GREATER SOPHISTICATION IN EVALUATION METHODS FOR INSPECTIONS OF THE HANSHIN EXPRESSWAY

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Abstract

The regular inspections of Hanshin expressway are conducted every five to eight years. Since the restrictions on budgets for maintenance are becoming more stringent, better, more efficient and effective maintenance methods are essential. Thus, we began work on a new generation inspection strategy. The more efficient inspections are required to more directly reflect the structural risk and more directly evaluate the structural soundness of expressway structures. In this study, the structural risk is studied by analyzing the damage occurrence rates of our Hanshin expressway structures, providing the basis for a proposal for more rationalized inspection intervals based directly on the structural risks. This study also develops a structural soundness evaluation method that analyzes the magnitude of the impact of damage on the overall road structure. The magnitude of the impact on the structure from the damage is expressed by integrating the evaluations of both deterioration speed of damage and the member redundancy of the structure. This paper presents the final proposal for the new inspection methods and evaluation for expressway structures.

Introduction

Inspection plays a key role in management of expressway structures, thus efficient, effective inspections despite restricted budget conditions are essential to sustainable management of such key and important infrastructure. Hanshin Expressway, serving as the primary expressway network in Osaka, Kobe, and the Kyoto metropolitan area in Japan, requires basic inspections of structures on a cycle of 5 to 8 years, using visual inspection at arm-length, to assesses the structural condition and repair needs in accord with the magnitude of damage. However, more efficient and effective maintenance procedures and methods are must be found to meet the needs of maintenance budget restrictions, thus building a new generation inspection strategy is demanded.

Currently, the greater part of the inspections is carried out in a process based scheduling. The inspections are usually conducted under the specified rules, regardless of the infrastructure's structural condition. In light of the structural soundness of the structure, the inspection methods and frequency should take into consideration, both the structural condition and characteristics of damage. This means the inspection required in current situation should be established more on the basis of risk, or perhaps we can say "performance" based.

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The damage detected by such inspections is currently categorized and defined according to the magnitude of the damage. But damage to critical members must be carefully annotated against future deterioration and is required to be repaired within a short time, whereas in non-structural members can be temporarily neglected in favour of more urgent repair work. This means, damage should be assessed considering not only the damage magnitude but also the speed of deterioration and the importance of the structural components being examined.

Moreover, recent inspections focus only on the inspection work. However, an arm's length inspection affords good opportunity for not only close inspections but also to take interim or other counter measures against damage detected. Appropriate temporary measures against further damage will contribute to prolonging the service life of the structure.

In this study, a new generation of inspection system is outlined. The system consists of a combination of multi-inspection strategies for improving inspection effectiveness , the new damage assessments that consider structural soundness, and the temporary or interim treatment measures to prevent rapid further deterioration .

This paper introduces the new generation of inspection system, so-called "Risk-based Inspection, Assessment, and Countermeasure Method" for the Hanshin Expressway.

Current inspection practices in Japan and throughout the world

The bridge inspection processes for the Hanshin Expressway structures include daily inspections, regular inspections, initial inspections, and special inspections. The major inspections among these are the daily and regular inspections. The daily inspection is a visual inspection from a distance intended to prevent damage to third parties. The regular inspection is a visual inspection periodically conducted at arm's length in order to identify damage, to evaluate the impact on the structure, and to draft plans for repair works.

The Hanshin Expressway is an urban expressway network constructed in a metropolitan area with high population density. The major concern of maintenance procedures is to preclude any impact on third party due to damage. Therefore, the inspection is carried out with the emphasis on daily inspections.

Table 1 shows the inspection and its evaluation method as used by the major expressway and rail road companies in Japan. The notable features of the inspections as conducted by Hanshin Expressway are:

1. The frequency of the daily inspections is rather high compared to those performed at other organizations.
2. The regular full inspection performed on a cycle of 5 to 8 years considers the state of the structure and broadens the inspection scope to include the bearings and their surroundings.

The inspection results are evaluated according to the magnitude of the damage, not the repair need.

Table 2 shows the inspection and its evaluation methods as adapted to the national

expressways in listed countries. The inspection and evaluation methods can be summarized as follows;

1. The regular inspections are performed every five to six years in major European countries. But in France and Finland, regular inspections are carried out over wider intervals, by considering the robustness of the structure and damage state.
2. The IQOA (Image de la Qualities des Outraged d'Art) inspection that is adopted in France is a kind of review process conducted every three years based on results of the regular inspection by inspector or certified engineer. This is an inspection to complement the regular inspection which has a wider interval.
3. The USA widely employs damage magnitude for the inspection evaluation index. Finland evaluates inspection results according to the repair need of the damage. France evaluates the inspection result not only by the magnitude of the damage but also to impacts on durability, impact to the landscape and so on.

Table 1. Inspection and evaluation methods adopted by Japan's major expressway and railway companies

		Hanshin Expressway	Metropolitan Expressway	NEXCO West	West Japan Railway
Daily inspections	Daily inspection （visual inspection from far site）	6 times / year	Twice / year	2 to 4 times / year	-
	Inspection using suspended path	Twice / year	-	Once / year	-
Regular inspections	Regular inspection （visual inspection at arm's length）	Every 5 to 8 years	Every 5 years	Every 5 years	Every 2 years
	Regular inspection only for bearings and its surroundings （ visualinpsection at arm's length）	Intermediate year	—	—	—
Inspection evaluation method		Magnitude of the damage	Repair need	Repair need	Repair need

Table 2. Inspection and Evaluation Methods Used for national expressways of major countries

	Hanshin Expressway	USA	France	Finland
Daily inspection （Visual inspection from far site）	6 times / year	Every 2 years	Every year	Every year
Regular inspection （Visual inspection at arm's length）	Every 5 to 8 years	Every 10 years	Every 1 to 9 years Very ill bridge every 1 to 3 years Regular bridge every 6 years Redundant bridge every 9 years IQOA inspection Every 3 years	Every 4 to 8 years Regular bridge every 5 years Long span bridge every 8 years
Inspection evaluation method	Magnitude of damage	Magnitude of damage	Magnitude of damage, durability, impact to the landscape, etc	Repair need

Recent Deterioration Characteristics of Expressway Structures

In order to study what constitutes an efficient, effective inspection strategy, it is necessary to investigate the deterioration characteristics of the expressway.

Generally, deterioration characteristics are investigated by analyzing the inspection results over a set time range; the characteristics are expressed by the deterioration speed or the detection rates of the damage. However, it is known that damage changes with time in terms of its type, extent, detection rate and progression over time. Therefore, an efficient and effective inspection strategy for expressways cannot be established without performing an analysis on the trends of damage characteristics in the past and present.

In this paper, to investigate the damage characteristics of the expressway, the data analysis was performed utilizing the inspection result database of the Hanshin Expressway which extends over a period of about 25 years.

The periodic inspection of the Hanshin Expressway conducted at approximate intervals of five years assesses the results into five categories. These are S: urgent repair need, A: repair need, B: observation, C: minor, and finally, OK: no damage.

"S" ranked damages urgently require repair.

"A" ranked damages should be repaired as soon as feasible.

However, some "A" ranked damage was held over because it was later judged to have no need of repair after closer investigations at the repair planning phase, even though they were judged as requiring repairs in the inspection assessment phase. The end result is:

"A" ranked damage tends to accumulate.

Therefore, this study particularly reviewed, the "A" ranked damage deteriorated from lower ranked damage using 25 years of inspection result database of Hanshin expressway.

Figures 1, 2 and 3 show the annual detection rates of the actual "A" ranked damage in the pre-stressed concrete viaducts, reinforced concrete viaducts, reinforced concrete piers, and in pier structures such as bearings.

The analysis was performed for each, separate expressway route.

The horizontal axis is years in AD, rather than years of operations of the structure in service.

This reason is, it is widely accepted that annual damage occurrence is strongly related to structural designs and years in service.

Comparing the Figure 1 and 2, a major difference can be observed difference in deterioration characteristics.

Figure 2 shows that the annual detection rate of "A" ranked damage for reinforced concrete girders monotonously increases with time whereas Figure 1 shows that that of the pre-stressed concrete viaducts decreased with time in the 1990's, showing minimum value around 2000, then again recently increasing. .

This indicates that the damage of the pre-stressed concrete viaduct, when still of young service age, was related to construction defects,, such as insufficient grouting for cables or insufficient sheath cover depth.

Then those damages disappeared with the completion of appropriate repairs, and

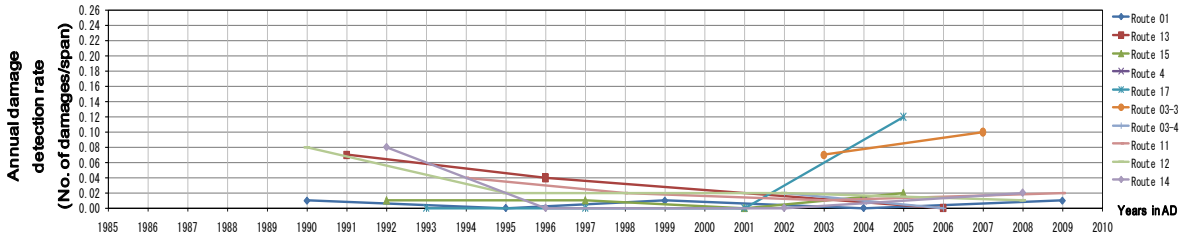

Figure 1. Annual damage detection rate of pre-stressed concrete viaducts

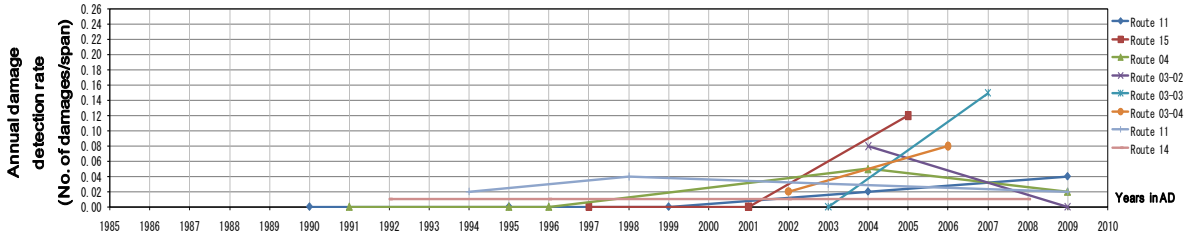

Figure 2. Annual damage detection rate of reinforced concrete viaducts

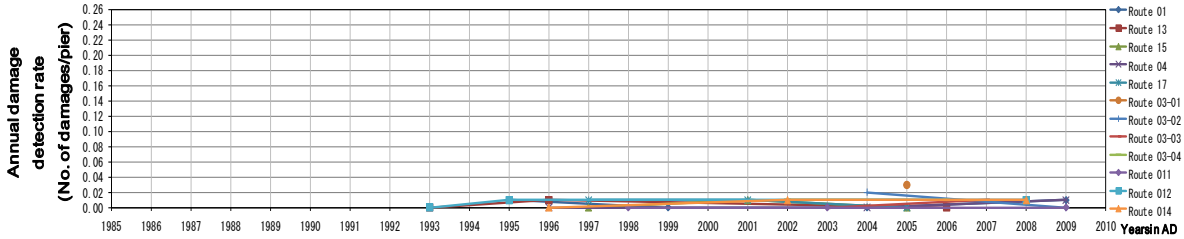

Figure 3. Annual damage detection rate of reinforced concrete piers

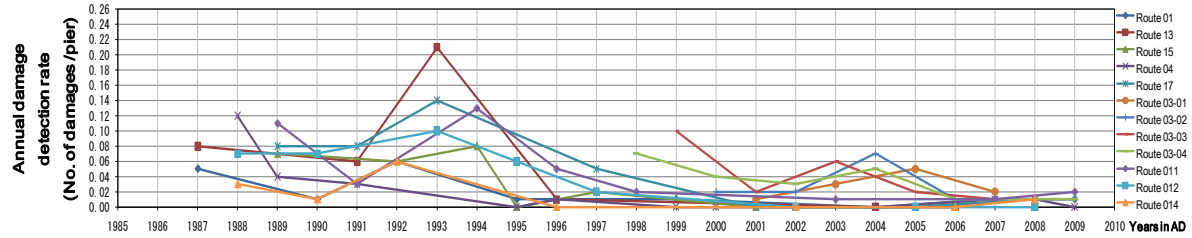

Figure 4 Annual damage detection rates of structures on the piers (Bearings)

came to the presumed increased at repair areas due to deterioration of repair materials.

This trend is known as a bathtub curve in the field of mechanical engineering, and this well-known curve was also observed in expressway structures.

Figure 3 shows the deterioration of the expressway piers have not bee severe so far. On the other hand, Figure 4 shows a different deterioration trend compared to Figure 1, 2, and 3.

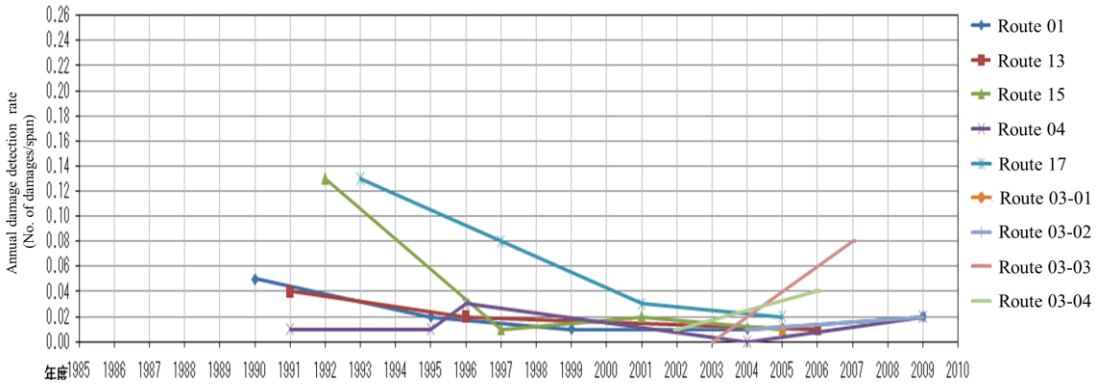

Figure 5 Annual damage detection rates of structures on steel girders

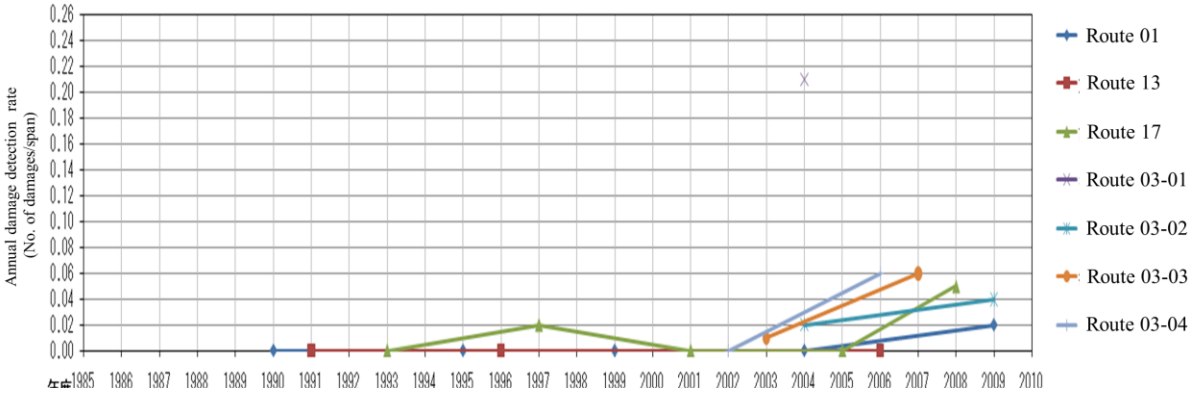

Figure 6 Annual damage detection rates of fatigue cracks in steel deck plates

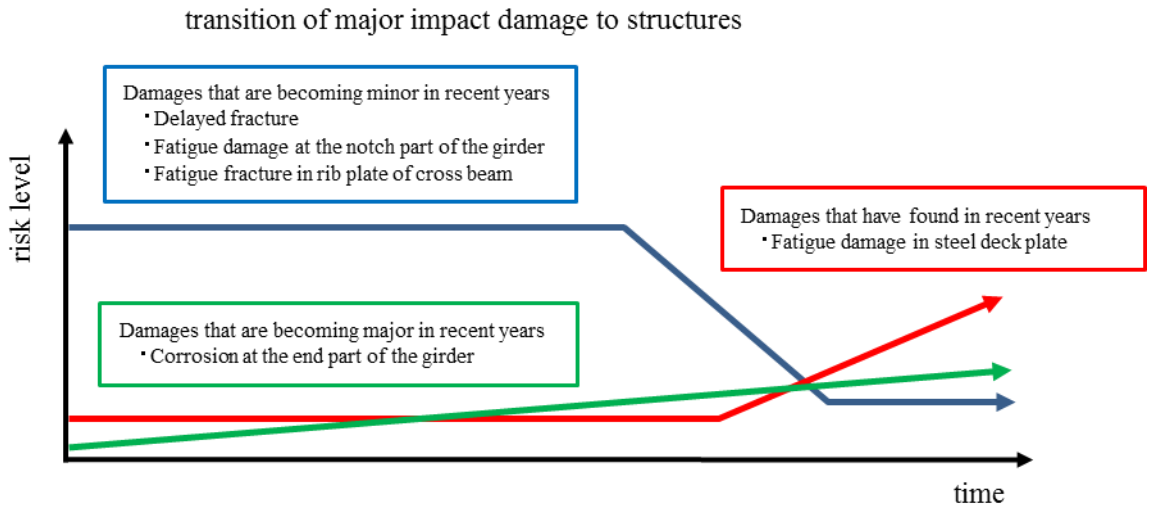

Figure 7. Image of the transition of major impact damage to structures in the Hanshin Expressway

Figure 4 shows the annual detection rate of "A" ranked damage to the structures located on the pier, such as bearings, of concrete as well as steel viaducts.

According to Figure 4, the deterioration trend shows a monotonous decrease with time that is different from the bathtub curve or the monotonic increase curve.

Also, it can be seen in Figures 1, 2, 3, and 4, that the annual occurrence rate for damage to bearings was much greater than for the rate of damage to girders in 1990s, although, , it is almost the same rate as those in 2000s.

Figure 5 shows the annual detection rate of "A" ranked damage to the steel girders. In the 1990's, extensive fatigue damage at the notch part of the girder or in the rib plate of cross beams was found due to immature design specifications. However, these damages are considered as to be initial defects. Retrofit work have been performed ; therefore, those damages have shown a tendancy to decrease recently. On the other hand, corrosion at the end part of the girder has appeared as more of a a major defect in steel girder due to water leakage from expansion joints.

Figure 6 shows the detection rate of recently found damage such as fatigue in steel deck plate. Those damages are becoming major issues in the Hanshin Expressway.

Figure 7 summarized the tendency of the damages detected in Hanshin expressway. According to Figure 7, it can be recognized that the damages to the Hanshin expressway have been changed over time.

1. Damages becoming less significant in recent years

   Damage due to insufficient grouting of pre-stressed concrete bridges, insufficient cover depth over steel bars in concrete structures, fatigue cracks at the notch part of girders or in rib plate of cross beam were found in 1980 – 1990's. Those damages were considered a kind of initial defects due to the immature design specifications in those days. Retrofit works have been performed so far; therefore, those damages tend to decrease recently.

2. Damages becoming major in recent years

   Damages such as corrosion at the end of girders have been becoming major defects in steel girder due to water leakage from expansion joints. Those damages have been detected since the commencement of service life, but these damages are not completely repaired so far.

3. Damages found in recent years

   Damages such as fatigue damage in steel deck plate. Those damages are quickly becoming major defects in Hanshin expressway.

Risk based effective, efficient inspection strategy

In a situation where the expressways are experiencing steadily progressing deterioration , the inspection plays a more important role in maintenance strategy. On the

other hand, the reduction of the maintenance budget was correlated to reduction of traffic as the result of economic recession.

Therefore, it is necessary to implement a more rational and more efficient inspection strategy into maintenance practices.

The Hanshin Expressway, taking into account the high detection rate of the damage to the structure on the piers, had been conducted intermediate inspections in the middle of five-year cycle of periodic inspections.

However, according to Figure 4, the average damage detection rate recently dropped compared to the 1990s, the current damage occurrence rate shows that the intermediate inspection focused on the structures on the piers currently becomes much less important.

Based on the above analysis and also the same analysis to the steel structures,

Table 3. New Inspection Strategy

	Periodic Inspection	
	Regular Inspection	Intermediate Inspection
Current Inspection Strategy	All structures Every 5 years (In arm length)	Structures on the pier (Bearings) Middle year in between regular inspection
New Inspection strategy	All structures Every 5 years (In arm length)	Repeatedly deteriorating structures Middle year in between regular inspection

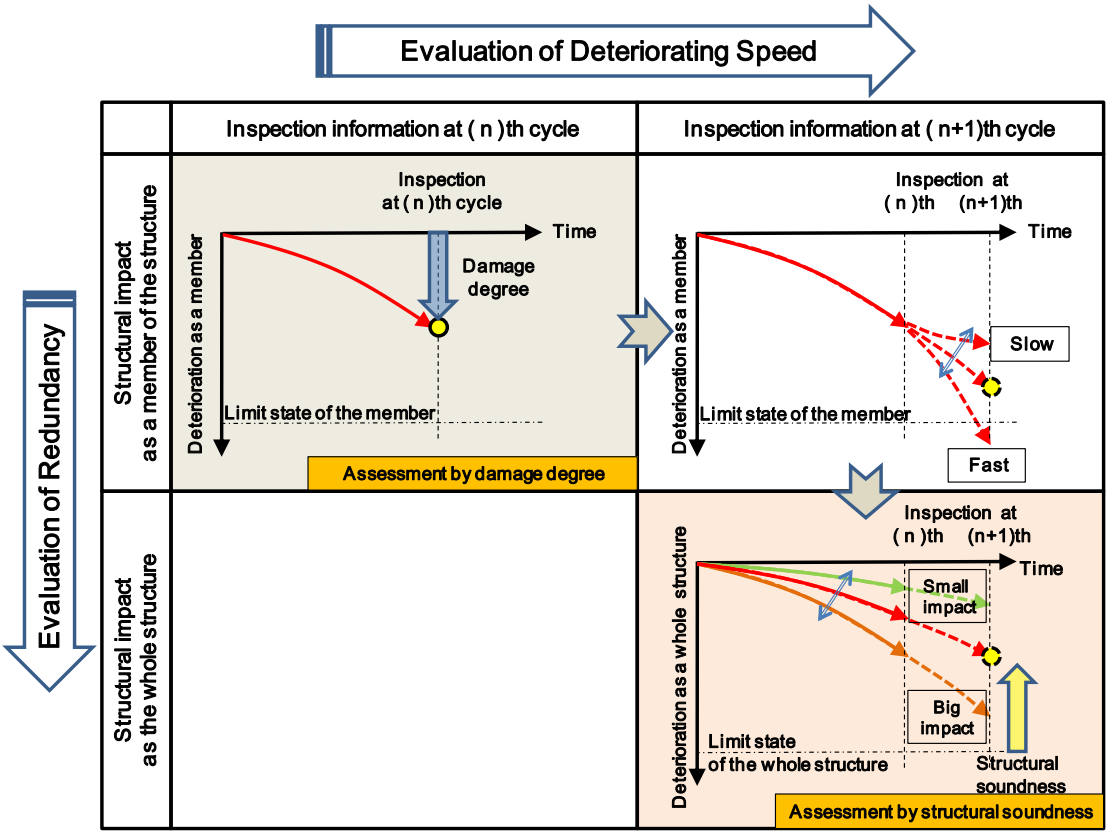

Figure 8. Concept of new inspection assessment with structural soundness

The frequency of periodic inspection is continuously performed in five-year cycle, but the intermediate inspection to the structures the piers such as bearings was discontinued.

Instead of this, a new intermediate inspection is established to inspect repeatedly damage structures that "must always be carefully observed".

Thus, without increasing the costs of inspection, inspection techniques could be an efficient and effective.

The new inspection strategy is summarized in Table 3.

Structural soundness assessment strategy

The assessment of damage to the structures is made by engineers to judge the repair needs by inspection data.

The damage assessment method is generally documented as inspection assessment manual as damage level basis.

However, such damage degree based assessment method sometimes assess the damage as repair needed without diagnosing the structural importance or damage deteriorating speed.

Therefore, the damage being repaired becomes accumulated and a lot of such not repaired stock confuses the current maintenance work.

In the assessment process, skilled engineers assess the damage considering the redundancy of the damaged structural component (importance), the deterioration speed, and the damage level itself.

The throughout process from inspection to repair will work properly by implementing such damage assessment process of those skilled engineers.

In other words, the inspection assessment process should be shift from the basis of "degree of damage" to the basis of "structural soundness".

Figure 8 shows the concept of the inspection assessment based on "structural soundness".

The conventional inspection assessment used to be based on the degree of the damage at the inspection; however, the new inspection assessment method is based on whether the structural soundness by the next inspection time and the estimated state of the damage then can be acceptable in the meaning of performing effective and efficient maintenance of the structure.

	Damage degree	Evaluation of deterioration speed	Evaluation of Redundancy	Overall Assessment by Experts
	A (=Repair) By conventional way	High	Big impact	A (Repair)
		Intermediate	Intermediate	B (Observation)
		Low	Small impact	C (Minor)
		No	No	OK
	A (=Repair) By conventional way	High	Big impact	A (Repair)
		Intermediate	Intermediate	B (Observation)
		Low	Small impact	C (Minor)
		No	No	OK

Figure9. Sample of inspection assessment survey sheet

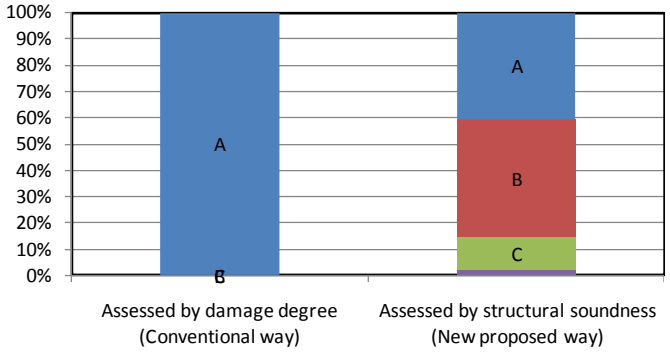

Figure 10. Comparison of conventional inspection result and assessment result by experts

In order to perform effective and efficient inspection, the assessment based on idea of "deterioration speed" and "redundancy" should be taken into account.

The "deterioration speed" is an index how close the damage will reach the limit state in the meaning of maintenance by the next inspection.

The "Redundancy" is an index how the damage will affect to entire structural stability when the damage reaches the maintenance limit state.

In order to confirm the applicability of this new inspection assessment method, the assessment questionnaire asking the inspection assessment, anticipated deterioration speed, and structural affection due to the damage individually was conducted to the maintenance engineers of Hanshin expressway; management hierarchy, engineering hierarchy, and inspecting hierarchy.

The purpose of this survey was to make it clear whether the judgement of skilled engineers can be simulated by the new concept of assessment method or not.

In the survey, each engineer assessed the samples of the damages as shown in Figure 9 by following three ways;

1) Degree of damage in accordance with the conventional method
2) Degree of structural soundness as the result of an expert engineer
3) Estimated deterioration speed and redundancy of the damage

Figure 10 shows the result of the questionnaire.

About 60% of the "A" ranked damages that were assessed as the damage that need repair in accordance with the conventional assessment based on damage degree were judged as no need of repair in the result of the skilled engineer considering structural soundness.

The result of the combination assessment of damage state, deterioration speed, and redundancy of the damages as shown in Figure 11 and 12 revealed that the combination assessment results nearly coincide with the result in terms of structural soundness by the expert.

Therefore, it was found to perform similar inspections as skilled engineers by performing combination assessment damage state, deterioration speed, and redundancy of the damages.

Inspection counter measures to damages

The new damage assessment method will allow more efficient and effective maintenance; however, remaining, untreated damage will accumulate in future.

In order to treat those minor untreated damages and prevent deterioration of them, quick and light measures will be introduced and conducted during the inspection.

Periodic inspection of the Hanshin Expressway has been carried out in five year cycle in arms length.

This is to perform more precise and detailed inspection; in other words, this is also a great opportunity to do repairs.

Evaluation of Deterioration Speed		Evaluation of Redundancy: Big impact		Intermediate		Small impact		No	
High	A	12.9%	A	7.5%	A	0.9%	A	0.4%
	B	0.4%	B	4.4%	B	1.6%	B	0.0%
	C	0.0%	C	0.1%	C	0.3%	C	0.0%
	OK	0.0%	OK	0.0%	OK	0.0%	OK	0.0%
Intermediate	A	7.8%	A	6.5%	A	0.3%	A	0.0%
	B	1.8%	B	19.6%	B	2.1%	B	0.0%
	C	0.1%	C	0.7%	C	1.4%	C	0.0%
	OK	0.0%	OK	0.0%	OK	0.1%	OK	0.0%
Low	A	1.6%	A	2.0%	A	0.3%	A	0.0%
	B	1.7%	B	9.4%	B	3.1%	B	0.0%
	C	0.3%	C	1.9%	C	6.2%	C	0.3%
	OK	0.0%	OK	0.0%	OK	0.6%	OK	0.2%
No	A	0.3%	A	0.2%	A	0.0%	A	0.0%
	B	0.1%	B	0.7%	B	0.1%	B	0.0%
	C	0.0%	C	0.1%	C	0.8%	C	0.2%
	OK	0.0%	OK	0.0%	OK	0.2%	OK	0.8%

[Legend]

Insepection assessemnt by experts: A B C OK

Inspection assesemnt by new method: A B C OK

Figure 11. Inspection assessment result by the experts and the new method

Inspection assessment by experts	Inspection assessment by proposed method: A	B	C	OK
A	28.2% (69.5%)	11.2% (27.6%)	0.3% (0.7%)	0.9% (2.2%)
B	6.6% (14.6%)	34.3% (76.6%)	3.1% (6.8%)	0.9% (2.0%)
C	0.2% (1.6%)	4.6% (37.0%)	6.2% (50.4%)	1.4% (11.1%)
OK	0.0% (1.9%)	0.2% (7.5%)	0.6% (28.8%)	1.3% (61.8%)

[Legend]

Insepection assessemnt by experts: A B C OK

Inspection assesemnt by new method: A B C OK

Figuer 12. Effectiveness of the new method by comparing between experts and the new method

Figure 13. Quick, non-intensive countermeasures for damage taken during inspections

Some damage can be repaired with the simple equipment at inspections.

By this countermeasure works during inspection, it is possible to maintain more effective and efficient maintenance.

The Hanshin Expressway has implemented the following measures during inspection.

Figure 13 shows the sample photos of the quick and light countermeasures for the damage during inspection.

1) Measures against rust on exposed steel bars (Shown in Figure 13)
2) Measures against cracks in concrete surfaces
3) Measures to prevent for rubber bearings from ozone degradation

Conclusions

This paper studied a risk-based effective and efficient inspection strategy for expressway structures.

The following conclusions were obtained in this study.

1) The damage seen in the expressway changes with time in terms of type, occurrence rate and progression.There was considerable damage related to initial defects in the early service days of structures ,but currently much real deterioration can be seen in the structures according to the data analysis of the Hanshin expressway.
2) Intermediate inspection should be conducted to the structures or members that must always be carefully observed according to the data analysis not to the structures on the expressway piers such as bearings as used to be.
3) A new inspection assessment method is developed and the result by the new method is quite effective in the point that the assessment result is almost the same as those by the experts.
4) It is quite effective to take countermeasures against damage at the site in the course of inspections.

5) Finally, this study proposes a new inspection method consisting of the multi-tiered inspection strategy for improving effectiveness of the inspection, the new damage assessment considering the health condition of the structures, and the temporary treatment measures for preventing rapid deterioration of the damages.

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