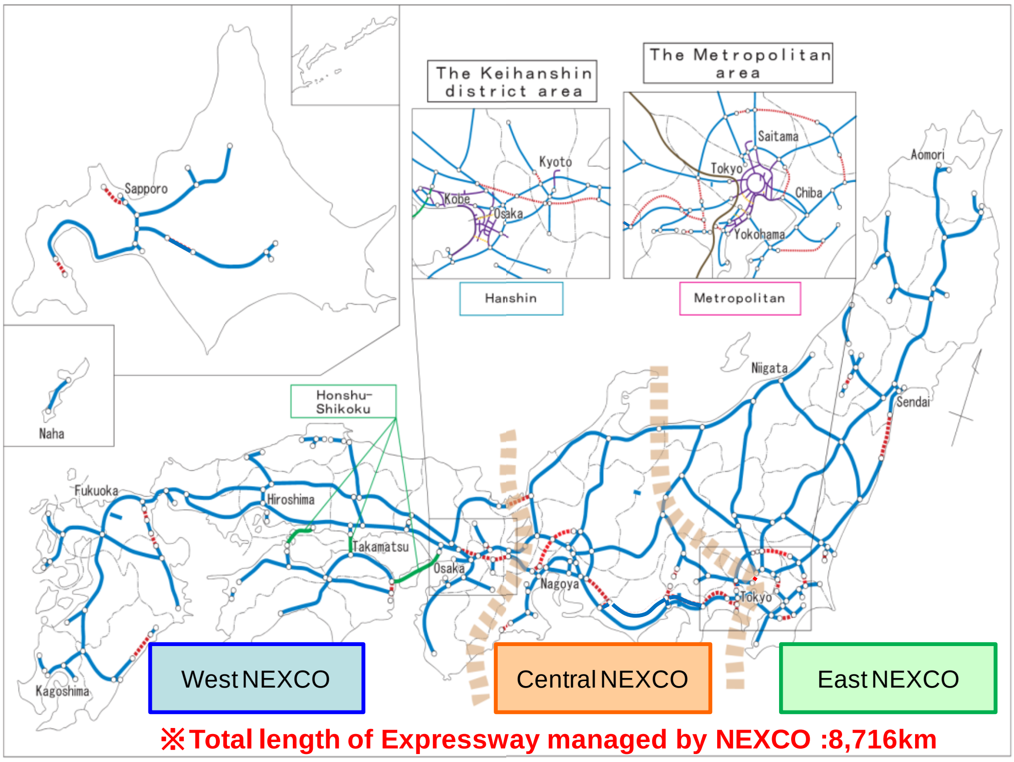


Figure 1. Expressway Network in Japan (march.2012)

Overview of expressways in JAPAN. The first expressway in Japan began services in 1963 between the RITTO and AMAGASAKI IC on the Meishin Expressway. The Tomei Expressway and other sections of the Meishin Expressway opened in the following years and, as of 2012, the total length of expressways in Japan has come to over 8,700 km (expressways and general toll roads). About 5 million vehicles use the expressways daily, including 200 thousand heavy vehicles. The expressways have played an important role in supporting Japan's high economic growth and which has delivered the people a more comfortable life. And now, with the expressway network being further developed, it carries out its role as an important social infrastructure aiding the growth of regional economies, supporting medical emergencies and other various needs by providing a convenient means of daily travel.

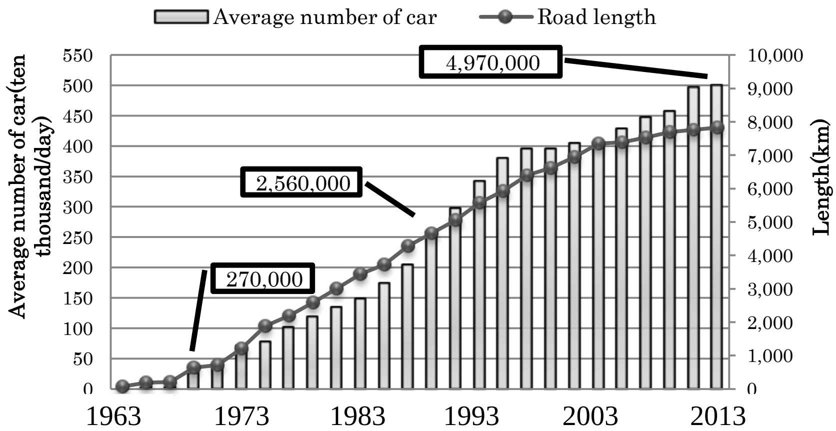


Figure 2. Structures Serviced by former JH(NEXCO)

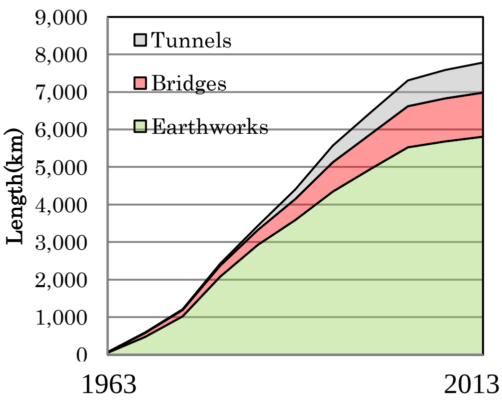


Figure 3. Ratio of Structures of expressway in JAPAN

With few expressways remaining to be completed, like the New Tomei, New Meishin, Ken-O and Tokyo Gaikan expressway, the majority of NEXCO's business has moved to management and maintenance. Currently, maintenance of expressway structures, like bridges, is a major issue facing the operations. Structures take up a considerable part of the roads with the total length adding up to about 2,000 km (bridges: 1,200km, tunnels: 800km), accounting for about 25% (bridges: 15%, tunnels: 10%) of the entire expressway network. As of 2012, the ratio of structures that have been in service for over 30 years was about 40%. The long years and harsh environment the structures have endured indicate that dilapidation of the structures is progressing.

With limited amount of funds available, NEXCO's challenge is to maintain these structures effectively and efficiently.

Outline of bridges. As indicated earlier, the length of bridges currently managed by

NEXCO is 2,400 km, in terms of number there are 18,000 bridges. The current average years-of-service is about 26 years, and those bridges that have been in service for over 30 years take up about 37%. As expressways were rapidly constructed from the 1970's, it is thought that the percentage will rise to 50% in the next eight years. The environment which the bridges are placed under is also becoming severer, with the number and the size of the vehicles, and the amount of de-icing salt used in winter increasing, further accelerating aging.
Of the bridges, about 30% are steel bridges, 40% PC bridges and 30% RC bridges. The bridge type that has the qualities to best meet the requirements of the site was selected for construction. Currently, from the viewpoint of durability, RC bridges are not employed, and, instead, highly durable PC and hybrid structure bridges are constructed.
Over the years, NEXCO has revised various standards to improve durability and rationalize the construction of bridges. For this reason various designs, methods and materials have been used to build one type of bridge. And, therefore, some bridges may harbor inherent risks of deformation which could not be anticipated at the time of construction.

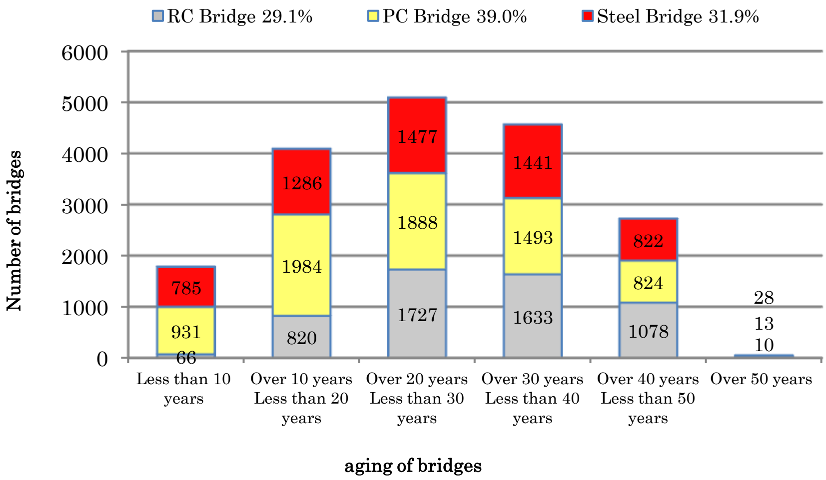


Figure 4. Number of bridge type and aging of bridges

Bridge construction technology. NEXCO's bridge technology was developed to meet the various requirements of the construction. NEXCO's technology was developed paying attention to promoting continuity, employing deck bridges, improving cost effectiveness and workability and the appearance in the landscape. In addition, the focus was placed on improving durability, ease of inspection and other maintenance items.
Followings are outlines of NEXCO'S typical bridge structures.
(1)RC bridge. RC bridges were initially employed as the standard viaduct constructed over plains; RC continuous hollow slab bridges were mainly employed at many locations. This bridge type has a rational design as a RC bridge, and has excellent qualities in terms of continuity and economy. For this reason RC bridges were considered the standard viaduct and have been employed at many locations over the years.
(2)PC bridges. PC bridges were initially used for small-scale bridges using pre-cast

girders. But as technology progressed, continuous/connected hybrid girders were developed to be employed for mid-sized bridges, and the arrival of PC box girders employing cantilever construction increased the number of large bridges constructed using the method. Currently, from the view point of improving workability and durability of concrete bridges, PRC bridges are now employed. Outer cable structures are actively employed for PC box girders in order to lighten the bridge weight, improve workability when placing concrete and steel members, and for ease of inspecting and replacing PC steel members.

Photo 1. Principal PC Bridge (OKAYA Viaduct)

(3)Steel bridges. Steel bridges were mainly employed for large bridges. But because of construction requirements and the need to cut costs, small to medium span bridges using I cross-section main girders are now built at many locations. Two issues facing steel bridges are corrosion and fatigue. To prevent corrosion, galvanized steel and weather resistant steel members have been employed. But now, using improved paint and by coating the whole member at the factory, we are trying to improve the coating quality and reduce the workload when constructing the bridge. As for fatigue, we are working to improve welding and the design to improve durability.

The other issue facing steel bridges is fatigue deterioration of RC slabs caused by increase of traffic loads. Recently, a minimum number of steel main girders are employed to reduce the workload of producing steel girders and durability is improved by using PC slabs.

Photo 2. RC Floor Slab/Multiple Main Girder   Photo 3. PC Floor Slab/Minimum Main Girder

(4)Hybrid structures. Conventional superstructures were classified as steel, PC and RC. But recently, hybrid structures appropriately combining concrete and steel members are being developed as a more rational method for building bridges. Corrugated steel web bridges with steel structure of concrete box girder web and steel truss web bridges are already employed as structures that reduce bridge weight, make pre-stressing more effective, rationalize construction and reduce costs.

Photo 4. Using corrugated steel web bridge
(AKABUCHIKAWA bridge in the new TOMEI exp.)

PRESENT CONDITION AND MAINTENANCE

Present health condition of bridges. With the number of aged bridges expected to increase in the future, NEXCO has carried out inspections, repairs and reinforcement appropriately, according to the degree of deformation or changes in the design standards, and has maintain an appropriate management level, while repeating trial and error.

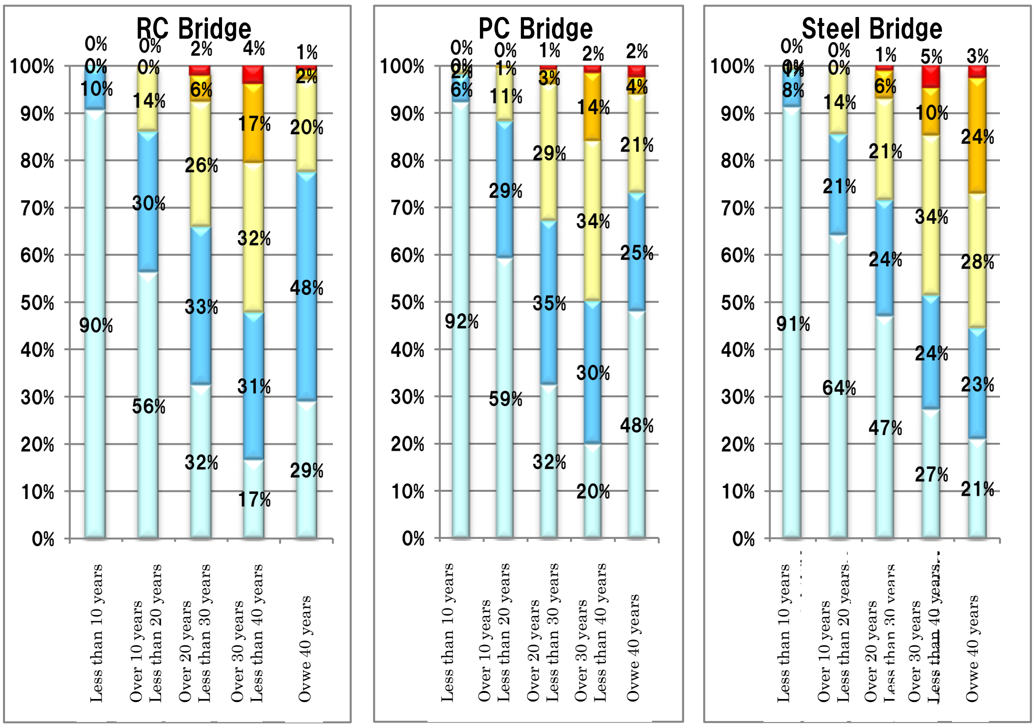
The situation of the deterioration of NEXCO's bridges is shown in figure 5.

NEXCO classifies the health of its existing bridges in five grades according to deformation levels to manage the bridges.

For bridges more than 30 years old, the proportion of bridges classified as deterioration grade or more, which require repairs, is increasing despite our earnest efforts to maintain them through repairs and reinforcements.

As the number of bridges in service for more than 30 years increases, we expect that the number of dilapidated bridges will increase at a faster tempo, which is causing concern.

Deterioration factors and statuses of bridges. Deterioration factors of expressway bridges vary, such as the geography, environment of usage or inherent factors at the time of construction.



(introductory notes)

Grade	Progress of deterioration	Performance of structure (e.g. load bearing capacity)
1	No problematic deterioration	No progress of deterioration
2	Minor deterioration	Deterioration progresses but no reduction in load bearing capacity
3	Deterioration occurs	Deterioration progresses considerably, and reduction in load bearing capacity demands monitoring
4	Large deterioration	Load bearing capacity decreases and required limit is likely to be reached
5	Critical deterioration	Load bearing capacity decreases to a serious level and there may arise safety concerns in the short run

Figure 5. Structural health condition of Bridge

The typical deterioration factors are shown in figure 6. De-icing salt is used commonly on Japanese expressways in winter. Consequently, salt damages to concrete and corrosion of steel structures are often observed.

Followings are typical deterioration factors and statuses.

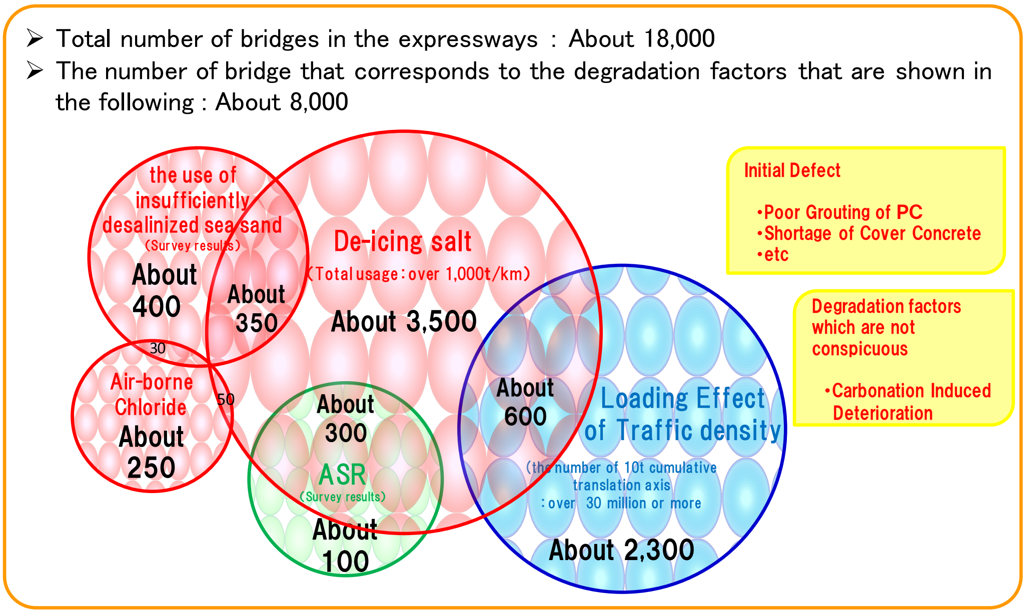


Figure 6. Deterioration factor of Bridge

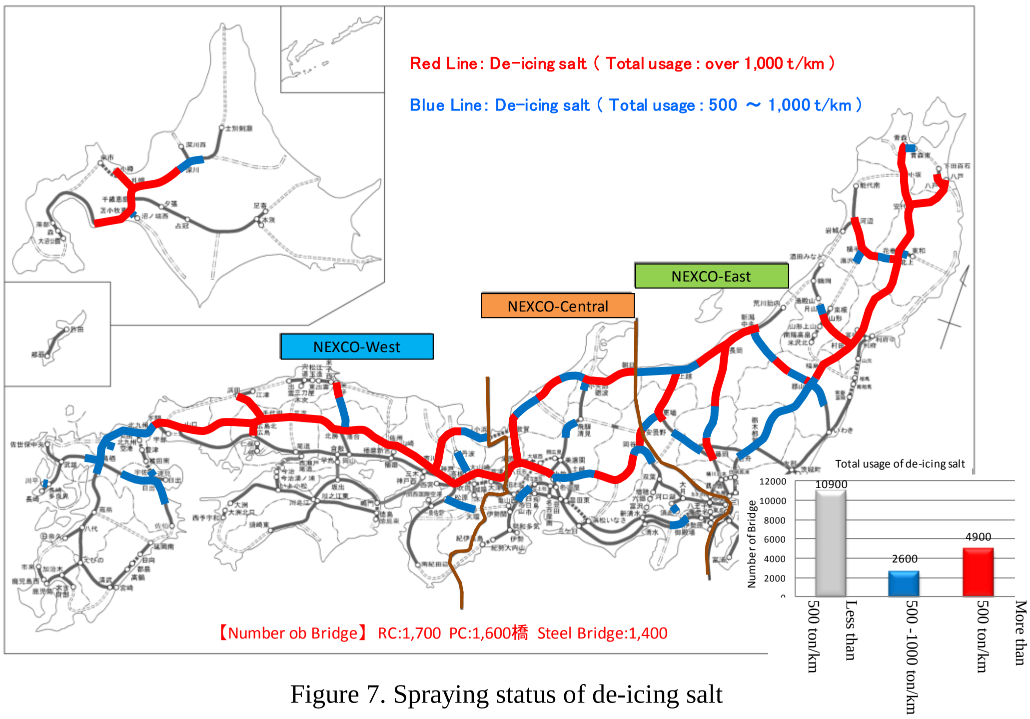


Figure 7. Spraying status of de-icing salt

(1)Geographical factors. Japan is surrounded by the Pacific Ocean and Japan Sea, and bridges near the coast are sprayed with sea water when typhoons hit or on windy rainy days during the monsoon season. This exposure to sea water cause salt damage to concrete and erosion of steel structures.

(2)Usage environment factors. The heavy volume of large vehicles on urban routes and the recent upsizing of vehicles synergistically cause deterioration by fatigue of floor slabs and steel members.

In addition to expressways in the northern and mountainous areas in Japan, many major routes connecting large cities pass through cold snowy districts. And, therefore, de-icing salt (Sodium Chloride: NaCl) are widely used to secure safety of the routes. This causes salt damages on concrete floor slabs and at the ends of girders, and also erosion of steel structures.

(3)Inherent factors at construction. In the 1970's, insufficiently desalinized sea sand was often used for fine aggregate due to the shortage of domestic concrete aggregate. As a result, salt damages caused by residual salinity are observed in concrete floor slabs of these concrete structures.

Aggregates inducing alkaline-silica reaction (ASR) are also found domestically. We have found that ASR caused by the reactive aggregate used is taking place in some concrete structures built before regulations for ASR were implemented.

Carbonation is found in most concrete structures as the structures age. But carbonation progresses faster under Japan's climate. Degradation caused by carbonation is noticeable at parts where there is little covering due to design standards or errors at construction.

Photo 5. Chloride induced deterioration (de-icing salt)

Photo 6. Degradation due to the use of insufficiently desalinized sea sand,

Photo 7. Alkali-aggregate reaction

Photo 8. Fatigue of RC floor Slab

Photo 9. Poor Grouting and broken PC bar of PC Bridge (Initial Defect)

Maintenance method. The maintenance method at NEXCO is as follows: the inspection plan is drafted, inspections are carried out, damages are assessed, examination and repair plans are drafted, and repair and reinforcement are carried out.

Inspection plans are drafted considering past inspection data and repair histories, and inspections are carry out at appropriate intervals and using methods to meet the purposes. The damaged condition is assessed and judged whether repairs are needed and the results are kept in the database. If it is decided that countermeasures are needed, necessary plans and designs are worked out, then site investigations, repair and reinforcements are carried out.

However, the maintenance procedure described above is for breakdown maintenance, which is carried out after damages occur. As the number of breakdowns is increasing, in recent years, appropriate inspections and repair/reinforcement works are becoming difficult to provide under current financial conditions and manpower shortages.

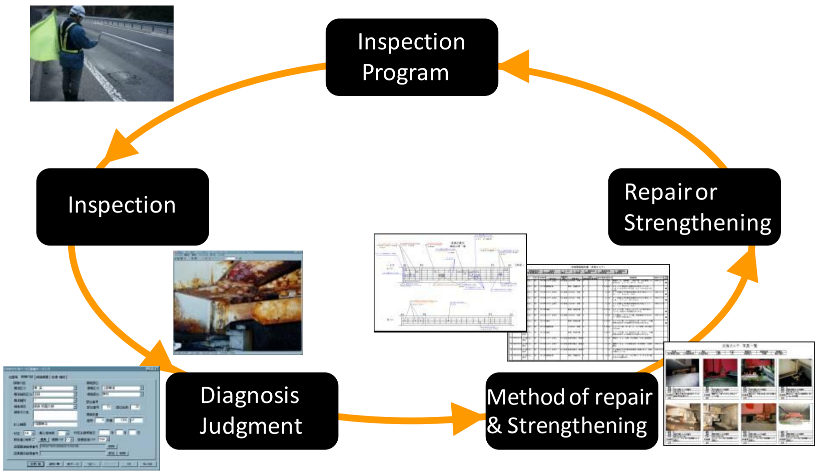


Figure 8. Maintenance Cycle of Expressways

Inspection and assessment. The purpose of bridge inspections is to ensure safety, prevent damages to third parties, and confirm the health to make sure that the structures can remain in service for a long time in good condition. Inspections are carried out according to the inspection plan, and appropriate measures are implemented after judging their functionality and safety (degree of influence on third parties) based on the damage data obtained through these inspections.
Followings describe inspections conducted by NEXCO.

Types of inspections. Inspections are classified as follows depending on the purpose.
(1)Daily inspection. An inspection is conducted daily by driving on the main carriageway and visually checking the structures or by the feel of the ride to confirm the safety of structures on a daily basis. These inspections are also for observing and carrying out simple diagnosis to confirm the functioning status of the structures so that changes in deformations may be grasped, daily.
(2)Periodic inspection. A yearly inspection is carried out per management district to grasp the current status of structural deterioration of expressways. The inspection is mainly carried out by telescopic observation from outside the main carriageway by checking the progress of aging and deterioration.
For structures with a less complicated damage mechanism, periodic inspections include detailed checks by observing from a close range or conducting hammering tests.
(3)Detailed inspection. The inspection is conducted on structures with relatively complicated damage mechanisms. An inspection includes detailed checks such as close-range observations and hammering tests. The inspection is conduced about every 5 years.
(4)Occasional inspection. This inspection is conducted irregularly to support daily inspections or when needed, such as in abnormal weather conditions.

Table 1. kind of inspection

	frequency	content
Routine inspection	Daily	Gross (on vehicle)
Regular inspection (gross)	Annual (all together)	Gross (by walk)
Regular inspection (detail)	About 5 years	detail
Temporary inspection	As needed	It depends


Photo 10. Regular inspection (Detail)

The results of inspection. Individual damages are classified into 5 grades: AA, A, B, C, and OK. The grades are determined according to the degree of the damage and the need for countermeasures. In addition, grade E is allocated to damages which are likely to inflict danger to third parties and need to be evaluated to decide whether measures are needed.

Data of the inspection such as the date, status of damage (including development diagram), judgment made and status of countermeasures are recorded in the "Inspection Data Control System," to be reflected in subsequent inspections.

Table 2. Inspection decision

grade		Assessment of function
A A		Serious damage and rapid maintenance
A		Rapid progress of damage and maintenance needed
	A1	When there are damages, and it is judged that influence on function decline is high
	A2	When there are damages, and it is judged that influence on function decline is low
B		Observation of progress of damage
C		Investigation needed to assess damage
O K		No or little damage

Health assessment. The purpose of conducting health assessments is to estimate the deterioration mechanism and progress of the deterioration through inspections and understand the health of bridge members. In the health assessment, structure sections and used materials are classified into types and the degrading mechanism, like salt damage or material fatigue, which affects the section or the material the most is specified. The health is assessed focusing on the required vehicle weight and usability of the structure.

Table 3. Deterioration grade and remedial measure

Grade	Progress of deterioration	Performance of structure (e.g. load bearing capacity)	Management range	Type of remedial
1	No problematic deterioration	No progress of deterioration	Standard control range	No remedial measures are taken.
2	Minor deterioration	Deterioration progresses but no reduction in load bearing capacity		Preventive maintenance
3	Deterioration occurs	Deterioration progresses considerably, and reduction in load bearing capacity demands monitoring	Control range	Repair or retrofit
4	Large deterioration	Load bearing capacity decreases and required limit is likely to be reached	Management limit	Retrofit
5	Critical deterioration	Load bearing capacity decreases to a serious level and there may arise safety concerns in the short run	Management limit is exceeded.	Large-scale remedial measures

Repair and reinforcement. Followings are descriptions of major repairs and reinforcements carried out by NEXCO on damages of concrete structures confirmed by inspections and investigations. Depending on the damage types and aims of the countermeasures, multiple combinations of repair and reinforcement methods are carried out.

(1)Crack Injection. To prevent degradation or erosion of concrete or steel bars, coating, injection and filler materials are injected into cracks in order to prevent air and water from penetrating into the concrete.

(2)Repair method of cross section. After removing the damaged part, such as peeling sections on existing concrete, caused by corrosion of steel bars, the durability of structures is restored by using restorative materials for cross sections like concrete or polymer cement mortar. The water-jet method which has less impact on the existing concrete and steel bars and matches well with the restorative material is used as the standard method to remove the damaged parts.

(3)Catholic Protection Method. When corrosion of steel members, such as steel bars, is considered serious and other preventive measures are thought to be ineffective, corrosion can be controlled electrochemically by applying electric current directly on the steel member in the concrete. There are two catholic protection methods, the external power supply method and the galvanic anode method.

Both methods require continuous maintenance work to maintain the power supply device and exchange consumable materials.

(4)Increasing the thickness of upper deck. Load resistance can be improved by adding reinforced or steel fiber reinforced concrete on the top face of the existing concrete to thicken and integrating the works. NEXCO has many experiences in this method for reinforcing RC slabs of steel bridges, but the works require time to construct and it is necessary to regulate the traffic for a selected time period.

(5)Continuous fiber sheet. Load resistance of concrete materials can be improved by gluing a sheet of carbon or aramid fiber using epoxy-resin adhesive on the face where stress is applied and integrating the works. Fiber sheets are light, have good workability, and effective in strengthening various parts.

(6)Using pre-stress for girder. Load resistance of concrete materials can be improved by placing additional outer cable tensioning materials on concrete members and introducing pre-stress. Generally, PC steel is used as tensioning materials, but recently, carbon fiber plates are used in some cases.

(7)Replacement of members. When the deterioration of concrete is serious and other repair and reinforcement works are likely unable to sufficiently maintain the health of the concrete, the whole deteriorated member is removed and replaced with a new member. NEXCO is replacing noticeable deteriorated steel bridge PC slabs with highly durable PC slabs.

Photo 11. Chipping with the water-jet

Photo 12. Patching or Increasing thickness by Shotcrete

Photo 13. Floor slab overlaying

Photo 14. Replacement floor slab

THE FUTURE OF EXPRESSWAY MAINTENSANCE (BMS)

Background of NEXCO's BMS. In order to maintain the health of aging bridges, which are expected to increase rapidly in the near future, with limited manpower and financial resources, it is necessary to extend the life of bridges through repairs and reinforcements by leveling the work and carrying out minimum work necessary. NEXCO is tackling this issue by managing bridges based on the concept of asset management to carry out future bridge maintenance rationally and efficiently. Under this concept, we have transitioned the focus of our operations from breakdown maintenance to preventive maintenance. Preventive maintenance aims to prevent damages from progressing and becoming notable so that the performance of structures does not deteriorate. Through preventive maintenance, we can expect to lower the risk of deformation and life-cycle-cost (LCC).
Massive amounts of data and various simulations need to be conducted to work out a maintenance scheme based on asset management for all bridges. To counter this issue, NEXCO has developed and is operating a bridge management system (BMS) that supports planning and carrying out preventive maintenance.

Outline of NEXCO-BMS. As shown in figure 9, the BMS applies bridge specifications and inspection data to evaluate the health of each member and calculate the needed cost, which will be used to work out maintenance plans.

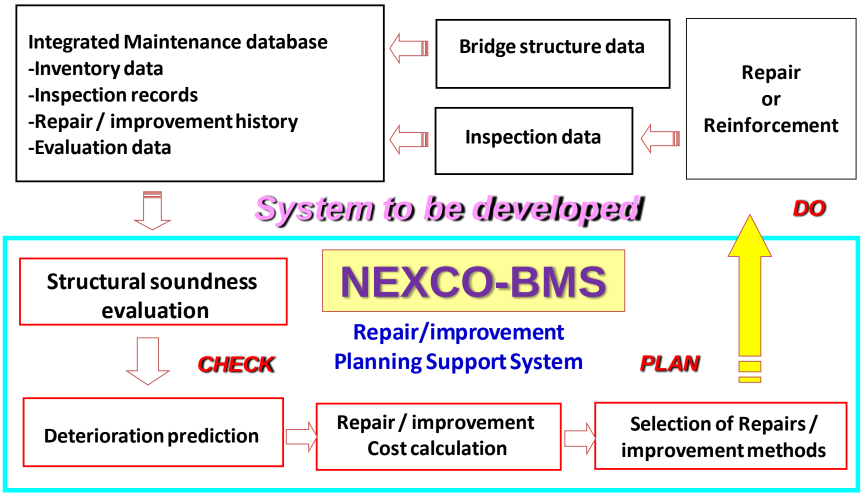


Figure 9. Component of NEXCO-BMS

(1)Forecasting deterioration. Future deterioration for each member is predicted by studying the health data collected at inspections, estimated deterioration mechanism, member specifications and the environment which it is placed. Theoretical formula derived from experiments and health status evaluations, as shown in figure 3-2, are statistically analyzed to decide the method for forecasting deterioration for each deterioration mechanism, such as neutralization and fatigue.

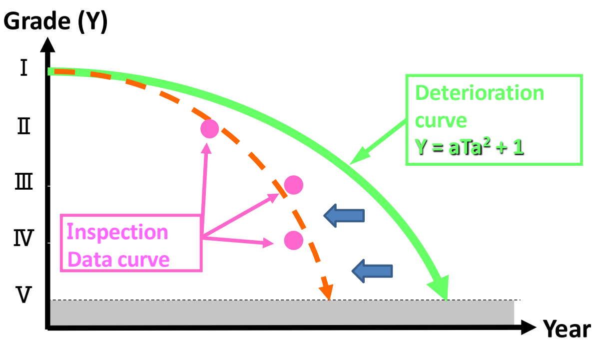


Figure 10. Deterioration Curve through Regression Analysis

(2)Calculating costs of repair/reinforcement. Cost calculations are made after selecting the best time and method to carry out maintenance based on maintenance management scenarios worked out applying deterioration predictions estimated for each member. The maintenance costs needed for each member throughout its service years are added up per unit (i.e., bridge, route, and jurisdiction) to forecast maintenance costs needed in the future.

(3)Utilizing BMS in maintenance. As an example of maintenance plans created using BMS, comparisons of LCC between existing interchanges are also possible. In this way, preventive and breakdown maintenance scenarios may be worked out by comparing LCC, or by incorporating maintenance schedules and methods calculated by BMS.

Optimization of maintenance and repair methods. Preventive maintenance is needed to guard against future damages. If inspections find lowered structural functions or deterioration that may inflict damages to third parties, emergency measures will be taken, if needed, or monitoring and detailed inspections will be carried out. And after that, at an appropriate time, the structure will be repaired and reinforced to improve the function using effective methods. Followings are examples of NEXCO's repair and reinforcement methods to prolong the life of structures.

Waterproofing for deck slabs. Waterproofing of slabs aims to prevent water and salt, which are deteriorative factors that lower performance, from penetrating the slab and improve the durability by preventing dilapidation before it occurs. After the revision of standards in 1998, NEXCO has decided to carry out waterproofing on all existing and newly built bridges. And therefore, waterproofing works are currently being carried out on all existing bridges, successively.
After the revision of standards in 2011, high-performance waterproofing for slab which can maintain the service life for longer periods has become the standard. In many cases, waterproofing is done using asphalt sheets or by blowing on urethane resin.

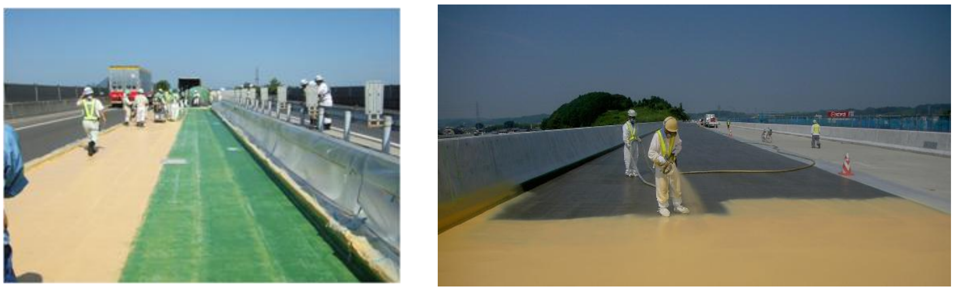


Photo 15. Laying waterproofing

Surface Protection of Concrete Structures. To protect concrete, a protective layer is placed on the face of the concrete structure by applying synthetic resin or polymer cement paint. The protective layer is placed to prevent deteriorative factors, such as carbon dioxide and salt, from permeating concrete and thus improve durability of the structures.
Protective layers are placed basically at the ends of concrete girders, and bridge pier and abutment crowns where future deterioration caused by de-icing salt is anticipated. Recently, surface penetrate materials are coated for further protection from salt damages.

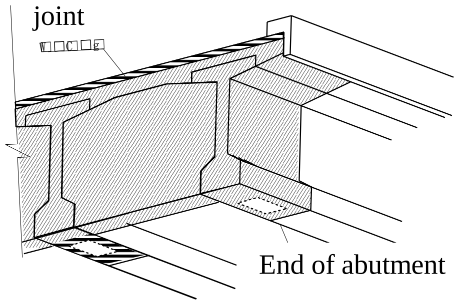


Figure 10. Outline of surface protection methods

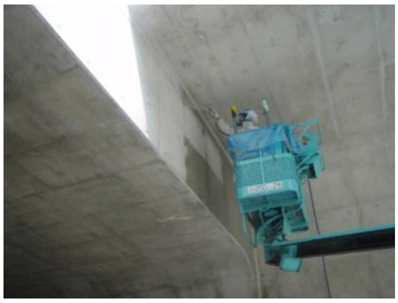


Photo 16. Concrete surface protecting

SUMMARRY

This paper describes the current status and maintenance operations of expressways (mainly of concrete structures) in Japan.

It is expected that aging of the structures will further progress and inspection frequency and the number of structures which need to be repaired or reinforced will increase in the future, increasing maintenance costs. It will, therefore, be necessary to upgrade inspection, repair and reinforcement technologies, and work out maintenance schedules for preventive maintenance, including the rebuilding of bridges, planned based on the concept of asset management and in consideration of LCC.

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