STUDY FOR SECURING SOUNDNESS OF PC STRUCTURES
- Approach to Establish Method of Applying Nondestructive Inspection for Advanced Management of Highway Structures -

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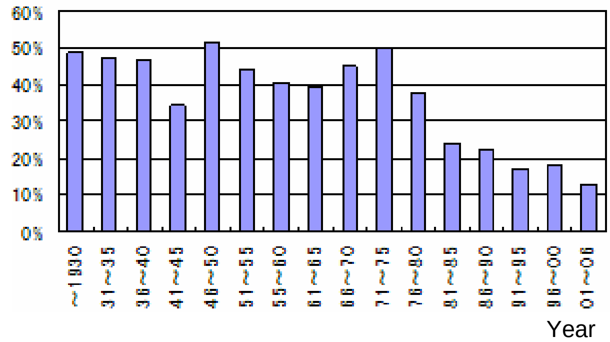
Abstract

In order to prevent accidents and serious damages by sophisticating maintenance of highway bridges, it is an urgent issue how to grasp damage and its influence rationally in areas where it is difficult to find it by current visual inspection for bridges that are aging gradually.

In this report, concept in terms of methodology of addressing the issue is described with studies to address damage of PC structures by decrease of prestress as example.

1. Introduction

Road network has been developed in Japan from around the high economic growth period. Presently there are approximately 150,000 road bridges above 15m in length. Due to aging of them, the rate of road bridges over 50 years or more, which is about 6% currently, will increase rapidly and be estimated at 50% approximately 20 years later. Figure1 shows the rate of bridges which needs early repair or another measure in respective ages that was estimated from the result of the major routine inspection for highway bridges managed by the national government. It clearly indicates the correlation of damage occurrence with age despite the cause of occurrence and propagation of deterioration are complex, which depend on its structure, environment and other matters.



Source: Survey by NILIM

*Rate of bridges by age for which repair of main members has been determined to be necessary as a result of the major routine inspection of national highways managed by the national government.

Figure1 Rate of bridges which need early repairs in ages

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For these bridges managed by the national government, the routine inspection is applied in every 5 years to evaluate condition and determine necessity of repairs, urgent repairs and other actions. However it is difficult to inspect condition of areas which they cannot see, such as inside of structures, underwater or underground, because the main method in the current routine inspection is close visual inspection.

As a correspondence to that, NILIM implement approaches to sophisticate bridge management by better utilization of nondestructive inspection techniques and promotion of development of them. In this report, in terms of approaches to address difficulties on maintenance of PC structures as example, methodology of better utilization of nondestructive inspection techniques and approach to clarify requirement to them, which would be the target for development of techniques, are described.

2. Difficulties on Highway Bridge Inspection

As method of grasping decrease of soundness and/or abnormalities of highway bridges, which are complicated and huge structure in general, visual inspection is usually adopted. It is currently the most efficient and reasonable method to visually inspect abnormalities, which are related to damage characteristics, by inspectors who have enough experience and knowledge.

On the other hand, it is required that abnormalities should be detected more efficiently and earlier and preventive maintenance should be applied due to increase and aging of stock and limitation of both quality and quantity of engineers and technicians who engage in maintenance of bridges. Especially, we recently focus on abnormalities which can not be easily detected by visual inspection or of which it is difficult to evaluate influence after suffering earthquake and which might lead to collapse. As for deteriorations, the followings are regarded as the abnormalities mentioned above.

- Cracks propagating inside steel structure, such as deck penetrating cracks in orthotropic steel decks
- Cracks or corrosion of steel members or materials propagating inside concrete members
- Corrosion of prestressing steels or reduction of prestress
- Corrosion underwater or scoring

In Japan, failures of diagonal members of truss bridges managed by the national government, which could lead to collapse, occurred last year. However those damages or sign of the accidents had not been detected in previous major routine inspections (refer to Figure2). In Canada, as collapse of a concrete Gerber bridge had occurred in 2006, deterioration of both concrete and re-bars inside a Gerber hinge, in which they could not inspect visually, was pointed as one of the causes of the failure of the hinge which led to the collapse (refer to Figure3)[1].

Figure2 Failure of diagonal member of truss bridge

Figure3 Collapse of de la Concorde Bridge and inside of Gerber hinge[1)]

Defects or insufficient conditions, which occur in designing or constructing stage and they fail to find, as follows are also hard to detect by visual inspection.

- Insufficient thickness of steel members
- Insufficient prestress in PC structures or insufficient tension of high tensile bolts
- Residual stress or inner stress in steel members

That is more severe problem than that on detection of invisible deterioration because it might fail to perform as designed against assumed loads such as seismicity just after completion of construction and more difficult to identify. In Japan, damage such as many cracks and displacement occurred in a partial prestressed concrete bridge before service several years ago. It was repaired and is being monitored despite unclearness of causes and its soundness (refer Figure4). In the US, though the cause of the collapse of I-35W bridge has not been identified, insufficient thickness of gusset plates was reported[2)].

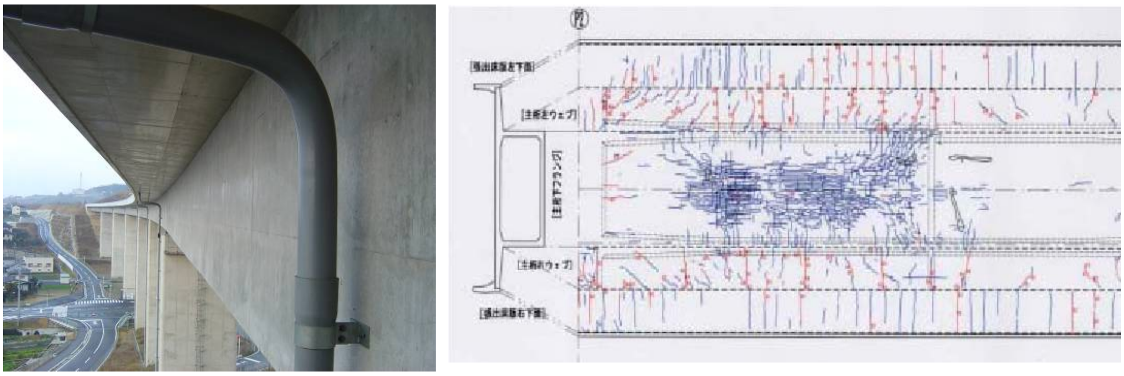


Figure4 Cracks on a partial prestressed concrete bridge

3. Approach to Difficulties as to Inspection

In order to detect various abnormalities assumed timely other than visual inspection, utilization of nondestructive inspection techniques is most reasonable in view of cost effectiveness and damage of structure. However they have not been utilized in the major routine inspection for highway bridges so far by the following reasons.

a) Optimum methods of applying nondestructive inspection techniques for structures, which have various characteristics and conditions, have not been established.

b) Requirement to nondestructive inspection techniques to evaluate soundness of structure have not been clarified.

The followings are difficulties to establish utilizing methods and requirement.

- In many cases, degree of abnormality which should be detected is smaller than that of noise contained in measured value or precision of nondestructive inspection techniques.
- In general, only relative difference of each state can be distinguished by nondestructive inspection techniques.

In order to prevent accidents and serious damages of highway bridges, it is important to sophisticate bridge management by better utilization of those nondestructive inspection techniques and promotion of development of them. Therefore we studied methodology of better utilization of nondestructive inspection techniques and approach to clarify requirement to them, which will be the target for development of the techniques. As case study, we chose a study for establishing a method of detecting decrease of prestress by the following reasons.

- It is generally difficult to be detected by alternative method such as visual inspection or destructive inspection. (In other words, there is no technique which has required sufficient performance.)

- It might affect whole bridge performance against probable loads such as live load or seismicity.

Decrease or loss of prestress occurs by various causes such as improper constructing works, corrosion or fire (refer to Fiqure5 to 7). Though it might be presumed by occurrence of cracks, crack occurrence is not usually allowed in PC structures. Therefore when cracks are observed on a PC structure, it might not satisfy performance required already.

As there is no nondestructive inspection technique which has sufficient performance to detect decrease of prestress so far, it is an important issue to develop the method to detect decrease because it influences soundness of PC structure.

Figure5 Corrosion of prestressing steels[3)]

Figure6 Falling out of prestressing steel

Figure7 PC beam suffered from fire

4. Approach to Develop Method of Detecting Abnormalities

We considered the followings as premises for establishing method of utilizing nondestructive inspection techniques and requirement to them which will be the target for development of the techniques.

a) *Identifying an event which is the target to detect an abnormality and a threshold to determine soundness in accordance with respective characteristics such as structure types, specifications applied and objective abnormalities*

Though each bridge was designed according to each situation and has particularity, it was designed by the same specifications in each period. Therefore it is thought that its characteristics such as response from a kind of load, degree of response and appearance of abnormalities would be similar, which will depend on design specifications applied and objective member.

b) *Selecting an event which has obvious correlation with soundness, clarifying a certain degree of precision required related to actions, and regarding it as requirement to nondestructive inspection techniques*

Actions, such as monitoring, detailed survey and repairs, according to inspection results are limited. Therefore the techniques only have necessary precision to determine an action taken rather than advancing precision to detect farther details.

c) *Noting "deference" of events targeted under same conditions as method of detecting abnormality*

For example, though there is no nondestructive inspection technique to measure stress absolutely, it is possible to measure relative deference of stress level or behavior of members.

We carried out the following studies for developing a method to detect decrease of prestress of existing bridges as example under the premises mentioned above. The outline of the studies is described in 5.

1) Clarifying a threshold to be detected and precision required to techniques
    - *Estimation of influence of prestress decrease over soundness (shown in 5-1)*

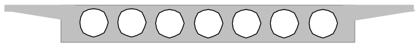
2) Clarifying target events to detect abnormalities
    - *Loading tests of beam-shaped specimens with different prestressing (shown in 5-2)*
    - *Application tests of nondestructive inspection methods to measure inner stress (shown in 5-3)*

<u>5. Studies for Developing Methods to Detect Prestress Decrease</u>

5-1 Estimation of Influence of Prestress Decrease over Soundness

In terms of detection of prestress and its decrease in existing bridges, we estimated correlation between residual degree of prestress and degree of cracking under dead load or both dead and live load for common structural types and spans (shown in Table1) in order to clarify the threshold and the precision required to nondestructive inspection techniques.

Table1 Bridge types and spans

Bridge Type	Span Length (m)	Image
T-Girder (Post-Tensioning System)	20～45	
Slab Bridge	20～30	
Box Girder	40	

Relation between degree of prestress and condition of the structure is shown in Figure8. It was found that there is no sufficient difference among them in terms of degree of prestress decrease. For example, it is estimated that 35% of prestress decrease causes occurrence of detrimental size of cracks and possibility of reducing strength in long terms for T-girders with post-tensioning system.

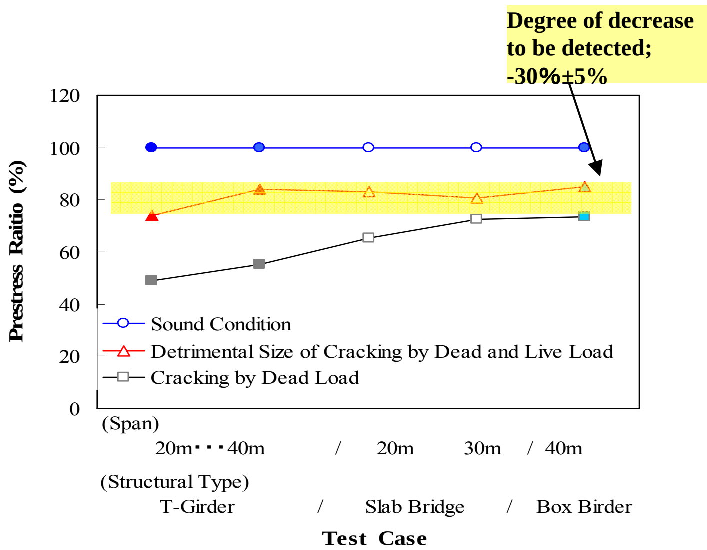


Figure8 Degree of prestress and condition of PC girders

5-2 Loading Tests of Beam-Shaped Specimens with Different Prestressing

Loading tests of beam-shaped specimens with different prestressing of 100%, 50% and 10% of the prestress designed was carried out. The form of the specimens is shown in Figure9.

While respective tests resulted in almost same loading capacities due to the same steel volume which relates to strength, the relation between load and displacement and the appearance of cracks were distinctly different (shown in Figure10 and 11). As shown in

Figure11, the location and dispersion of cracks deeply depended on degree of prestress.

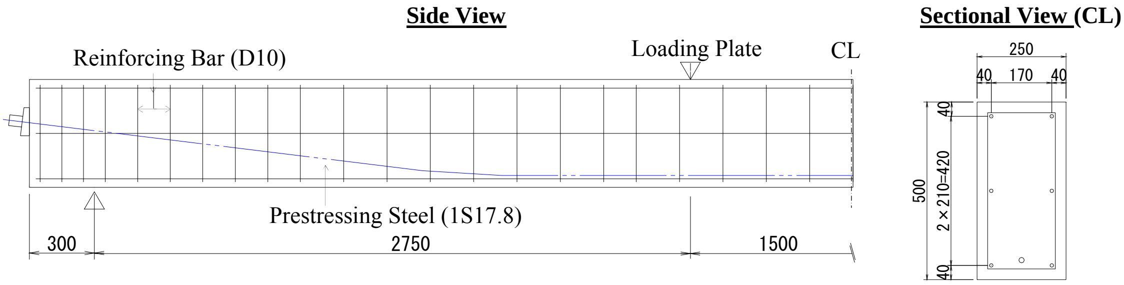


Figure9 Form of specimens [mm]

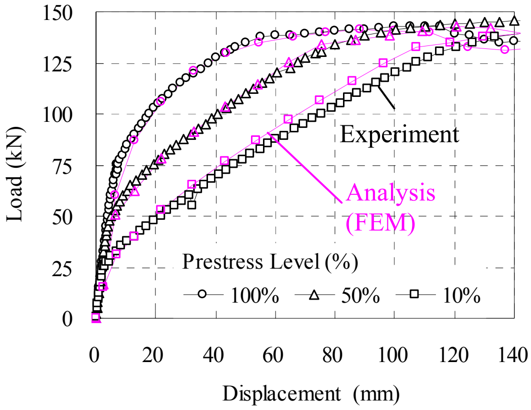


Figure10 Load and Displacement

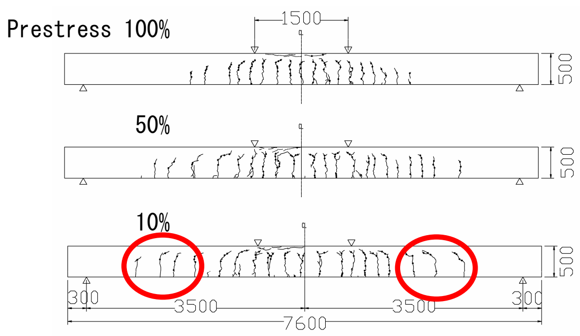


Figure11 Crack Dispersion before Failure

5-3 Application Tests of Nondestructive Inspection Methods

Application tests by using elastic-wave method, which is one of the most common techniques applicable for diagnosis of deterioration of concrete structures, were carried out for an actual-size T-girder with post-tensioning system. Its length was 45m, height was 2.5m and specified concrete strength was 40N/mm2. One of the tests was as to transmission propagation characteristics of ultra sonic wave through the web while the other was as to surface propagation characteristics of impact elastic-wave.

1) Transmission Propagation Characteristics of Ultra Sonic Wave through Web

Influence of inner stress state over propagation velocity of ultra sonic wave transmitted through the web was examined by measuring propagation time from one side to the other side of the web. The applied voltage was 1200V and resonant frequency was 40kHz. The distribution of the transmission propagation velocity measured is shown in Figure12. It shows a tendency that the transmission propagation velocity was varied in accordance with the height of a measuring position on the web. That indicates the correlation between the transmission propagation velocity of ultra sonic wave and the inner stress by prestressing which would be estimated by the nondestructive inspection using ultra sonic wave.

2) Surface Propagation Characteristics of Impact Elastic-Wave

Impact waves by a steel sphere (φ9.6mm) were received at two places and surface propagation velocities were estimated by the difference of the two arrival times. Horizontal surface propagation velocities were measured in each height on the web in order to evaluate difference of stress degree. The relation between the stress degree estimated and the horizontal surface propagation velocity is shown in Figure13. The stress degree is obviously correlated with the propagation velocity. That indicates to be able to detect relative difference in stress degree at least.

The followings were found by the examination from 5-1 to 5-3.

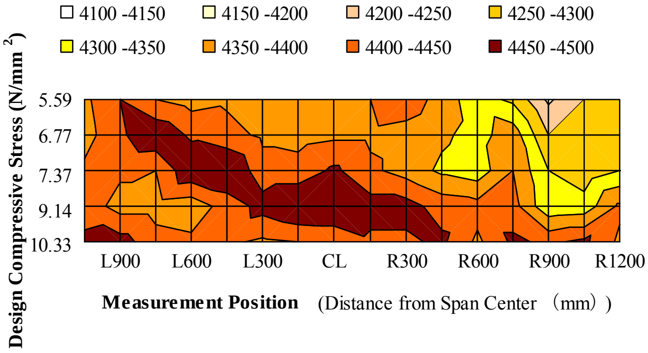


Figure12 Distribution of Transmission Propagation Velocity of Ultra Sonic Wave

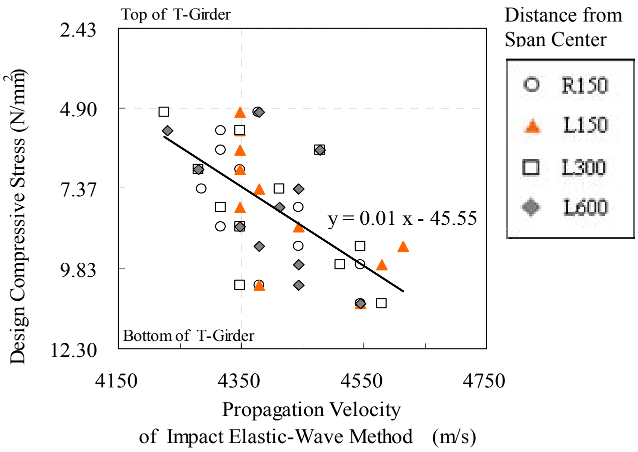


Figure13 Relation between Propagation Velocity and Design Stress

- As for common types of PC structure with normal spans, ability only to detect 30% decrease in designed prestress within ±5% error is required to inspection methods. Hereinbefore it was proved to be able to clarify the threshold, which would be the target to determine actions, and the precision required to inspection techniques by identifying characteristics of the bridge inspected such as bridge types, spans and design specifications.
- It is possible that decrease of prestress could be estimated by the observation of displacement of the girder and crack appearance on it under loading or location of existing cracks.
- By noting “difference” of stress degrees, it is possible to be able to detect the abnormality by applying nondestructive inspection techniques commonly used in current.

6. Conclusion

In order to prevent accidents and serious damages by sophisticating maintenance of highway bridges, we proposed the methodology of properly utilizing nondestructive inspection techniques and requirement to them which will be the target for development of the techniques. Moreover the examination case of the methodology for prestress decrease of PC structures was shown in the report as example.

The examination result proved that existing nondestructive inspection techniques could be utilized more effectively by clarifying an event which is the target to detect an abnormality, a threshold to determine soundness and precision required to inspection techniques in accordance with respective characteristics such as structure types, specifications applied and objective abnormalities. In other words, in order in the future to apply nondestructive inspection techniques to bridge inspections more broadly, it is important to identify characteristics or conditions of structures inspected, not to simply require advancement of precision of the techniques, for surely grasping abnormalities.

For example, with respect to prestress decrease of PC bridges, we found that ability only to detect 30% decrease in designed prestress within ±5% error is required to inspection methods for common types of PC structure with normal spans and decrease of prestress could be estimated by the observation of displacement of the girder and crack appearance on it under loading or by noting “difference” of stress degrees measured by nondestructive inspection techniques.

In addition, by clarifying requirement to inspection techniques from conditions of structures, it is expected that nondestructive inspection techniques applicable to bridge maintenance would be developed and introduced effectively and efficiently. We will clarify targets for detection and requirements to techniques for other abnormalities and damages.

On the other hand, at the time of construction or rehabilitation of bridges, it is important to clarify inspection and evaluation methods in advance in order to detect abnormalities timely as sophistication of maintenance. We will study how to establish design specifications for that as requirement on “maintenancibility”.

References

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