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Evaluation of Strength and Maintenance Methods for Railway Reinforced Concrete Structures with Aged Deterioration

Ichiro Murata[1], Takahiro Yoshida[2], and Yoshihiko Watanabe[3]

[123]West Japan Railway Company Co., Ltd., 2-4-24 Shibata, Kita-ku, Osaka, Japan
[1]ichirou-murata@westjr.co.jp, [2]takahiro-yoshida2@westjr.co.jp,
[3]yoshihiko-watanabe@westjr.co.jp

ABSTRACT

Early deterioration of concrete structures built during the period of rapid economic growth in the 1970s was recognized as a problem in society after concrete pieces fell from San-yo Shinkansen tunnel lining surfaces in 1999. In general, railway structures are designed for a long service life because they are not easily replaced, and their soundness and availability are ensured through many appropriate inspections and repairs. Since replacement of deteriorated railway structures due to aging is rare, the role of maintenance management is extremely important. This paper describes the current situation and approaches, as well as topics regarding evaluation of soundness and maintenance of San-yo Shinkansen RC structures.

Keywords: Railway concrete structure, maintenance, inspection, repair/strengthening

1. INTRODUCTION

The latter half of the 20th century was a period of development and construction in Japan during which, supported by rapid economic growth, a succession of new structures were built. In particular, railway and road structures, including Tokaido/San-yo Shinkansen and Tomei/Meishin Expressway, opened one after the other from the 1960s to the 1970s, and their contribution to rapid economic growth in Japan is immeasurable. However, a series of incidents of concrete falling from viaducts and tunnel lining surfaces of San-yo Shinkansen in the late 20th century emphasized the importance of maintenance.

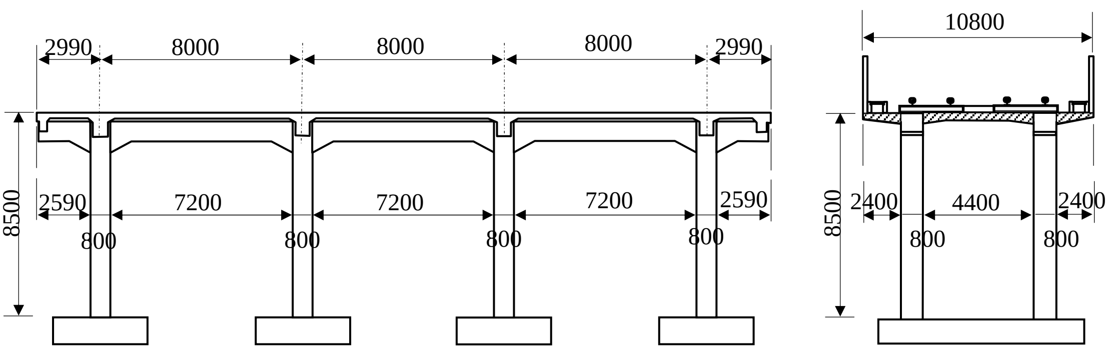
Essentially, railway concrete structures are designed to be maintenance-free for 50 years and to have a service life of 100 years under normal environmental conditions when appropriately maintained. If designed and constructed properly, they are extremely durable structures. However, it has been found that some concrete structures, built during the period of rapid economic growth, contained insufficiently desalinated sea sand or were otherwise inferior in quality.

During the 21st century, the appropriate maintenance of a huge number of existing structures will become very important. Therefore, the following will become increasing important: 1) clarifying the condition of concrete structures through inspections, and 2) establishing the design of maintenance scenarios, such as appropriate repair/strengthening in cases where deformation has occurred or is predicted to occur.

2. OVERVIEW AND DETAILED SURVEY OF SAN-YO SHINKANSEN RC STRUCTURES

2.1 Overview of San-yo Shinkansen RC structures. San-yo Shinkansen (between Shin-Osaka and Hakata: 560 km) was opened between Shin-Osaka and Okayama (158 km) in March 1972 and between Okayama and Hakata (402 km) in March 1975. Almost 90% of its total length (approximately 560 km) is occupied by concrete structures such as tunnels or viaducts. The viaducts employ a standard design according to each standard viaduct height (distance from top surface of footing to top surface of slab) based on the results of comparative studies. Span length, number of spans, beam-to-column stiffness ratio, span length of overhang, and so on, were modified at the design stage, taking into account factors such as economic efficiency, ease of construction, and external appearance, as well as adaptability to track requirements and ground conditions. A basic diagram of a double overhanging-type standard viaduct is shown in Figure 1.

2.2 Outline of Review by Committee on Investigation for San-yo Shinkansen RC Structures. Construction of San-yo Shinkansen during the period of rapid economic growth



<Unit: mm> (a)Side view (b)Cross section

Figure 1. Basic diagram of a standard double overhanging-type viaduct

in the 1970s was completed within a short time period, overcoming difficulties such as inflation and a scarcity of building materials due to the oil crisis. However, within just 30 years of its completion, deformation such as flaking and falling of cover concrete on some viaducts had become apparent (Photo 1). Therefore, the Committee on Investigation for San-yo Shinkansen RC Structures (hereinafter, Committee on Investigation) was established (August 1999 to July 2000) with the aim of recommending measures to maintain the soundness of San-yo Shinkansen RC structures. The Committee on Investigation ordered that approximately 400 sets of samples be taken on San-yo Shinkansen viaducts and examined the intermediate slabs and overhanging slabs of each viaduct for cover, depth of carbonation, chloride ion content, and the level of rebar corrosion. A final summary of the results was published, the main points of which are the following.

Photo 1. Deterioration of the slab

(1) The primary factor causing deterioration of San-yo Shinkansen RC structures is carbonation. Also, it was found that the greater the chloride ion content, the more advanced the rebar corrosion.

(2) An investigation into the strength of viaduct slabs using rebar sampling and cross-section reduction survey results showed that there were no structural problems.

(3) In order to maintain soundness in the future, it is important that timely and appropriate inspections and repairs be conducted.

2.3 Comprehensive Inspection on San-yo Shinkansen viaducts

2.3.1 Outline of Comprehensive Inspection. From the results of the approximately 400 sets of samples be taken on San-yo Shinkansen viaducts, the Committee on Investigation indicated causes of deterioration in viaducts, gave evaluations of strength of structures at present, and developed a flowchart to select repair methods. In order to maintain the viaducts of San-yo Shinkansen in accordance with the proposed flowchart, it was necessary to prepare records showing the state of deterioration of each structure. Therefore, the Comprehensive Inspection on San-yo Shinkansen viaducts (hereinafter, abbreviated as “the Comprehensive Inspection”) was carried out, and it was decided that the Comprehensive Inspection would be used in subsequent maintenance, including repair planning.

The Comprehensive Inspection was conducted from October 1999 to December 2000, and it covered approximately 12,000 of the 16,000 reinforced concrete structures. The survey primarily covered the intermediate slabs, beams, and columns of rigid-frame viaducts, but also included RC girders, piers, etc.

2.3.2 Results of the Comprehensive Inspection. As an example of the results of the Comprehensive Inspection, a summary of the results concerning causes of rebar corrosion is given here. Figure 2 shows the results of examining the relationship between the uncarbonated depth (= cover minus depth of carbonation) and level of rebar corrosion in intermediate slabs. This relationship is that the smaller the uncarbonated depth, the greater the proportion of rebar corrosion of Level I (light corrosion is found in places) and above. Classifications for level of rebar corrosion established by West Japan Railway Company (JR-West) are listed in Table 1.

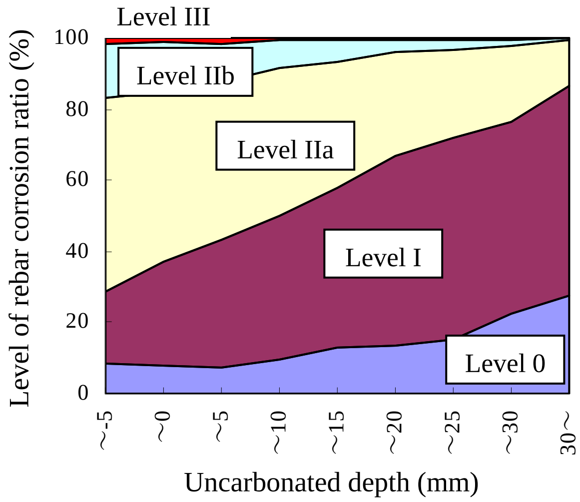


Figure 2. Relationship between the uncarbonated depth and the level of rebar corrosion

In addition, the results of examining the relationship between amount of chloride ions and level of rebar corrosion are shown in Figure 3. The relationship is not as clear as that of the uncarbonated depth, but it was found that the greater the chloride ion content, the more advanced the rebar corrosion.

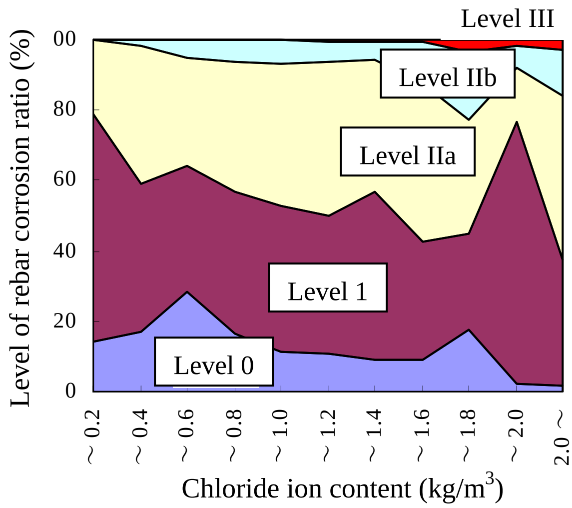
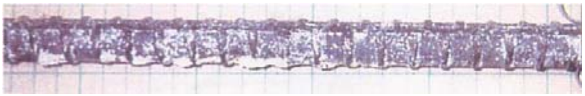


Figure 3. Relationship between chloride ion content and the level of rebar corrosion

Summarizing the above, it was reconfirmed that, as reported in the outline of the review by the Committee on Investigation, the primary factor causing deterioration in San-yo Shinkansen RC structures is carbonation; the trend that the greater the amount of chloride ion content, the more advanced the rebar corrosion was also found.

2.3.3 Preparation of repair methods selection flowchart for San-yo Shinkansen

Table 1. Level of rebar corrosion

Level	Evaluation Standard	Photo
0	The condition at the time of corrosion have been maintained and no subsequent corrosion is seen	
I	Light corrosion seen over the partly of the surface	
IIa	Corrosion seen over the majority of the surface	
IIb	Loss of cross-section seen over the partial surface	
III	Loss of cross-section seen over the entire surface	
IV	Loss of cross-section is 1/6 or more	

RC structures. A repair methods selection flowchart for San-yo Shinkansen RC structures (Figure 4) was prepared by combining the results of the Comprehensive Inspection and the flowchart proposed by the Committee on Investigation. This flowchart is primarily applied when selecting a repair method for an RC structure with rebar corrosion due to the complex effects of carbonation and internal chloride attack. Based on the results of surveys/inspections of factors such as flaking, carbonation, and chloride ion content, a repair method is selected from among the five groups labeled as “a” through “e” and listed in a table within Figure 4.

3. APPROACH TO MAINTENANCE OF RAILWAY RC STRUCTURES

With regard to maintenance of structures such as viaducts, “Maintenance Standards for Concrete Structures” were established in JR-West in March 2006, and maintenance of structures is currently carried out in accordance with these standards. The standards give the basic approach to maintenance sequences including inspection methods, determination of soundness, repair/strengthening, and recording.

3.1 Approach to inspections

	Maintenance Method
a	Whole surface concrete restoration
b	Desalination and re-alkalization, or cathodic protection
c	Re-alkalizarion
d	Whole surface coating
e	Patch repair

Mark	Explanation
[Sf]	Nominal safety factor
[Hr]	The area hammering off / the area of each member
[Re]	The area removing for repairs / the area of each member
[Co]	Level of rebar corrosion
[R]	Uncarbonated depth (= cover minus depth of carbonation)

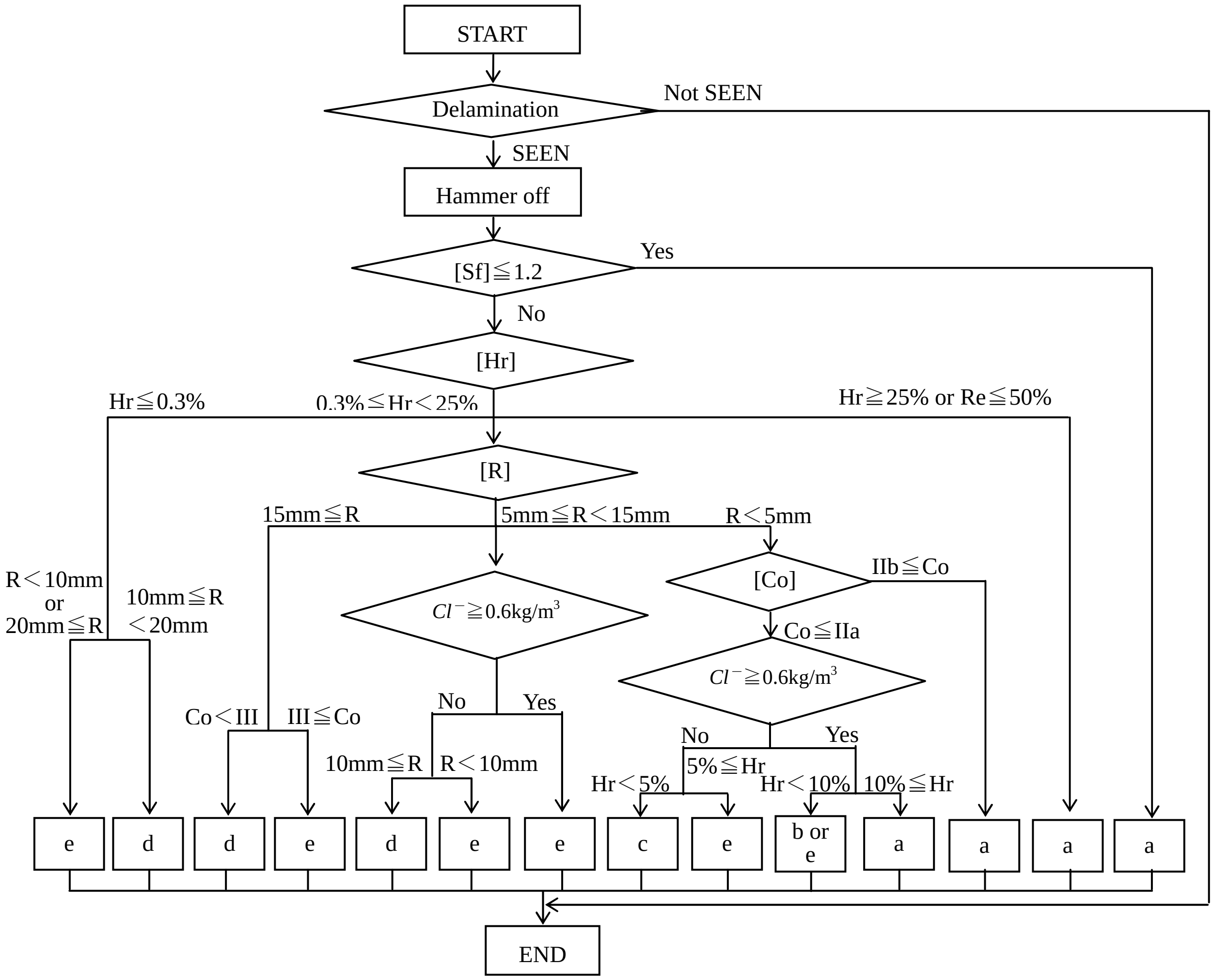


Figure 4. Repair methods selection flowchart (for San-yo Shinkansen RC structures)

3.1.1 Inspection system for railway RC structures. The Routine inspections of RC structures were carried out once every two years and the special inspections were carried out once every 10 to 20 years. In addition to those inspections, viaduct inspections are carried out as needed with the aim of preventing objects falling from structures.

The routine general inspection is intended to detect deformation as well as ascertaining the soundness of the entire structure. The inspection method is based on visual inspections from the ground.

The special general inspection was newly introduced in 2006 with the aim of improving the accuracy of the determination of soundness. A careful visual inspection is carried out at close range using a vehicle-mounted aerial platform or scaffolding, and drawings of the growth of deformation such as cracking and flaking are created.

Inspections of viaducts targeting sections intersecting or running parallel to roads and leased sites under overhead structures are conducted with the aim of preventing third-party damage, in addition to confirming safety. A careful visual inspection is carried out at close range using a vehicle-mounted aerial platform or scaffolding, and concrete in areas of deformation is hammered out.

3.1.2 Detection of delamination of RC structures using infrared camera. Since 2001, JR-West has been working to develop a method for detecting concrete delamination in viaducts from the ground using an infrared camera in areas where a close-range inspection using a vehicle-mounted aerial platform or scaffolding is difficult. Before widely introducing infrared cameras, testing was carried out on San-yo Shinkansen viaducts, and a manual that established conditions of application and judgment criteria was drawn up. Also, attempts to improve inspection accuracy were made, such as using the infrared camera at night as well as during the day.

3.1.3 Bridge Analysis and Maintenance System (BRAMS) (Figure 5). In order to conduct appropriate maintenance of RC structures, it is necessary to gather a wide variety of data and also to regularly update the data using the latest information. For this purpose, the Bridge Analysis and Maintenance System (BRAMS) was constructed in 2002. This system compiles a database of information such as bridge specifications, inspection data, and repair history with the aim of simplifying/accelerating processing and assisting in the planning of inspection and repair. Currently, information such as the history of sequential inspections/construction work is entered and updated using this system.

3.2 Approach to repair

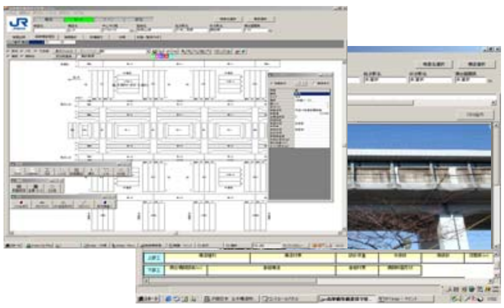


Figure 5. Bridge Analysis and Maintenance Sysytem(BRAMS)

With regard to repair of concrete structures, “Repair Work Guidance for Concrete Structure” was established in 2001. This guidance describes in an easy-to-understand manner the materials and procedures for various repair methods, and the methods are applied to repair work. The approach to repair is given below.

3.2.1 Patch repair methods. In patch repair methods, as shown in Figure 6, the concrete in and around the site of deformation is removed and the area is repaired using a patch repair material, such as polymer cement mortar.

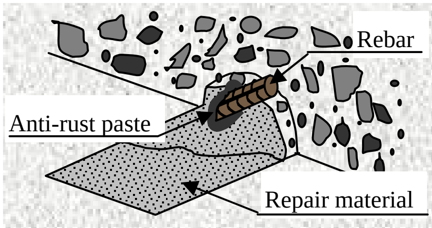


Figure 6. Patch repair

(1) Review of acceptance criteria for patch repair materials : Considering factors such as carbonation resistance, adhesiveness, and anti-rust performance of the patch repaired section, a polymer cement mortar with a fixed amount of resin mixed in or an inorganic mortar containing no polymer is used as a patch repair material for RC structures

In the past, JR-West indicated performance indexes and established acceptance criteria for materials, and fulfillment of these criteria was a requirement for approval of a material. However, because the materials were confirmed using data from a laboratory, it was assumed that the performance confirmed in the laboratory could not necessarily be guaranteed in construction work carried out on site. Therefore, JR-West decided to stipulate new testing methods and acceptance criteria using actual viaducts and accept as “approved materials” only those that passed the testing. There are currently 22 approved materials.

(2) Development of small spray machine for partial patch repair : Conventionally, a plastering method using a trowel was usually adopted for partial patch repair. However, ensuring the quality of, for example, repair material filling behind rebar and around rebar intersections was a challenge. The spraying method is considered to be suitable for ensuring a consistent construction quality, but the available spray machines were large and could not be applied to small repair areas. Therefore, a small spray machine for partial patch repair was developed, making it possible to apply the spray method even in places where it is not possible to bring in a large spray machine (Figure 7).

3.2.2 Surface coating methods. As shown in Figure 8, in surface coating methods, a coating 0.1 to 5 mm thick is formed on the surface of the concrete structure, and this coating has the effect of inhibiting the entry of deterioration


Figure 7. Small spray machine for partial patch repair

elements and the falling of concrete. Based on the recommendations of the Committee on Investigation mentioned in Section 2.2, JR-West adopts these methods when the uncarbonated depth is 15 mm or more.

In order to upgrade durability when this method when it is applied for the purpose of stopping further deterioration, on-site tests and exposure specimen tests were conducted from 2001, and various examinations were carried out in 1, 3, and 5 years from the application of the coating. As a result, seven surface coating methods were recognized as "approved methods" satisfying the acceptance criteria. Also, in response to the results of 5 years of on-site tests and exposure specimen tests, testing methods and acceptance criteria were stipulated for the performance requirements of surface coating methods applied to San-yo Shinkansen RC structures with regard to four items: carbonation prevention, adhesiveness, durability of coating, and rebar corrosion inhibition.

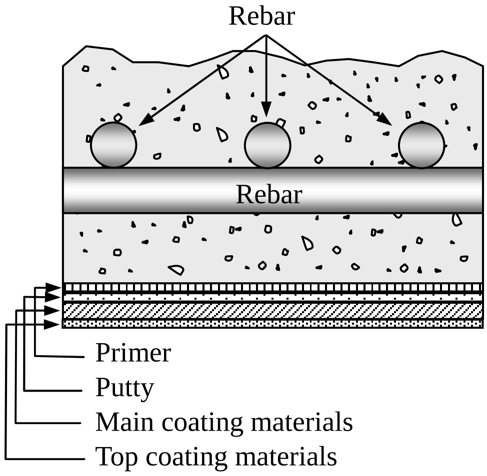


Figure 8. Surface coating method

3.2.3 Cathodic protection methods. Cathodic protection is a method of improving the durability of concrete structures by controlling the electric potential of steel using an electric current that flows continuously in the structure to electrochemically inhibit the steel corrosion reaction, as shown in Figure 9. This method is often applied to structures located in coastal areas, where they receive a constant supply of chloride ions, but this paper will introduce cases of application to San-yo Shinkansen RC structures that are located inland and have suffered complex deterioration due to carbonation and internal chloride ion content.

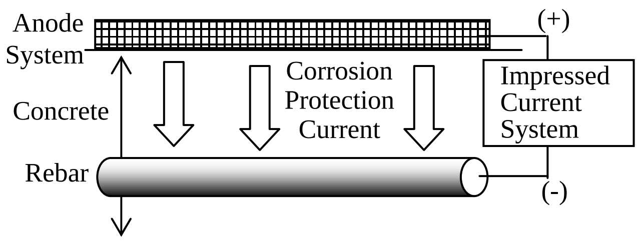


Figure 9. Cathodic protection method (Impressed current method)

<u>(1) Cathodic protection using impressed current method</u>: Six methods of cathodic protection using impressed current system were implemented in 2003 in order to examine the applicability of cathodic protection in the repair of viaducts that have suffered complex deterioration due to carbonation and internal chloride ion content, particularly in places where inspections and repair are difficult, such as small spaces above railway station ceilings and at intersections with other means of transport. Measurements such as resistivity and

depolarization taken up to 5 years after implementation confirmed that rebar in viaducts effectively protected against corrosion of all six methods.

(2) Cathodic protection using sacrificial anode: Cathodic protection using a sacrificial anode method with zinc as the sacrificial anode material was implemented in 1999. During a period to approximately 7.5 years after implementation, it was confirmed that corrosion protection current flows from the sacrificial anode to the rebar and depolarization is maintained at around 100 mV.

Also, when carrying out patch repair of RC structures that have deteriorated as a result of rebar corrosion, it is usual to remove the deteriorated section of concrete as far as possible behind the rebar in order to inhibit macro-cell corrosion. However, this removal work requires much labor and places a large burden on workers, in addition to being expensive. Therefore, the possibility of reducing the depth of concrete removal behind the rebar during patch repair of RC structures by using a sacrificial zinc anode in combination with the patch repair material was tested. As a result, it was found that a reduction in depth of concrete removal behind the rebar is possible in test specimens. Testing is currently underway on actual structures.

3.2.4 Management Engineer for Concrete Structure Repair Works. When repairing concrete structures, it is necessary to use an appropriate method that is based on factors such as the state of deformation and conditions at the repair site, taking into account the characteristics of the materials and machinery used. In order to achieve this, the responsibility for supervising construction must be undertaken by someone who not only has a fundamental knowledge of concrete and concrete repair materials/methods, but also is familiar with the repair specifications established originally by JR-West. Therefore, JR-West decided to try to further improve the quality of concrete structure repair by conducting professional training and screening aimed at construction company engineers with certain qualifications in order to certify them as “Management Engineers for Concrete Structure Repair Works” (JR-West certification). These certified engineers would then be stationed on repair sites.

This system was adopted for repair work on San-yo Shinkansen RC structures from 2001, and it was also adopted for similar repair work on conventional lines from 2002. Currently, there are approximately 700 certified engineers. Continuous training is provided for certified engineers in order to improve their technical capabilities and awareness.

3.3 Approach to strengthening. The recommendations of the Committee on Investigation mentioned in Section 2.2 made it clear that the strength of viaduct slabs in

San-yo Shinkansen RC structures is currently adequate. However, with regard to post-tensioned PC structures of San-yo Shinkansen, there is concern that if internal cables were to break, as well as suffering a decline in functions including load resistance, running safety, and comfortable riding, the structures may be put out of service for long periods of time. Therefore, an external cable tension monitoring system is being developed in which, as shown in Figure 10, an external cable is installed on the side of a PC I-section girder and, as well as detecting breaking of the internal cable using a sensor that monitors tension fluctuation in the external cable, the external cable also functions as a strengthening cable if the internal cable breaks. The effectiveness of this external cable tension monitoring system has been confirmed by the results of experiments and analyses using test specimens, and its application in actual structures is currently being tested.

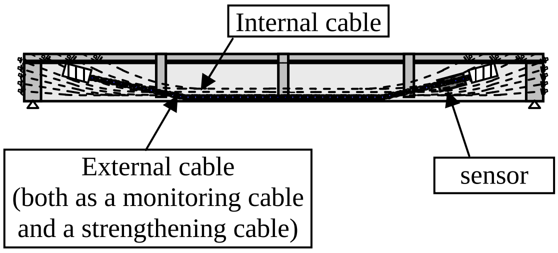


Figure 10. PC External cable tension monitoring system

4. IN CLOSING

Construction of San-yo Shinkansen was completed in a short time period, overcoming difficulties such as inflation and a lack of building materials due to the oil crisis. However, within just 30 years of its completion, a series of incidents occurred in which concrete pieces fell from its structures. Although there are currently no problems concerning the strength of the structures, it is considered necessary to implement the approaches mentioned in this paper, as well as to verify their effectiveness, in order to maintain soundness for many years to come.

ACKNOWLEDGEMENTS

We would like to take this opportunity to express our gratitude to all members of "Committee on Investigation" and "The Committee of Survey and Investigation Concerning Maintenance of Concrete Structures", appointed by the Society of Materials Science, Japan, from whom we received various suggestions regarding methods for inspection and repair to promote maintenance of San-yo Shinkansen RC structures, and also to everyone who cooperated with the testing.

REFERENCES

Hasegawa S., Yokota K., Araki K., and Aramaki S. (2004). “Applicability of cathodic protection method to railway concrete viaducts deteriorated by complex effects”, *Proceedings of the 59th annual meeting of Japan Society of Civil Engineers,5-262.*

Maruyama N., Murata I., Kondo T., and Morikawa H. (2012). “Development of External Tendon Monitoring System for Effective Stress Change in Prestressed Concrete I-section Girders”, *Proceedings of the 21st Symposium on Developments in Prestressed Concrete*

Nomura N., Kakio T., and Koide T. (2005). “Inspection the effective of rebar corrosion protection using sacrificial zinc anode”, *Proceedings of the 60th annual meeting of Japan Society of Civil Engineers,5-165*

Railway Technical Research Institute Japan. (2004). “*Design standards for railway structures and commentary”; Concrete structures*

Tottori S., Jinno Y., Kitago Y., Miyagawa T. (1998). “Durability evaluation of actual railway viaducts with regard to rebar corrosion in concrete”, *Proceedings of the Rehabilitation of Concrete Structures, 49-54*

Watanabe Y., Osada F., Inoue H., Mushiake N. (2003). “Diagnosing flaking off of concrete railway viaduct with the infrared camera in the nighttime”, *Proceedings of the 55th annual meeting of Japan Society of Civil Engineers,5-403.*

Watanabe Y., Aramaki S., Matsuda Y., Yamada T., and Miyagawa T. (2009). “Evaluation of Concrete Surface Coating Method Applied to San-yo Shinkansen RC Structures”, *Journal of the Society of Materials Science Japan, 58-8.*

Watanabe Y., Kamio M., Yamamoto K., Yamamoto T., and Miyagawa T. (2009). ”Applicability of patch repair with sacrificial zinc anode for RC members deteriorated by chloride induced corrosion”, *Proceedings of the Concrete Structures Scenarios Vol.9,331-336, JSMS.*

Watanabe Y., Koiwai T., and Ooe T. (2009). “The survey carried out in 5 years from repairing San-yo Shinkansen viaducts by cathodic protection method”, *Proceedings of the 64th annual meeting of Japan Society of Civil Engineers,5-258.*

West Japan Railway Company. (2001). *Repair work guidance for concrete structure.*

West Japan Railway Company. (2001). *Guidance for infrared camera to detect delamination of RC structures.*

Yoshida T., Nakatsuka T., Watanabe Y., Nishii M., Matsukubo H.(2012). “Investigation on Cathodic Protection Range of Sacrificial Zinc Anode for RC Structure Deteriorated by Chloride Induced Corrosion”, *Proceedings of the Concrete Structures Scenarios Vol.12, 95-100, JSMS.*