Third International Conference on Sustainable Construction Materials and Technologies http://www.claisse.info/Proceedings.htm

Construction of bridge slab ends repair system

Shungo Matsui[1*], Atsuo Ogawa[2], Tatsuo Ogata[3], Toshiyuki Kanda[4]

,Atsuro Kano[4], Masakatsu Kunikawa[4], Saiji Fukada[5] and Yoshiyuki Momiyama[1]

[1] *West Nippon Expressway Engineering Kansai Co., Ltd., Japan*
[2] *Former West Nippon Expressway Engineering Kansai Co., Ltd., Japan*
[3] *West Nippon Expressway Co., Ltd., Japan*
[4] *Chemical Construction Co., Ltd., Japan*
[5] *Kanazawa University, Japan*
[*] *5-26 Nishi-Ekimae-Cho, Ibaraki city, Osaka, Japan, s_matsui@w-e-kansai.co.jp*

ABSTRACT

Due to damage of the steel rebar in concrete hollow slab bridges caused by water leakage containing chloride, the covering concrete of the slab ends are deteriorated. This study investigated a repair system for the concrete slab end, which is damaged by the chloride. Firstly, a chipping technique using a water jet robot for the deteriorated concrete in small clearance under slab on the abutment was developed. This study also proposed shotcrete spraying method (a wet process) using polymer cement mortar with short fibers containing lithium nitrite, as a repair material. Moreover, estimation methods for performance of the repaired slab using non-destructive inspection methods are recommend.

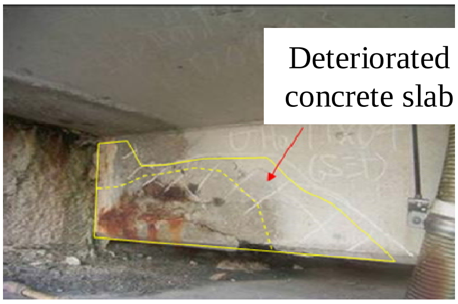
Keywords. repair, corrosion, concrete, water jet, shotcrete spraying

INTRODUCTION

Deicing salt (NaCl) is provided to maintain road safety of a Japanese expressway. The steel rebar at the ends of the objective concrete hollow slab bridges are damaged by water leakage containing chloride, which flows through the expansion joints that lack water sealing. The cracking of the covering concrete due to corrosion of rebar affects the strength and durability of the slab ends. Photo 1 (a) and (b) show the deterioration at the slab end of the reinforced concrete hollow slab bridge in 2006 and 2009, respectively. These photos show that deterioration at the slab end is progressing prematurely, once the steel rebar begins to corrode due to chloride penetration.

Table 1 shows the ratio of the deterioration area at the slab ends and general section of the bridge in each type of bridge (Metal, PC and RC). The ratio of the deterioration area at the slab ends of the RC bridge is the largest in other types of bridges. When deterioration at the slab ends progresses and reaches the bridge shoes, the deterioration affects the seismic performance and load-carrying capacity of the bridge. Specifically, clearance under hollow slab on the abutment (or pier) is about 14-20cm high and 120cm deep, as shown in Photo 2.

Due to small clearance, repairing the slab end is difficult. Therefore, this study developed the repair method which repairs the deterioration at the slab ends.



(a) Inspection in 2006 **(b) Inspection in 2009**

Photo 1. Deterioration at slab end of reinforced concrete hollow slab bridge

Table 1. Ratio of the deterioration area in each type of bridge

Type of bridge	Slab ends	General part
Total	8.1	1
Metal bridge	2.9	1
PC bridge	6.3	1
RC bridge	17.2	1

Photo 2. Clearance under hollow slab on abutment

INVESTIGATION OF REPAIR METHOD

In order to develop the repair method of the deteriorated concrete slab ends, the following problems are considered (JSCE, 2007). a) Method of removal of deteriorated concrete, b) Method of removal of rust; method of protection against corrosion of the rebar; method of repair after chipping deteriorated concrete c) Estimation of repair method.

Method of removal of deteriorated concrete. In order to remove the deteriorated concrete completely, this study considered following items. 1) Selectivity; ensuring that only the removal of deteriorated concrete is performed without damaging the rebar still intact, 2) Roughness; a water jet method is required to prevent micro cracks. The smoothing of roughness of the concrete surface after removal of deteriorated concrete is ensured. 3) Remove the corrosive environment; concrete behind the rebar is removed by water jet. 4) Shortening; ensuring required time for chipping deteriorated concrete is short.

Removing method of rust and shotcrete spraying method. In this study, the rust is removed from the rebar by water jet. Utilizing a repair material containing lithium nitrite, future corrosion of the rebar is inhibited. The concrete surface after removal of the deteriorated concrete is repaired using a shotcrete spraying method (wet or dry-process). The repairing method is necessary to guarantee the performance of the filling, performance of bond strength, and the decrease of the amount of sprayed material that rebounds.

DEVELOPMENT AND ESTIMATION OF CHIPPING TECHNIQUE FOR DETERIORATED CONCRETE USING WATER JET

Outline of examination for concrete specimen. This study made a concrete specimen to develop the chipping technique for the deteriorated concrete by water jet. Based on a slab end on an abutment, a model concrete specimen (200cm wide, 150cm deep, thickness is 15cm) was produced. The clearance under the concrete specimen on the base concrete is 14cm, corresponding to that of Photo 2, as shown in Fig 1. The compressive strength of the concrete specimen is 24N/mm^2 (maximum size of coarse aggregate; 25mm). This study developed a water jet robot (machine) which can control in X and Y directions, as shown in Photo 3. The moving speed and the number of times of passage were changing variables in the examination.

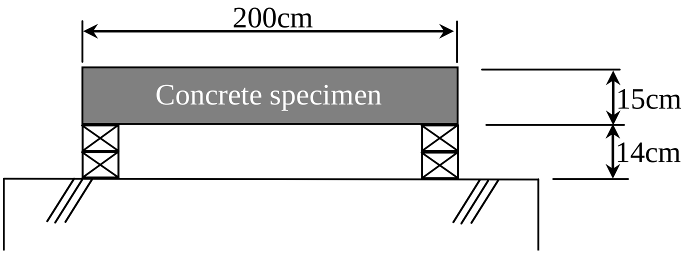
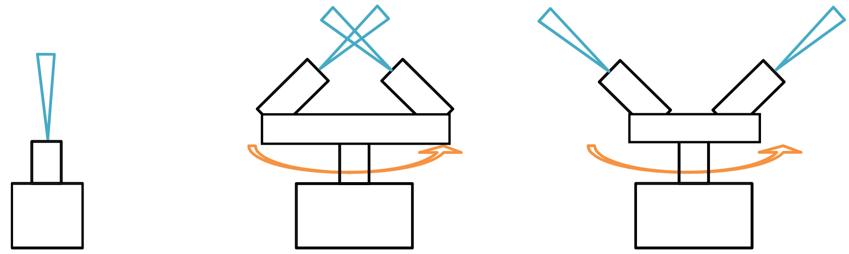


Figure 1. Concrete specimen

Photo 3. Water jet robot

Consideration of spray nozzle. Three types of water jet spray nozzle to control the direction or characteristic of a jet flow are used in general construction, as shown in Fig. 2. Type A is a single spray nozzle. This type has a low performance in the chipping of concrete behind a steel rebar, as well as in the smoothing of roughness. Type B is constituted of double spray nozzles, whereby jet flows make double collision. This type has good performance in the smoothing of roughness. However, a clearance of over 18cm is required under the slab. Type C is constituted of double spray nozzles with a wide angle, which is suited for placed with a wide angle or a low spray clearance. In considering the clearance of actual construction, this study selected the double wide angle spray nozzle. Then, the examination was conducted to estimate the capability of the water jet using this nozzle.

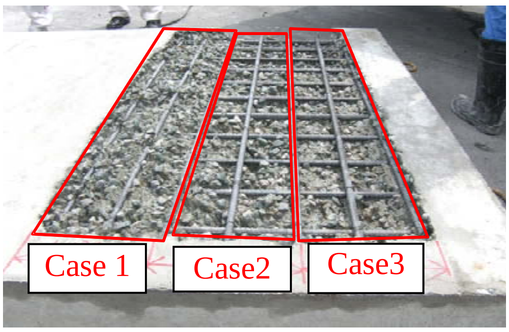


(a) Type A **(b) Type B** **(c) Type C**

Figure 2. Types of water jet spray nozzle

Confirmation of capability of water jet. Water jet (hydraulic pressure; 200MPa, flow rate; 36L/minute) is used to ensure good chipping performance. Here, the chipping depth required to expose the second rebar, which overlaps the first rebar, is 70mm. The chipping method of this examination focused on the following three test cases: Case 1; Water jet by robot in one pass, Case 2; Water jet by robot in two passes, Case 3; Water jet by robot in two passes, followed by an additional hand gun water jet.

Estimation by appearance. Photo 4(a) shows the concrete specimens after chipping in each case. Case 1 (water jet by robot in one pass) could not expose the first rebar completely, as shown in Photo 4(b). Case 2 (water jet by robot in two passes) could expose the first rebar, as shown in Photo 4(c). However, this case could not expose the second rebar completely. Photo 4(d) shows the results of Case 3 (water jet by robot in two passes, followed by an additional hand gun water jet), in which case the second rebar was completely exposed.



(a) Each case

(b) Case 1

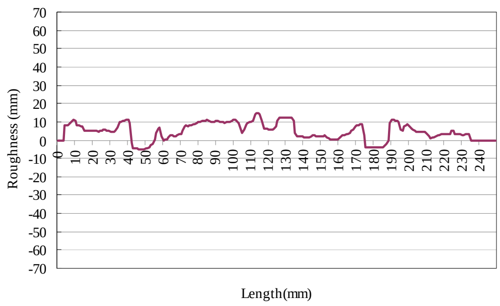
(c) Case 2

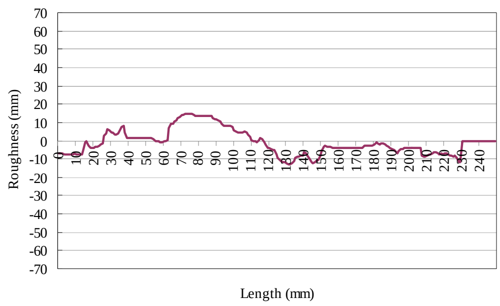
(d) Case 3

Photo 4. Concrete specimens after chipping by water jet

Roughness of chipped concrete surface. The roughness of chipped concrete surface was measured using laser light scattering device as shown in Photo 5. Fig. 3 shows the roughness of the concrete surface, which was chipped using water jet by robot in two passes, followed by an additional hand gun water jet. The maximum roughness of concrete surface was 20-30mm, which was the same size as the maximum size of coarse aggregate. The concrete behind the rebar was completely removed.

Photo 5. Laser light scattering device





(a) Longitudinal direction **(b) Transverse direction**

Figure 3. Roughness (Plus side is deeper than planning depth)

DEVELOPMENT AND ESTIMATION OF REPAIR TECHNIQUE

Situation and problem of repair technique. The repair method for deteriorated concrete (depth 70mm) at the slab end, which has a small clearance under the slab (14cm high, 120-150cm deep), is as follows.

a) Grouting method; this repair method requires forms to inject the repair material and needed the prevention method for stripping in trowel finish. The blocking of air in the interface between old and new concrete is problematic.

b) Shotcrete spraying method (dry / wet process); this repair method is difficult to conduct at one time. However, it does not require the use of forms. After chipping concrete, this method can be performed immediately. In this method, the issues concerned with air blocking are minimalized.

This study selected shotcrete spraying method (wet process) in consideration of the performance of construction, roughness, and rebound material (Araki, A. et al., 2004).

Construction of shotcrete spraying method (wet process) and its estimation. Construction examination by shotcrete spraying method (wet process) was performed using concrete specimens cut by water jet. The shotcrete sprayed repair material is polymer cement mortar with short fibers (Chemical construction Co., Ltd.) containing lithium nitrite (Sumitomo osaka cement Co., Ltd.) (Nitrite ion; mole ratio 0.8 for chloride ion 4kg/m^3) as a corrosion inhibitor. Here, the flow rate is 2L/minute, 1st layer (between chipped concrete surface and second rebar) is 10-20mm depth, 2nd layer is filling behind first rebar, and 3rd-4th layer are 20-30mm.

Estimation of filling performance. In order to estimate the performance of the filling between the surface of the chipped concrete and shotcrete sprayed repair material, the concrete test specimens were divided into four specimens on 28 ages after spraying. The performance of the filling was satisfied by confirming that repair materials fill in fully around the rebar and local cavity of concrete as shown in Photo 6.

Estimation of bond strength performance. A tensile strength test was conducted to estimate the bond strength of divided specimens. The results of the respective bond strengths were shown in Table 2. The bond strength of all specimens, minus No.2-2, satisfied the criteria of 1.5N/mm^2. However, since all specimens were broken between layers of sprayed repair material, this study investigated the prevention method for such weak points.

(a) Local cavity of concrete **(b) Around rebar**

Photo 6. Filling of repair material

Table 2. Results of bond strength

Case No.	1-1	1-2	2-1	2-2	3-1	3-2	4-1	4-2
Bond strength (N/mm^2)	1.87	2.29	1.68	0.66	2.51	1.46	2.18	1.51
Breaking	Layers	Layers	Layers	Layers	Layers	Layers	Layers	Layers

Influence of bond strength on concrete surface textures. An examination of bond strength was conducted to investigate the influence of bond strength on concrete surface texture between each sprayed layer. The bond strength was measured using pull off adhesion tester as shown in Photo 7. Specific parameters for each examination test case are shown in Table 3. In order to keep the wet or dry condition on the surface of chipped concrete, two cases (spraying water or spraying water proofing agent) are considered. Two types (trowel finishes or broom finishes) of concrete surface textures on each layer are also considered. This table shows that the case showing the highest bond strength employs a combination of spraying water and broom finishes. Therefore, this study maintained wetness on the surface of chipped concrete by spraying water, and made the concrete surface textures by broom finishes. Here, the ratio of rebounding sprayed material was 4%.

Photo 7. Pull-off adhesion tester

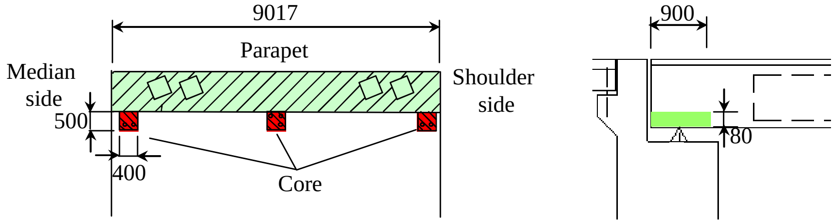
Table 3. Results of bond strength examination (14 ages)

Case	Surface condition	Surface textures	Bond strength (N/mm^2)	Standard deviation	Coefficient variation (%)
A	Spraying water proofing agent	Trowel finishes	1.24	0.44	35.1
B		Broom finishes	1.47	0.37	24.9
C	Spraying water	Trowel finishes	1.06	0.45	42.4
D		Broom finishes	1.78	0.28	16

EXANIMATION FOR AN ACTUAL BRIDGE

Outline of examination for an actual bridge. Using the results of the examination for concrete specimens, examinations were carried out on an actual bridge, Maenosho-Daini Viaduct (Chugoku Expressway, down line, A2 abutment), which has existed in a cold and snowy area for over 30 years. Fig. 4 (green area) shows the target of repair construction. Here, Fig. 4 (red area) shows the core sampling point for bond strength examination.

Removal of deterioration concrete by water jet. After consideration of the thickness of the covering concrete and congestion of the rebar at the slab ends of the bridge, the deteriorated concrete is removed by water jet robot in six passes, and by hand gun. Two water jets at a maximum hydraulic pressure of 240MPa, and a maximum flow rate of 38L/minute, were used. The capacity of two water jets is at a maximum hydraulic pressure of 220MPa, and a maximum flow rate of 68L/minute. The chipping depth is 80mm. Chipped concrete is shown in Photo 8. The deteriorated concrete and other concrete behind the rebar are removed completely.



(a) Plane view **(b) Side view**

Figure 4. Target of construction for an actual bridge

Photo 8. Slab and rebar after chipping deteriorated concrete by water jet

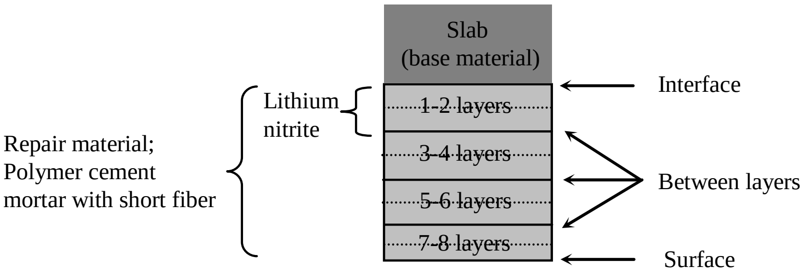


Figure 5. Each layer

Table 4. Results of the bond strength examination for actual bridge

No.	1	2	3	4	5	6	7
Bond strength (N/mm^2)	2.1	1.8	2.3	2.0	2.3	1.5	2.2
Breaking surface	Base material	3-8 layer	Surface layer	Base material	Surface layer	1-2 layer	Interface

Repair by shotcrete spraying. Polymer cement mortar with short fibers containing lithium nitrite is used as a repair material. Eight layers (Fig. 5) were constructed in five days for a depth of 80mm. The wetness of the surface of chipped concrete was maintained by spraying water (using 5L spray device, $240g/m^2$), and the concrete surface textures were made by broom finishes. Here, ratio of rebound sprayed material is 1.8%. In addition, by ultrasonic testing of the filling, no voids between layers were confirmed. Table 4 shows the results of the bond strength examination for the bridge. The bond strength of all specimens was larger than the criteria of $1.5N/mm^2$.

EXAMINATION METHOD AND ESTIMATION

Non-destructive inspection methods, including visual inspection (video scope, fiber scope), ultrasonic testing, elastic impulse wave method, electromagnetic wave radar method, infrared radiation method, are conducted to estimate the following:

1) Filling performance (filling concrete around rebar, appearance of surface of sprayed concrete).

2) Bond performance (stripping between old concrete and sprayed repair material, stripping between each layer of sprayed repair material).

This study recommends the following estimation methods for performance of repaired slab using non-destructive inspection methods, as shown in Table 5. Visual inspection using fiber scope should be conducted to validate good performance in the concrete surface after repair in the small clearance under the slab. Additionally, ultrasonic testing and the electromagnetic wave radar method should be conducted to confirm that there are no voids between layers or around the rebar.

Table 5. Non-destructive inspection method

Contents	Inspection methods
Stripping of interface, Stripping between	Ultrasonic testing, Elastic impulse wave method
Void around rebar	Electromagnetic wave radar method
Surface of concrete	Visual inspection, Fiber scope

CONCLUSIONS

Based on the results of the examinations for concrete specimens and for actual bridge, which has existed in a cold and snowy area for over 30 years, this study investigated a repair system for the concrete slab end, which is damaged by the chloride. The conclusions obtained from this study are as follows:

(1) Chipping technique using a water jet robot for the deteriorated concrete in small clearance under slab on the abutment was developed.

(2) This study proposed shotcrete spraying method (a wet process) using polymer cement mortar with short fibers containing lithium nitrite, as a repair material. Specifically, the future corrosion of the rebar is inhibited by lithium nitrite.

(3) This study recommends estimation method for performance of repaired slab using non-destructive inspection methods.

REFERENCES

JSCE. (2007). "Standard Specifications for Concrete Structures Maintenance." *Guidelines for Concrete, 17*.

Araki, A. et al. (2004). "Properties of Repair Splayed Mortar with Accelerating Agent." *Proceedings of the Concrete Structure Scenario,* JSMS, 4, 253-260.