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Investigation of Deteriorated RC Slabs on Steel Girder by Chloride Attack of Deicing Salt

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ABSTRACT

The inspections and the investigations that we conducted upon the deteriorated RC slabs on the steel girders of expressway bridges in snowy areas in Chugoku region so far drew a supposition that the deterioration should have been mainly caused by chloride attack of deicing salt spread over the road surface in winter, and that it should have occurred at the upper surface of RC slab and extended downward. Further investigations upon deteriorated RC slabs under repairing and upon removed RC slabs after replacing were conducted. It became clear that the cold joints of asphalt pavement on RC slab should cause deterioration of the upper surface, passing-through cracks made by drying shrinkage or by vertical construction joints should also cause deterioration downward, and that inappropriate repairs of the upper surface of RC slab should probably accelerate deterioration of the slab. Furthermore, it was confirmed that some horizontal cracks in the slab were hardly detected by hammering test conducted on the upper surface of slab.

Keywords. RC slab, Chloride attack, Deicing salt, Deterioration, Investigation

1. INTRODUCTION

RC slabs on the steel girders of expressway bridges in Chugoku region, particularly where the expressway goes through snowy mountainous areas, are often partially repaired or totally renewed because of the slab delamination caused by corrosion of rebar in the RC slabs.

From the detailed investigations so far, it is considered that the slab delamination and rebar corrosion as well are caused by deterioration affected by chloride attack coming from deicing salt spread on the road during winter period. It is also considered that the salt water infiltrates into slabs through passing-through cracks.

In order to study further upon these considerations, detailed investigations upon the deteriorated RC slabs of particular bridges (Bridge E & F) before and after replacement were conducted in 2009 and 2010.

2. DETERIORATION MECHANISM FOR RC SLABS ON STEEL GIRDER

Typical deteriolation in appearance of RC slabs on the steel girder in Chugoku region is slab delamination caused by corrosion of rebar in the slab (Refer to Fig 1 & 2.). It is noted that the slab delamination often appeares on slabs on the steel girder located snowy mountainous area where deicing salt is spread over the road surface in winter period. Thus, it is considered that the slab delamination is caused by chloride attack of deicing salt(Honjo,2008).

Figure 1. Delamination around middle of slab

Figure 2. Delamination at the construction joint of slab

Slab delamination on the lower surface appears where water is leaking or leaked in the past. Detailed investigation at the time of repairing confirmed that the deteriorated area of upper rebar roughly coincided with the deteriorated area of the lower rebar (Refer to Fig 3). Few deterioration was observed separately on the lower slab surface except in the area where water was leaked through construction joints or drain pipes, whereas the deterioration often appears independently on the upper slab surface.

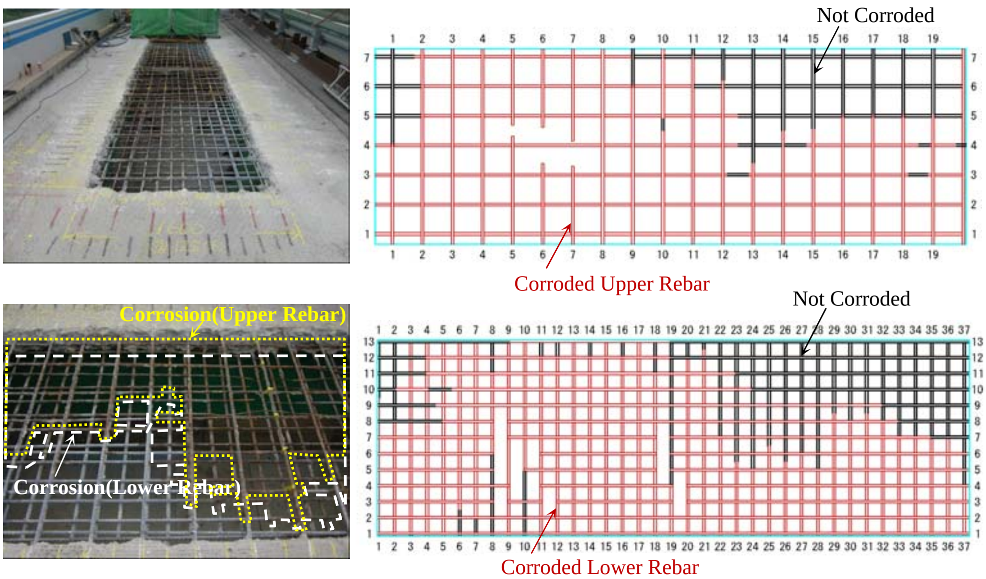


Figure 3. Corrosion area of upper and lower rebar of partially repaired slab

So far, deterioration mechanism and deterioration progress for RC slabs on steel girder have been considered as described below(Honjo,2008).

1) Deicing salt (NaCl) spread over the road surface melts into water, which can be either rain or melted snow, and the solution infiltrates into pavement and forms a pool on the upper slab surface. 2) The pooled solution further infiltrates into slab through cold joints or vertical passing-through cracks caused by drying shrinkage and temperature expansion/contraction . 3) Salinity in the solution destroys passive membrane of rebar and initiates corrosion. 4) Corrosion expansion forms cracks and slab delamination. Deterioration further develops as the solution infiltrates through cracks and spaces formed by a lost cover. (Refer to Fig 4)

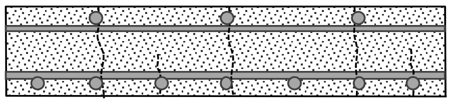
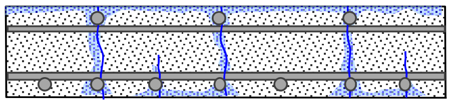
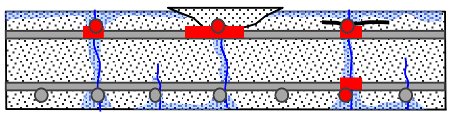
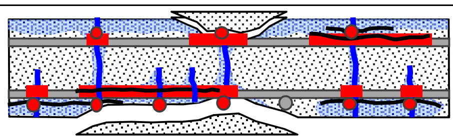
Deterioration Process	Images of deterioration progress in RC slab section
Initiation Stage	
Propagation Stage	
Acceleration Stage	
Deterioration Stage	

Figure 4. Deterioration progress in RC slab on steel girder

3. DETAILED INVESTIGATION OF EXISTING RC SLAB

3.1 Deterioration along Construction Joints of Pavement and of Upper Slab Surface

Normally, pavement repair is worked on the driving lane and the passing lane alternately to minimize traffic jam. Thus, the construction joints are inevitably formed along the center line. It is noted that the deterioration of RC slabs on steel girder is mostly actualized under the center line. As a typical case, a detailed investigation was conducted on the bridge E and F when a repairing was carried out.

It should be noted that there is a V shape ditch for drainage of melted snow carved outside of the lane mark on the shoulder side. When hammering test was conducted on the pavement, dull sound was detected in the wide area around the ditch (Refer to Fig 5, 8 & 9).

After the pavement was removed, upper slab surface was investigated. It was noted that there was slab delamination widely spread under the construction joint and ditch. It appeared to be true that the construction joint and ditch of pavement were the major water infiltration channels in the slab (Refer to Fig 6, 10 & 11).

The deteriorated area of the lower slab surface almost conformed to that of the upper slab surface. It was noted that there was slab delamination widely spread under the ditch area and water leakage was mostly actualized along construction joint near the center line (Refer to Fig 7, 12 & 13).

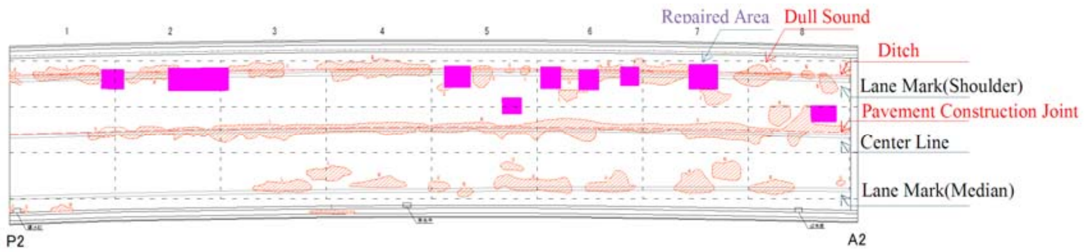


Figure 5. Slab Surface of Bridge E (Pavement)

Figure 6. Slab Surface of Bridge E (Upper slab surface after pavement removed)

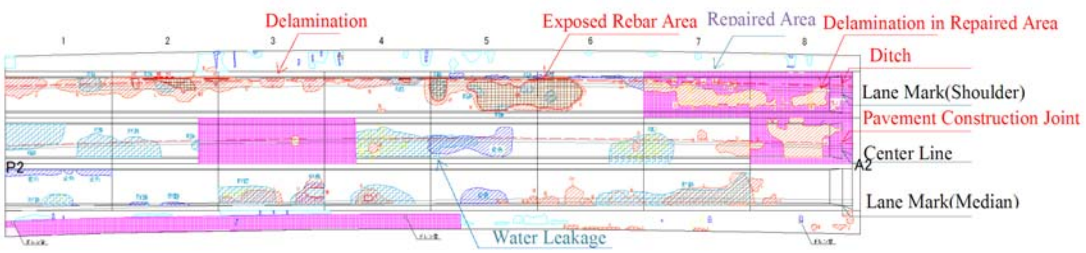


Figure 7. Slab Surface of Bridge E (Lower slab surface)

Figure 8. Pavement surface (Ditch)

Figure 9.Pavement surface (Construction Joint)

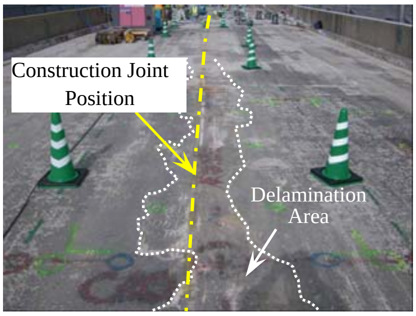


Figure 10. Upper slab surface (Under the ditch of the pavement)

Figure 11.Upper slab surface (Under the construction joint of the pavement)

Figure 12.Lower slab surface (Under the ditch of the pavement)

Figure 13.Lower slab surface (Under the ditch of the pavement)

3.2 Leaked Water Channel in the Slab

Deterioration mechanism is generally explained in such a way that salt water on the upper slab surface infiltrates into a slab through cold joints or vertical passing-through cracks caused by drying shrinkage and temperature expansion/contraction, and then the infiltrated water causes corrosion of rebar in the slab.

It is rather easily understood that the cold joint can cause leaked water channels in the slab, while a possibility of water channel caused by narrow cracks, which are mainly made by drying shrinkage, has not been quite confirmed. Thus, water leakage test was conducted by pouring water on the upper slab surface (Refer to Fig 14).

After pavement was removed, a water pooling device was prepared around deteriorated area on the upper slab surface. Then, liquid penetrant containing fluorescent pigment was poured in the pool. 3 hours afterward, liquid penetrant appeared through the cracks (less than 0.1mm width) on the lower slab surface (Refer to Fig 15).

The section of the removed slab was investigated in detail. Then it was confirmed that the actual deterioration mechanism was very similar to the image that had been presumed (Refer to Fig 16).

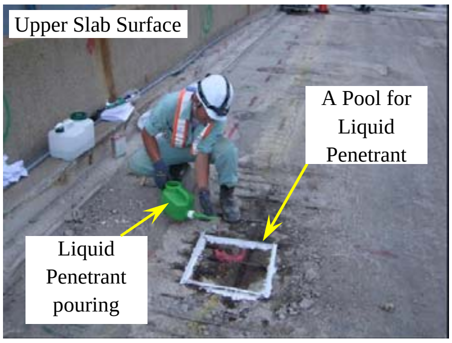


Figure 14.Liquid penetrant test on the upper slab surface

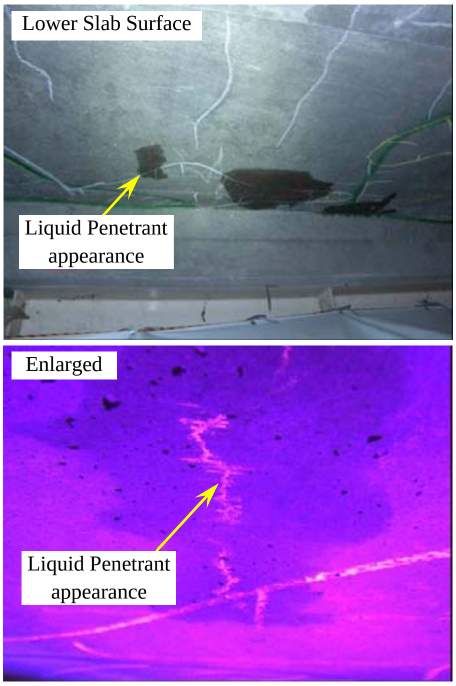
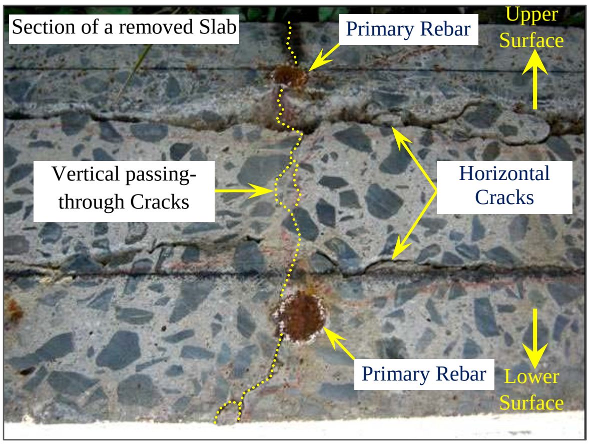


Figure 15.Liquid penetrant appearance on the lower slab surface



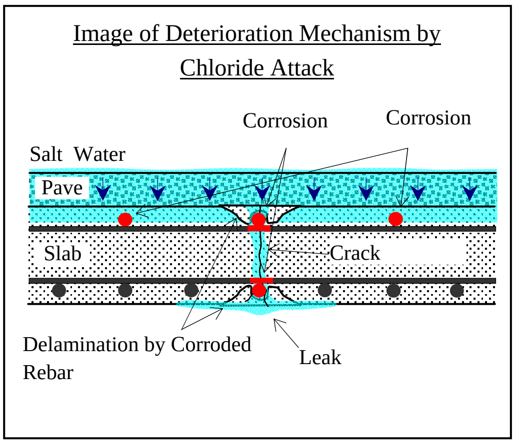


Figure 16.Section of a removed slab similar to an image of deterioration mechanism

3.3 Correlation between the Repair of Upper Slab Surface and the Deterioration of Lower Slab Surface

As mentioned before, it is considered that salt water on the upper slab surface infiltrates into a slab through construction joints or vertical passing-through cracks caused by drying shrinkage and temperature expansion/contraction. Detailed investigations on the section of the removed slab revealed that there were some cases to prove that the repaired area of upper slab surface roughly coincided with the deteriorated area of lower slab surface (Refer to Fig. 17).

In the case of an urgent repairing, such as a pothole(peeling of pavement) repairing, repairers cannot necessarily work in a good condition in terms of weather or time constraint. As a result, the repair work may not be totally satisfactory in quality. The repaired part of the slab may not completely adhere to the base slab, of which boundary could easily develop into water leakage channel. Accordingly, such inappropriate repair work causes deterioration of the base slab (Refer to Fig. 18).

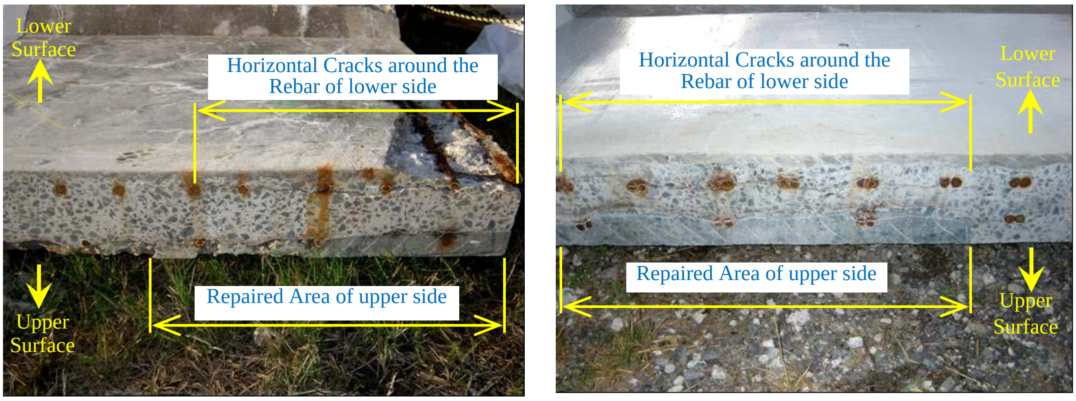


Figure 17.A case of deterioration developed under the repaired area

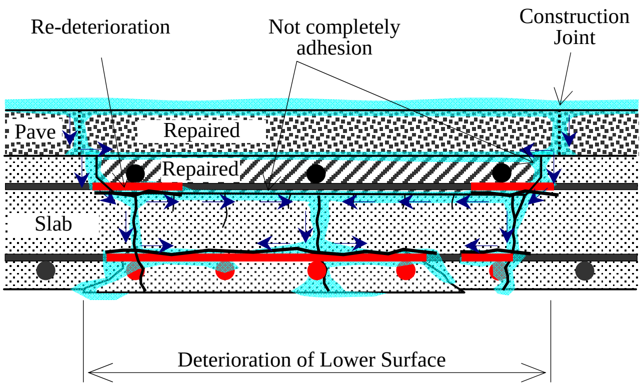


Figure 18.An image of deterioration developed under the repaired area

3.4 Unpredictable Horizontal Cracks

On the cross sections of the removed RC slab on which delaminations are widely spread, horizontally developed cracks (hereunder called horizontal cracks) can be seen along the delamination boundary. Such horizontal cracks were also observed on the removed slab sections of Bridge F. It should be noted however, some of these cracks could not be detected by hammering test (Refer to Fig. 19 & 20).

Detailed investigations shows that horizontal cracks located in a rather shallow area (approximately less than 40 mm in depth) or, cracks located in a deep area with a wide crack width can be detected by hammering test. However, horizontal cracks located in areas more than 50 mm in depth with a narrow crack width failed to be detected by hammering test even performed by a skilled inspector (Refer to Fig. 21).

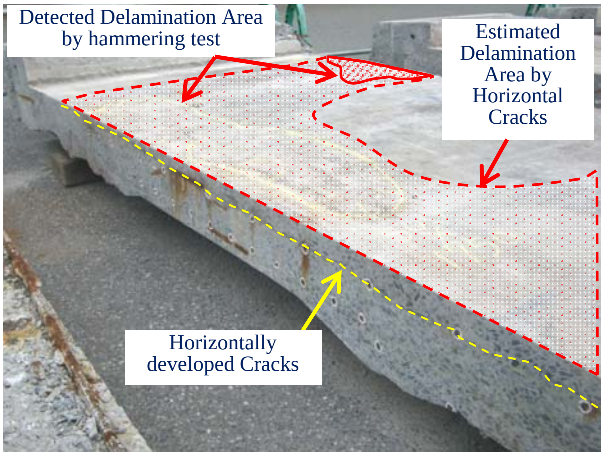


Figure 19.Comparison between the delamination area detected by hammering test and the delamination area estimated by horizontal cracks

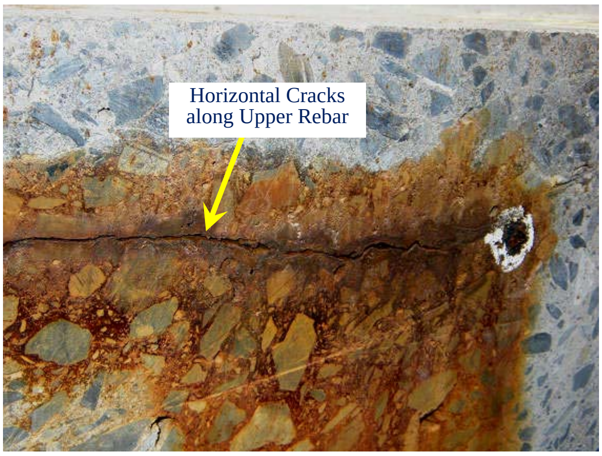


Figure 20.Horizontally developed cracks

Detectable in all area (40~70mm in depth) | Detectable in partial area (40~70mm in depth) | Not detectable (50~70mm in depth)

Figure 21.Horizontal cracks detected by hammering test

4. CONCLUSIONS

Findings resulted from the detailed investigation of the existing slabs are summarized below.

(1) Construction joints and drainage ditches can be major causes to accelerate the deterioration of upper slab surface.

(2) It was confirmed that vertical passing-through cracks can become the leaked water channels through the slab.

(3) Inappropriate repair work on the upper slab surface can cause deterioration of the lower slab surface.

(4) Horizontal cracks located in areas more than 50 mm in depth and with a narrow crack width are not always detectable by hammering test.

REFERENCES

Kiyoshi Honjo et al.(2008).”Field Investigation of Deteriorated RC Slabs on Steel Girder by Chloride Attack of Deicing Salt”, Proceedings of the Concrete Structure Scenario,Oct.2008,Japan,JSMS,Vol.8,pp.125-130.