Maintenance of Railway Structures with Aging Deterioration and Amarube Bridge Reconstruction

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The JR West railway network extends a total distance of about 5013 km through 18 prefectures and carries about 5 million passengers every day. The history of much of JR West's railway infrastructure, especially the conventional narrow-gauge lines between Osaka and Kobe, is old, starting in 1874, while the San'yo Shinkansen between Shin-Osaka and Okayama dates from 1972, and between Okayama and the Hakata terminus from 1975. This article describes the maintenance methods and approaches to enhancing the safety of aged railway infrastructure, such as reinforced concrete (RC) structures, prestressed concrete (PC) structures, steel bridges, tunnels, etc. It also covers the reconstruction of the Amarube Bridge as an example.

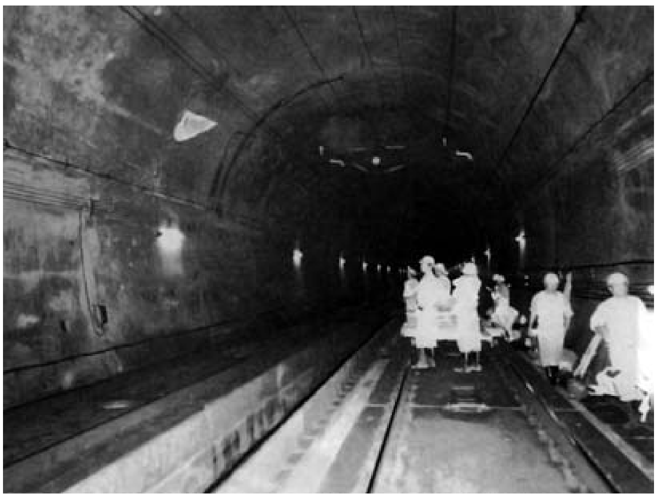
Maintenance of Reinforced Concrete Structures

Shimadagawa Bridge (1.83 m) between Yonago and Yasuki on the San'in Line, constructed in 1907, is the oldest railway RC bridge in Japan. It has remained in sound condition with absolutely no repair work at all since the initial construction. In contrast, some RC structures built in the 1970s during the period of rapid economic growth contained insufficiently desalinated beach sand or were otherwise inferior in quality and have begun showing signs of early deterioration in less than 30 years.

In general, railway structures are designed and constructed for long-term durability, because they cannot be replaced easily; inspection and repair work are done as necessary to ensure structural safety and usability. Construction of the San'yo Shinkansen was completed within a short time period in the 1970s, overcoming difficulties such as inflation and scarcity of building materials due to the oil shock crisis. However, within 30 years of its completion, deformation such as flaking and dropping of cover concrete on some viaducts was apparent. In 1999, concrete blocks weighing about 220 kg fell from the San'yo Shinkansen Fukuoka Tunnel lining, hitting a train. In response, the Committee on Investigation of Tunnel Problems was established immediately by the then Ministry of Transport to study the causes and recommend measures to maintain the soundness of tunnels. The final summary concluded that the causes were:

- Interruptions during concrete placing caused cold joints to grow in the concrete lining.
- Wide-area cracks grew in lining under the cold joints due to vibration of steel supports during concrete placement and/or removal of forms.
- Further vibration and pressure changes caused by

Shimadagawa Bridge, first RC railway bridge in Japan (JR West)



Concrete falls from Fukuoka Tunnel lining of San'yo Shinkansen in 1999 (JR West) running shinkansen trains caused cracks to develop until the accident occurred.

At the same time, deformation such as flaking and dropping of cover concrete had become apparent on some viaducts. To maintain soundness into the future and prevent recurrences, JR West conducted the timely and appropriate countermeasures described below.

Inspection System for Railway RC Structures

Routine inspections of RC structures are carried out once every 2 years and special inspections are carried out once every 10 or 20 years. In addition, viaduct inspections are made as necessary to prevent objects falling from structures. The routine general inspection is intended to detect deformation as well as ascertain the soundness of the entire structure. The inspection method is based on visual inspections from the ground, and inspectors update the database for structures where deformations such as cracking and flaking have occurred or are developing. The special general inspection introduced in 2006 aims to improve the accuracy of the soundness determination using a careful close-up visual inspection. Inspections of viaducts targeting sections intersecting or running parallel to roads and over leased sites are conducted to prevent third-party damage as well as to confirm safety. The close-up inspection uses either a vehicle-mounted elevating platform or scaffolding, and deformed concrete is detected by tapping.

Detection of RC Delamination Using Infrared Camera

Since 2001, JR West has been working to develop a method for detecting concrete delamination in viaducts from the ground and to improve inspection accuracy using an infrared camera in areas where close-up inspection from elevated platform or scaffolding is difficult. Testing was carried out on San'yo Shinkansen viaducts before wide introduction of infrared cameras to draw-up criteria that established conditions for application, and to create a manual.

Review of Criteria for Patch Repair Materials

In patch repair works, the concrete in and around the deformation is removed and the area is repaired using a patch repair material, such as polymer cement mortar.

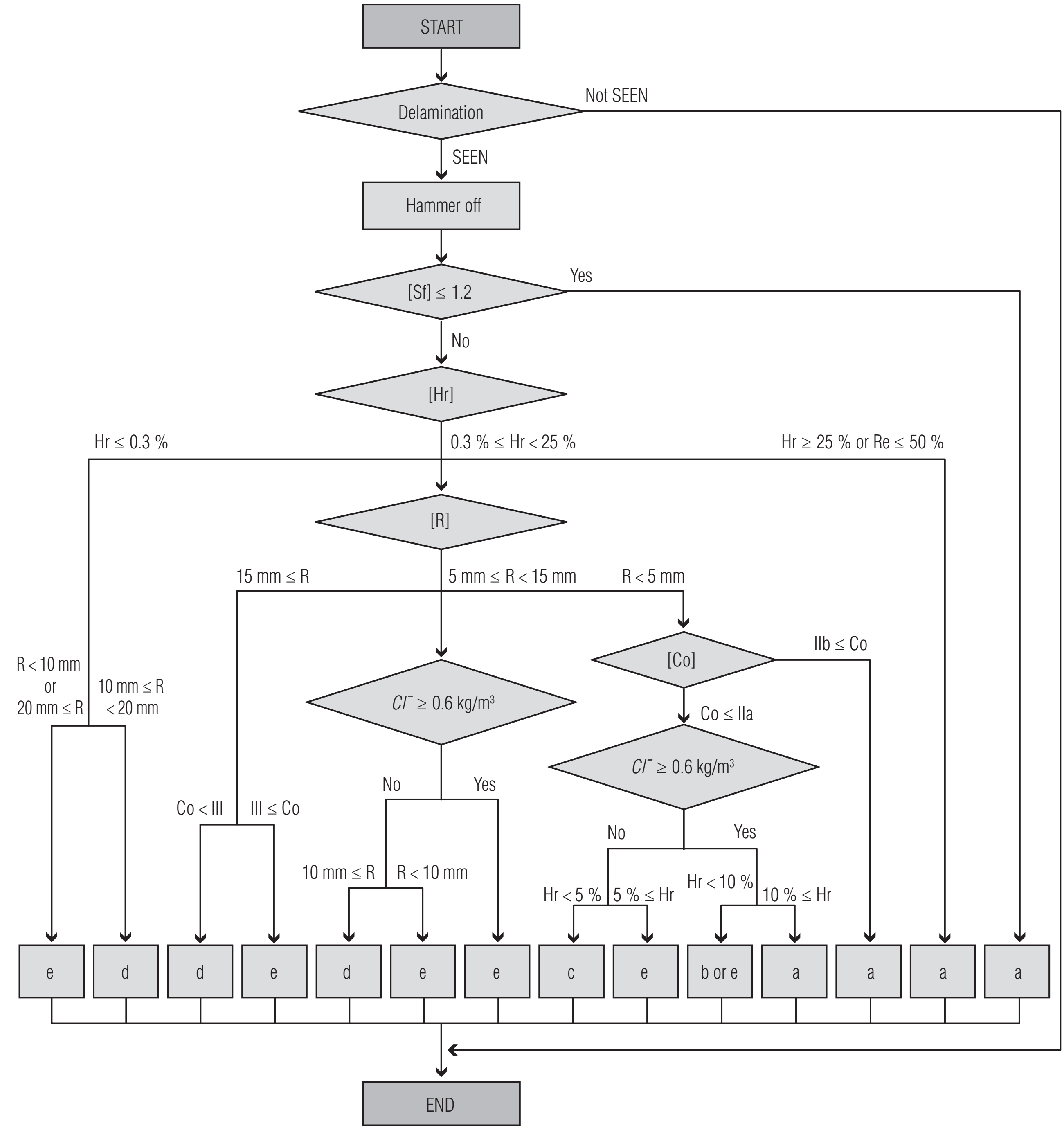
In the past, JR West indicated performance indexes and established acceptance criteria for materials, and fulfillment of these criteria was a requirement for approval of the material. However, because the materials were confirmed using laboratory data, it was assumed that the performance

Hammered-off areas under viaduct slab (JR West)

Infrared camera for detecting concrete delaminations (JR West)

On-site weathering tests of repair materials (JR West)

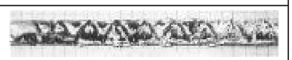
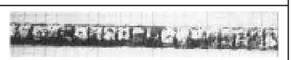
Figure 1 Repair Methods Selection Flowchart (for San'yo Shinkansen RC Structures)



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

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

Level of Rebar Corrosion

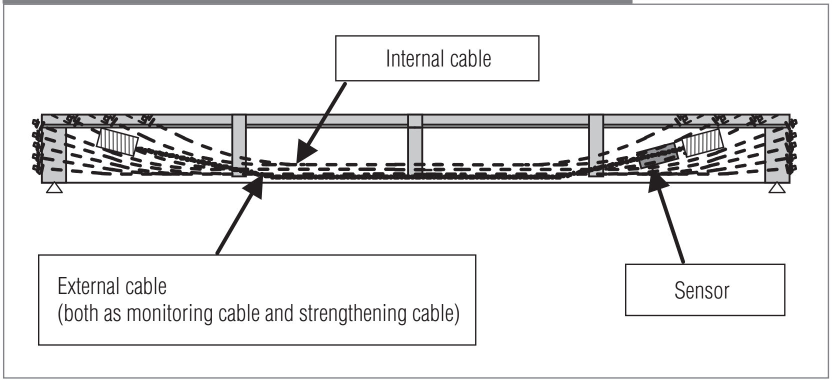
Level	Evaluation Standard	Appearance
0	Conditions at time of corrosion maintained and no subsequent corrosion seen	
I	Light corrosion seen over part of surface	
IIa	Corrosion seen over majority of surface	
IIb	Loss of cross-section seen over part of surface	
III	Loss of cross-section seen over entire surface	
IV	Loss of cross-section ≥ 1/6	

in the laboratory could not necessarily be guaranteed at on-site construction work. Therefore, JR West decided to stipulate new testing methods and acceptance criteria using actual viaducts and accept those 'approved materials' that passed testing. There are currently 22 approved materials. The *Repair Work Guidance for Concrete Structures* was established in 2001 to regulate repair work. It describes the materials and procedures for various repair methods used at repair works in an easy-to-understand manner.

Introduction of Repair Methods Selection Flowchart for San'yo Shinkansen RC Structures

The primary factor causing deterioration in San'yo Shinkansen RC structures is carbonation. The degree of reinforcing bar (rebar) corrosion is greater with higher chloride ion content. A flowchart for selecting repair methods for San'yo Shinkansen RC structures was introduced by combining the results of surveys/inspections of factors, such as flaking, carbonation, and chloride content. The best repair method for each structure is selected from among the five groups labelled *a* through *e* listed in Figure 1.

Figure 2 PC External Cable Tension Monitoring System



PC External cable tension monitoring system (JR West)

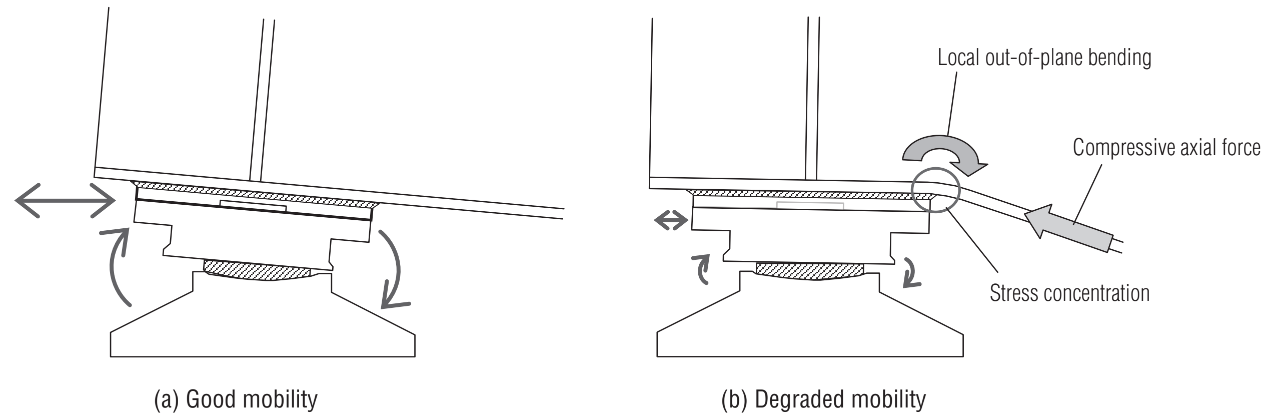
Management Engineers for Concrete Structure Repair Works

When repairing concrete structures, an appropriate method based on factors such as the state of deformation and conditions at the repair site must be applied, taking into account the characteristics of the materials and machinery. Achieving this goal depends heavily on a management engineer with key knowledge about concrete and concrete repair materials/methods, as well as familiarity with the JR West repair specifications. Therefore, to improve the repair quality of concrete structures, JR West conducted professional training and screening of qualified construction company engineers and certified them as Management Engineers for Concrete Structure Repair Works (JR West certification). These engineers are stationed at repair sites. Currently, there are about 700 certified engineers. Continuous training is provided to improve their technical abilities and awareness. This system has been used for repairs on San'yo Shinkansen RC structures from 2001.

Maintenance of Prestressed Concrete Girders

Many medium-span bridges on the San'yo Shinkansen used post-tensioned PC structures to reduce noise. In some cases, tendons that were left ungrouted at construction are found at maintenance. Water infiltration around these ungrouted tendons eventually causes corrosion that breaks the wire. To remedy this serious situation, JR West makes repairs by regrouting voids along tendons. However, for post-tensioned PC structures on the San'yo Shinkansen, there is a worry that broken internal cables would cause a decline in functions such as load resistance, running safety, and ride comfort, as well as putting structures out of service for long repair periods. Therefore, an external cable tension monitoring system is being developed (Fig. 2). In this system, an external cable is installed on both sides of the PC structure. As well as detecting internal cable breaks using a sensor to monitor tension changes in the external cable, the external cable also functions as a strengthening

Figure 3 Behaviour at Front of Sole Plate due to Degraded Bearing Mobility



Reinforcement by patch plates (JR West)

Tunnel lining surface imaging vehicle (JR West)

cable if an internal cable breaks. The effectiveness of this external cable tension monitoring system was verified by experiments and analyses using test specimens, and 2012 marked its application to actual structures.

Maintenance of Steel Bridges

Corrosion and fatigue are the main durability problems on steel bridges. Regular periodic painting works have minimized corrosion despite the passage of about 40 years since steel bridges were first built on the San'yo Shinkansen. About 90% of these steel bridges (800 in total) are composite girder bridges and in recent years, fatigue cracks have been found around welded joints at the sole plate. Generally, the main factor causing these cracks is degraded bearing mobility (Fig. 3). Therefore, sole plate and bearing replacement are effective methods for reducing this fatigue damage. However, the cost is high, and development of an alternative repair method is imperative. An easy low-cost reinforcement method has been developed using FEM analysis and test construction. This method uses installation of angle steel with vertical ribs at the upper side of the lower flange to reinforce the fatigue-damaged welds of the sole plate.

Full-scale tunnel for developing additional inner lining (JR West)

Tunnel Maintenance

The serious June 1999 Fukuoka Tunnel accident when concrete tunnel lining fell and hit a running shinkansen had a great safety impact. In response, JR West immediately implemented a Comprehensive Total Safety Inspection for the San'yo Shinkansen in which 69,000 engineering staff closely examined all concrete surfaces in 142 tunnels (280.5 km in total) on the San'yo Shinkansen over a 52-day period. The inspections included tapping tests of all concrete surfaces and removal of flaking concrete. Tapping tests can find honeycombs and cold joints in concrete based on changes in sound when tapped.

Development of Automatic Inspection System for Concrete Surfaces

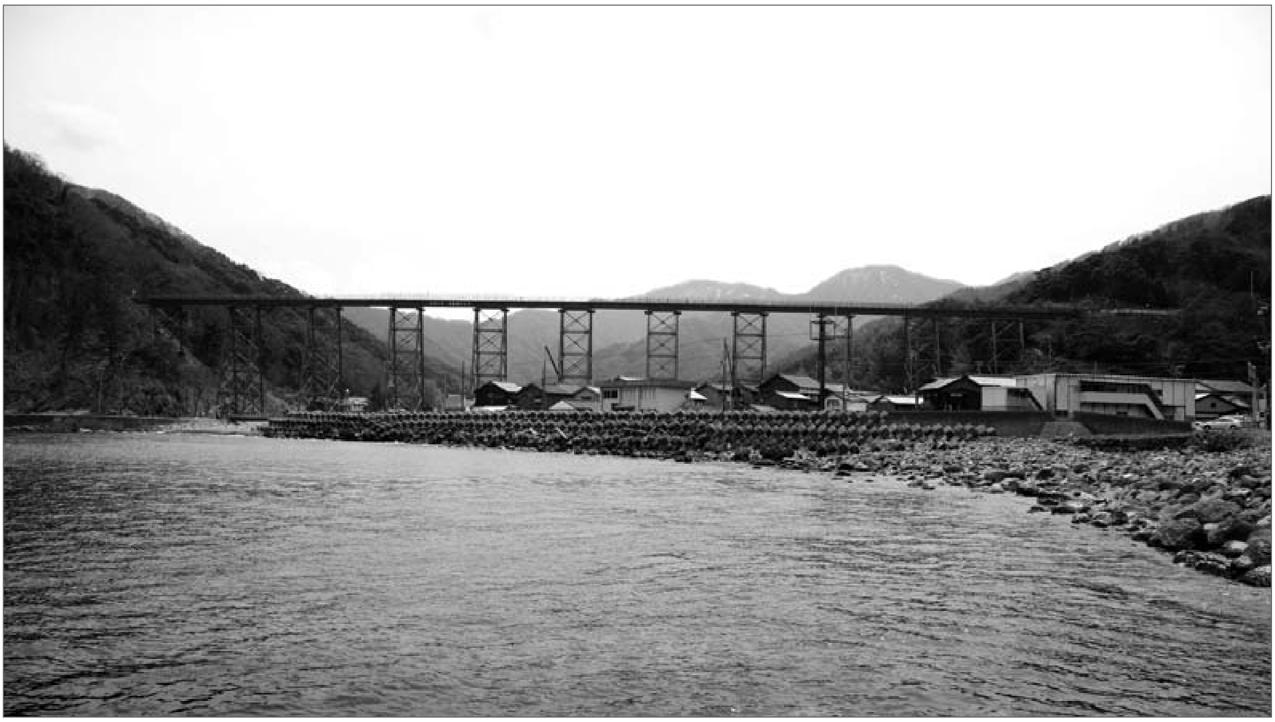
At tunnel inspection, the condition of the tunnel lining must be determined accurately, reliably, and efficiently. The main method for inspecting tunnel surfaces is by eye, but maintaining uniform and continuous visual inspection is very difficult, and accurately recording findings is difficult too. Other problems include the possibility of human error. To solve these problems and improve inspection accuracy, we developed a tunnel lining surface imaging vehicle using a laser detection system. It can operate at speeds up to about 9 km/h (when inspecting half the tunnel cross-sectional area), and can detect cracks just 0.5-mm wide.

Development of Inner Lining Works to Prevent Concrete Flaking and Falling

Generally, tunnels are lined with plain concrete, but RC lining is used at tunnel portals or where the earth cover is shallow. Some of these linings have experienced progressive rebar corrosion due to lack of protective cover and use of salty beach sand and/or portland blast-furnace slag cement at construction, leading to surface concrete flaking. To prevent flakes falling off, loose parts are hammered frequently. Additional lining has been developed using fiber plastics and grouting as a basic countermeasure. The remediation method was tested and validated by constructing a full-scale shinkansen tunnel and the new method will be applied to some RC tunnel linings from 2013.

Reconstruction of Amarube Bridge

The 40-m high Amarube Bridge (310 m) is in the San'in region of western Honshu facing the Sea of Japan. It was completed 100 years ago in 1912 as the pre-eminent trestle



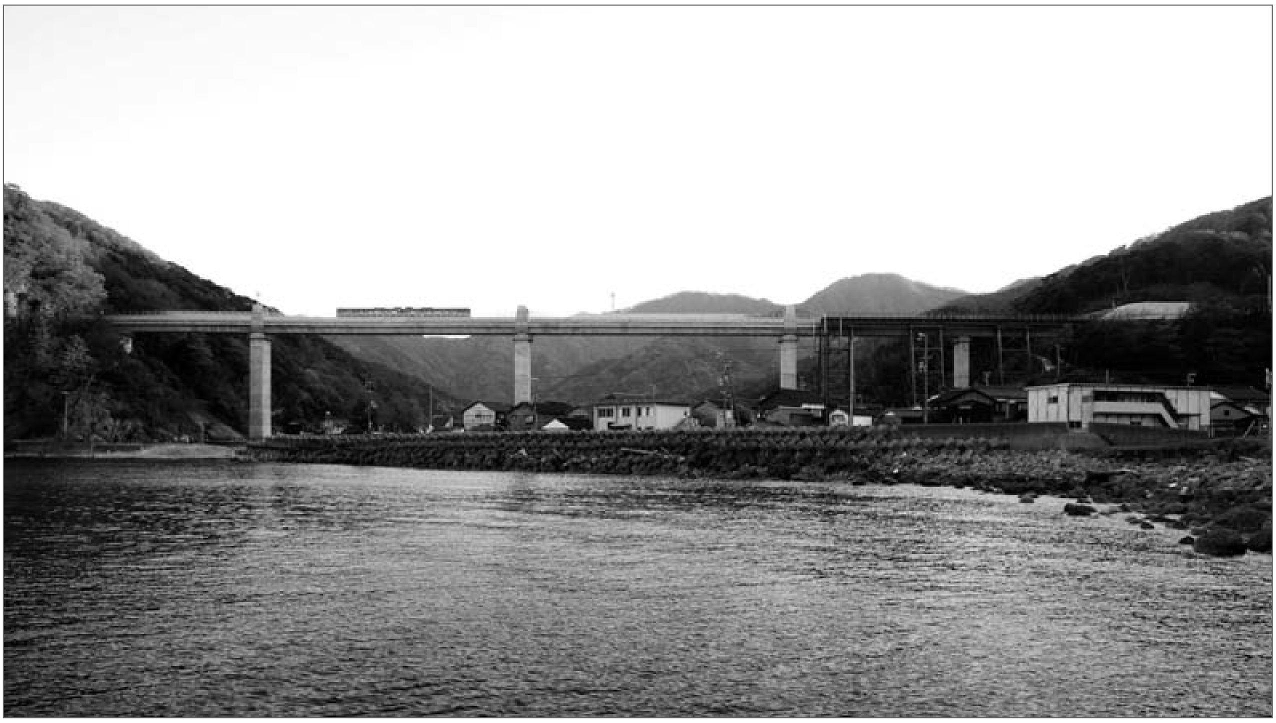
Old Amarube Bridge (JR West)

Lateral motion of girders and turning erection method (before) (JR West)

Lateral motion of girders and turning erection method (after) (JR West)

bridge in the Orient. The steel for the bridge piers was imported from the Pencoyd plant of the American Bridge Company by landing barge. Since the bridge is close to the coast, it is at risk of salt-spray corrosion, but professional bridge painters kept it well covered in bright vermilion for a long time, making the bridge and its rich natural surroundings a favourite of railway fans and local residents. Unfortunately in 1986, a severe storm from the Sea of Japan created strong side winds and forced a train off the bridge, killing six people.

After the accident, JNR revised its operational standards so that wind speeds of more than 20 m/s would require train operations to stop. Consequently, operations were suspended on 15 more days each year on average, especially during the winter months, greatly inconveniencing many passengers. To lessen the inconvenience, an



New Amarube Bridge (JR West)

investigative commission was set up in response to requests from local people to discuss reinforcement and reconstruction of the bridge. As a result, 2002 saw the decision to build a new bridge assuring train operation at wind speeds up to 30 m/s.

An extra-dosed PC bridge with a span of five continuous box girders was designed to blend and assimilate the bridge's rectilinear beauty into the landscape. The new bridge was constructed along the south side of the old bridge at a track-centre distance of 7 m. Since the tunnel adjacent to the old Amarube Bridge was not to be rebuilt, the track to the new bridge follows an S-curve with a 300-m radius. Construction proceeded as follows:

- Girders (3800 tonnes total) fabricated at temporary site adjacent to main track
- Old bridge partially removed during track closure period
- New girders moved 4 m laterally and turned 5° into place
- Rails and electrical works completed after bridge meeting at centre

Using this unprecedented construction method shortened the track closure period to just 26 days and the new Amarube Bridge was opened in August 2012.

The partially remaining old bridge is a tourist observation deck called Sky Station. Steel from the old bridge was sent to universities, research institutes, etc., to provide data on aging after exposure to salty sea breezes for 100 years. Local people hope the new and remnant bridges will help further develop the area.

Postscript

This article provides a brief explanation of the challenges facing JR West engineers in maintaining the company's railway infrastructure, safety, and usability. I hope the solutions described will be useful to other railway engineers in meeting the challenges they face. ■

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