1. Introduction

The operation on the San- yo Shinkansen Line (between Shin-Osaka and Hakata, see Fig. 1) began in March 1972 between Shin-Osaka and Okayama, with the section between Okayama and Hakata opening in March 1975. The length of this line is approximately 600km. Fig. 2

**JR-West’s Network**

The Type of Railway Structures on the San- yo Shinkansen Line
shows the amount of its structures. Ever since its opening, the San-yo Shinkansen has played a major role in the balanced development of national lands, the promotion of interaction among the various regions the line serves, and the improvement of people's daily lives. In addition to serving these types of social functions, the San-yo Shinkansen is also peerless as a means of transportation in terms of safety, convenience and reliability.

However, the line also experienced problems with pieces of concrete falling from tunnel linings, first in June 2000 in the Fukuoka Tunnel (between Kokura and Hakata) and then in October 2000 in the Kita-Kyushu Tunnel (between Kokura and Hakata). Around the same time, there was also a series of situations with concrete pieces falling from viaducts. Therefore, JR-West conducted the "San-ya Shinkansen Tunnel Comprehensive Safety Inspection" for its tunnels to ensure safety. Likewise, for the problem of concrete falling from viaducts, etc., emergency inspections were performed, loose concrete was hammered off in the areas of delamination, and necessary measures were taken in order to prevent further accidents. Furthermore, with the goal of obtaining plans to maintain the soundness of concrete structures on the San-ya Shinkansen line, the "San-ya Shinkansen Concrete Structure Investigation Committee" (Chairperson: Professor Shigeyoshi Nagataki, Niigata University) was established in the Railway Technical Research Institute under the guidance of the Ministry of Transport. This new committee is working to examine plans and measures for ensuring the safety of concrete structures.

In this report, we will introduce the current conditions of structures such as reinforced concrete rigid-frame viaducts on the San-ya Shinkansen Line, present the results of the comprehensive inspections at approximately 16,000 sets for viaducts, etc., and discuss other projects undertaken by JR-West.

2. Overview of Conditions at the Time of the Construction of Viaducts, etc.

2-1 Standard Design
The reinforced concrete rigid-frame viaducts on the San-ya Shinkansen Line were designed taking economic factors, construction factors, appearance, etc., into consideration, as well as suitability to track and ground conditions. At the design stage, span length, the number of span, beam and column rigidity, etc., were modified in accordance with these conditions, then, based on the results of comparative studies, a standard design was established based on each standard viaduct height.

The design conditions for viaducts, etc., on the San-ya Shinkansen Line are shown in Table 1.
Design Conditions
The data is shown in the units used at the time of construction.

2-2 Mix Proportion
The general requirements for concrete construction work are defined in public work standard specifications. For mix proportion, however, additional specification is showed defining mix proportion for each type of structure, based on the conditions of the construction site. Table 2

<table>
<thead>
<tr>
<th>Construction Type</th>
<th>Standard Design Strength [kgf/cm²]</th>
<th>Cement Type*</th>
<th>Maximum Coarse Aggregate Dimension [mm]</th>
<th>Water/Cement Ratio</th>
<th>W/C [%]</th>
<th>Air [%]</th>
<th>Unit Cement Weight [kgf/cubic m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vachut</td>
<td>270</td>
<td>NC</td>
<td>20</td>
<td>12±2</td>
<td>4.5±1</td>
<td>53</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SCB</td>
<td></td>
<td>51</td>
<td>42</td>
<td>315</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>FCB</td>
<td></td>
<td>50</td>
<td>41</td>
<td>313</td>
<td></td>
</tr>
<tr>
<td>Vachut Foundation</td>
<td>270</td>
<td>NC</td>
<td>40</td>
<td>12±2</td>
<td>4.0±1</td>
<td>54</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SCB</td>
<td></td>
<td>53</td>
<td>39</td>
<td>291</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>FCB</td>
<td></td>
<td>51</td>
<td>39</td>
<td>291</td>
<td></td>
</tr>
<tr>
<td>Vachut, from, Beam,</td>
<td>240</td>
<td>NC</td>
<td>20</td>
<td>12±2</td>
<td>4.5±1</td>
<td>52</td>
<td>42</td>
</tr>
<tr>
<td>Bottomslab</td>
<td></td>
<td>SCB</td>
<td></td>
<td>51</td>
<td>42</td>
<td>313</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>FCB</td>
<td></td>
<td>50</td>
<td>41</td>
<td>313</td>
<td></td>
</tr>
</tbody>
</table>

* NC: Normal Portland Cement, SCB: Blast furnace Slag Cement (B Type), FCB: Fly Ash Cement (B Type)

Standard Mix Proportion (As of February 1971), Crushed Stone Concrete shows the standard mix proportion when crushed stone is used. AE concrete is used as the standard concrete for these mix proportion.
3. Results of the Comprehensive Inspections of Viaducts, etc.

3-1 Overview of the Comprehensive Inspections
Reinforced concrete structures on the San- yo Shinkansen Line (total length, approximately 209 km) consist of approximately 16,000 sets of structures. Comprehensive Inspections on the San- yo Shinkansen Viaducts, etc. (hereafter, calling "Comprehensive Inspections") were performed in order to obtain fundamental data about the depth of carbonation, chloride ion content, etc., for each structural set. This data is needed for use as evaluation indexes when applying the maintenance method selection flow to each structural set. The items covered by the comprehensive Inspections are listed in Table 3.

<table>
<thead>
<tr>
<th>Component Structure</th>
<th>Location</th>
<th>Data Extraction</th>
<th>Item A</th>
<th>Item B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viaduct</td>
<td>Bottom, Surface of Slab</td>
<td>For items A, 2 to 3 locations per set, for item B, 1 location</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Column</td>
<td>1 location per set</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Beam</td>
<td>1 locations per set</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Bridge</td>
<td>RC girder</td>
<td>1 location per bridge</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Bridge Pier</td>
<td>1 location per bridge</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Rigid Frame Abutment, Pier</td>
<td>1 location per bridge</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

Items Covered by the Comprehensive Inspections

3-2 Comprehensive Inspections Results
(1) Cover
The cover is measured directly as the distance from the concrete surface to the reinforcing steel. The cover on slabs averaged approximately 31 mm. For all members measured, approximately 20% to 30% of measuring values were thinner than design specifications.

(2) Depth of Carbonation
The depth of carbonation was measured by spraying the concrete surface with a solution of 1% phenolphthalein after breaking cover concrete and then measuring the area that turned red. The depth of carbonation on slabs averaged approximately 22 mm. This value is 1.7 times greater than the expected carbonation depth estimated by the Kishitani Formula using the mix proportion indicated at the time of construction (normal Portland cement, water-cement ratio: 53%). This increase is thought to be due to inherent factors such as the quality of the concrete, its construction and so on.

(3) Reinforcing Steel Corrosion Level
The level of reinforcing steel corrosion was evaluated by observing the part of embedded reinforcement after breaking cover concrete, and the degree of corrosion was on a 6-level scale. (seeTable.4)
Reinforcing Steel Corrosion

The reinforcement in the slabs showed greater corrosion than the reinforcement in the beams and columns, which is thought to be due to the fact that the design specifications indicate a thinner cover for the slabs than for other members.

(4) Chloride Ion Content

When analyzing concrete samples taken from cover concrete near the reinforcement, the values for the chloride ion content fluctuate due to the effects of the progress of carbonation and transitional concentration, so it is inappropriate to use the results as an index for the selection of maintenance methods. Therefore, for the comprehensive inspections, the samples used were taken from an area approximately 10 centimeters from the surface of the reinforced concrete in order to eliminate such effects, and the chloride ion content was measured using the "Method for Analyzing the Chloride ion content of Concrete" (JCI-SC4). The measurement results indicate an average chloride ion content of 0.97 kg/m$^3$.

3-3 Analysis of Factors Causing Reinforcing Steel Corrosion

Based on comprehensive inspections result, the factors causing reinforcing steel corrosion are estimated. As shown in Fig. 3

Relationship between the Residual Carbonation and the Reinforcing Steel Corrosion,
the relationship between the residual carbonation (= cover – depth of carbonation) and the level of reinforcing steel corrosion is such that the corrosion progresses as the residual carbonation becomes lower. This verifies that the primary factor in reinforcing steel corrosion is the carbonation of the concrete. The relationship between the chloride ion content and the level of reinforcing steel corrosion is shown in Fig. 4.

![Diagram showing the relationship between chloride ion content and reinforcing steel corrosion.](image)

Relationship between the Chloride Ion Content and the Reinforcing Steel Corrosion
This verifies that, although the mutual relationship between chloride ion content and corrosion is not as obvious as that of residual carbonation and corrosion, there is a tendency for reinforcing steel corrosion to progress with increased chloride ion content.

4. Maintenance Management and Future Topics

4-1 Maintenance Management
(1) Inspection System
The inspection of concrete structures was conducted in accordance with "Maintenance Management Standards and Description for Railway Structures (Concrete Structures)" (Railway Technical Research Institute, September 1987), etc.

1) General Inspection
A general inspection is conducted to examine the conditions of a structure, whether or not there are already progressing changes, and the environmental changes in the areas around railway track, from which functional deterioration or the threat of functional deterioration can be detected. General inspections are either conducted at regular intervals of not more than two years, or, based on the conditions of a structure, etc., at irregular intervals such as prior to periods of high passenger use (the end of the year, etc.) and prior to the beginning of the rainy season and typhoon season.
2) Individual Inspections
In order to determine the maintenance method, timing of plan implementation, etc., for structures in which a functional deterioration or threat of functional deterioration has been found, individual inspections are conducted to examine the cause of the changing conditions and the current level of functionality in order to precisely judge the soundness of the structure.

(2) Inspection Result Records
When an inspection is conducted, the date of the inspection as well as all necessary items such as inspection results is recorded. These records are then used for maintenance method selection, etc. Comprehensive inspections are also conducted in which measurements are made of the cover, residual carbonation, chloride ion content, etc., of the concrete in the viaducts, etc., with the goal of collecting the basic data needed for the maintenance management of the concrete rigid-frame viaducts, etc., on the entire span of the San-yo Shinkansen Line.

4-2 Repair for Viaducts, etc.
Fig. 5

The Ratios of Patch Repairs Area in Fiscal 1999 shows the ratios of patch repairs, by area, made deteriorated concrete patch repairs implemented in fiscal 1999. The total area of the repaired areas was approximately 15,000 m². Looking at the repaired areas of every member, slab areas, including overhangs, accounted for more than 60% of the all areas repaired.
Nitrate-based material or calcium-aluminum compound hydroxide saline-absorbent material was used as the inhibitor in the patch repairs, and polymer cement mortar was used for the patch repairs.
We also plan to implement surface coating, electrochemical repairs, etc., at necessary locations using the maintenance method selection flow proposed by investigation Committee shown in
4-3 Technological Development Efforts

(1) Delamination Detection Using Infrared Cameras

JR-West is working to develop a method for detecting delamination by processing thermal images taken with an infrared camera. This process is based on temperature differences resulting from differences in thermal capacity between areas of concrete delamination and areas of no delamination. (Photo 1)

Infrared Camera
(2) New Repair Methods
Test work for new repair materials and new repair methods was implemented through the end of fiscal 1999. A list of the test work is shown in Table 5.

<table>
<thead>
<tr>
<th>Test Work</th>
<th>Time of Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric protection</td>
<td>Jan. 1992</td>
</tr>
<tr>
<td>Desalinization and re-alkalization</td>
<td>Jan. 1994</td>
</tr>
<tr>
<td>Re-alkalization</td>
<td>Nov. 1996</td>
</tr>
<tr>
<td>Whole surface concrete restoration</td>
<td>Mar. 2000</td>
</tr>
<tr>
<td>Zinc Anodes</td>
<td>Mar. 2000</td>
</tr>
<tr>
<td>Permeable inhibitor</td>
<td>Feb. 1987</td>
</tr>
</tbody>
</table>

List of the Test Work, and Photo 2

The Conditions of Desalinization and Re-alkalization work shows the conditions of desalinization and re-alkalization work. JR-West is continuing its work to reduce costs and to verify the durability of each repair method.

4-4 Future Topics
Based on the proposals of the Investigation Committee, JR-West shall work to further improve the reliability of the maintenance management for reinforced concrete structures, and shall also work steadily on the following projects.
1) Revision of the "Concrete Maintenance Management Manual" (internal document, issued 1993).
2) Record of maintenance and condition of structures, etc., into databases.
3) Improvement of technological training for employees and improvement of employee technical skills.
4) Improvement of the durability, cost and quality of patch repairs and electrochemical maintenance.
5) Development of non-destructive inspection methods (inspection of loose areas, inspection of the conditions of reinforcing steel corrosion).

5. In Closing
Through various projects undertaken in response to the series of delamination incidents in order to re-establish the reliability of the San- yo Shinkansen Line, we realize keenly that safety is our primary concern, and we have realized the necessity and importance of maintenance management for concrete structures again.

At present, there are absolutely no structural problems with the concrete structures on the San- yo Shinkansen Line, however, in terms of materials, there is an ongoing progress of the deterioration of the concrete and corrosion of the reinforcing steel. In order to continue to ensure the capacity of these structures and provide its passengers with reliable transportation services, we must conduct appropriate inspections and take suitable measures, making a constant effort at maintenance management.

Considering the life of railway concrete structures, these projects have just started; ongoing projects that will run through the 21st century have really just gotten underway.

In the future, we must now more than ever push forward with improvements to inspection precision and the development of effective repair methods, with all engineers working in maintenance management as well as the engineers in charge of on-site maintenance doing their utmost to create a system of maintenance management in which we can feel pride and confidence.

References
4- Report from the San- yo Shinkansen Concrete Structure Investigation Committee, July 2000
5- Kishitani, Nishizawa, edit.; Concrete Structure Durability Series "Carbonation" : Gihodo Publication, August 1986