The influence of anti-freezing agents on the deck of highway bridge, and its countermeasures

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ABSTRACT
Recently, the deterioration and damage to bridges, which were constructed in the period of high economic growth, to handle the growth of traffic and the increased of heavy vehicles, are becoming serious issues. Also, in regions which have heavy snow, we sprinkle anti-freezing agents on the road surface of highway bridges to maintain the safety in driving. But some people point out that there is salt damage and deterioration from the anti-freezing agents to the decks. Therefore, to manage the highway bridges efficiently and accurately within a limited budget and time is a task for the road managers.This thesis reports the construction to replace a part of the RC deck, which was damaged by fatigue and salt after 40 years from the date of commencing service. Since this construction was conducted under various conditions, we examined how to manage the highway bridges, which have salt damage, after their construction.

1. INTRODUCTION

Recently, the deterioration and damages of bridges, which were constructed in the period of high economic growth, to handle the growth of traffic and the increased of heavy vehicles, are becoming serious issues. Also, in regions which have heavy snow, we sprinkle anti-freezing agents on the road surface of highway bridges to maintain the safety in driving. But since the anti-freezing agents, which was sprinkled over the surface of bridges, melts into the water on the road surface and erodes the reinforcing bars within the deck, salt damage occurs. And it brings about the development of many pot holes on the road surface[1)] [2)] . Therefore, it is our task to grasp the status and reasons of the damage on the deck and to maintain it efficiently within a limited budget and time.Michinoku Bridge on TOHOKU Expressway, which is the research target in this thesis, has heavy traffic since it is located near Tokyo metropolitan area. It also has heavy snow during winter since it is located in a mountain area. 40 years have passed from the day of commencing service, and since pot holes frequently occur on the road surface, damage to the deck was suspected. Though aging and an increase of traffic could be one of the reasons, we thought the damage from the anti-freezing agents to the deck must be a major reason, because we have sprinkled anti-freezing agents continuously during winter to prevent the road surface from freezing from snow.When we were discussing repair scenarios, a punching out of the damaged deck was proposed because of the reduction of congestion and budget considerations. Therefore, after an inspection of the damaged road surface and decks, we conducted a salinity measurement research to clarify the salinity and the damage to the deck to decide the range of punching out. The main construction was carried out from 2011 by the partial punching out with the WJ method and placing the extra rapid hardening concrete while traffic control was addressed throughout day and night (15 times).

Since we conducted the salinity measurement research, we report the analysis and considerations of the relationship between the anti-freezing agents and the damage on the deck in this thesis. Also, since this construction was conducted under various conditions such as time and budget, based on the result of the construction, we examined the maintenance method of highway bridge decks, which have salt damage, after their construction.

2. MICHINOKU BRIDGE

2.1 Outline of Michinoku Bridge

Michinoku Bridge is located between Nasu IC and Shirakawa IC on TOHOKU Expressway, which is the longest highway in Japan (698.0km). Since service started in 1972, the bridge has been used as a main artery between Tokyo and the main cities in 8 prefectures. But recently, the structure and pavement have become superannuated considerably. The average daily amount of traffic in the jurisdiction in 2011 is about 38,000 vehicles. （(the general chart (Figure 1, 2, and 3), the outline (Table 1)）

Table 1-Outline

Type of bridge	Steel 3 trave continuous non-composite girder bridge ×3 sets
Road structure	2 lanes on each side, there are 4 lanes in total
Length of bridge	330.0m
Length of effective span	36.5m×9trave
Longitudinal slope	1.66%～3.0%
Cross slope	6.00%
Alignment	A=400m～R=700m～A=150m
Commencing service	1974

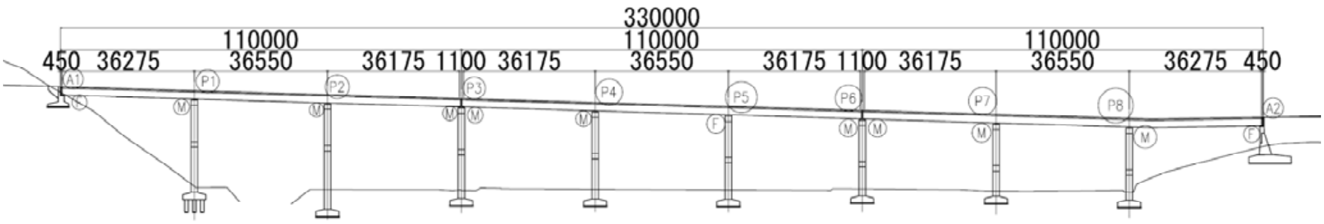

Figure 1-Side view

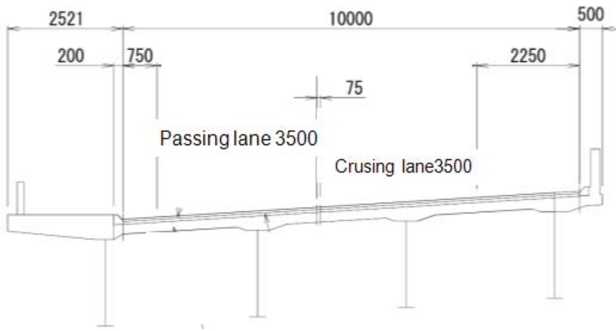

Figure 2-Cross section

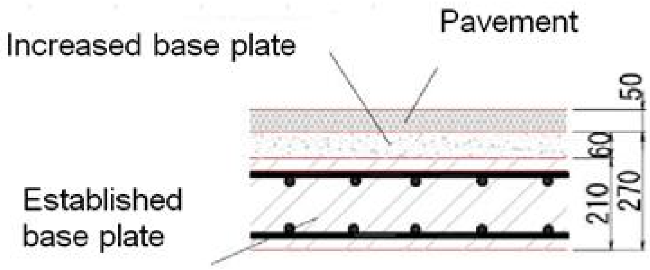

Figure 3-Cross section of the pavement and the base plate

2.2 The damage and repair history

Since pot holes occurred frequently, we conducted research to discuss the reinforcement of the deck and repair of the damaged section when 15 years had passed since the commencing of service. Also, to handle the increase in the size of vehicles and amount of traffic, construction to increase the thickness of the deck with steel fiber concrete was planned. The construction was conducted on the down line in 1995, and on the up line in 1996.The pavement repair, including replacing the deck, was intensively conducted, because pavement damage such as pot holes, cracks, and subsidence occurred frequently on the cruising lane of the up line since 2004.The repair methods included the cutting of the pavement in the damaged spot, and afterward, we conducted a deck inspection and cleaning. And we cut down the loosened concrete little by little. Then, after we poured super rapid hardening concrete, performed water proof processing on the deck and finished it with the heated asphalt.We will report the findings for the damage to the RC deck, which was conducted in the deck repair construction on the next section of this thesis.

3. RESEARCH ON DAMAGE TO THE RC DECK WHICH HAD SALT DAMAGE

The following is the work flow for the damage research for Michinoku Bridge. (Figure4)

3.1 Detailed inspection (distant visual observation・sound inspection)

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3.2 Structure repair inspection (Impact echo inspection)

3.3 Base plate repair plan research (stick scanner・salinity measurement research)

3.4 Prior research from the hanging scaffoldings for the construction
4. Construction(Close visual observation from the hanging scaffoldings・sound inspection, salinity measurement research)

Figure 4-Work flow

3.1 Detailed inspection

3.1.1 *Purpose*

A detailed inspection, which is included in the inspection work, is conducted once every 5 years to ascertain the extent of damage to the structure over-all and to apply the results to make a structure repair plan to follow.In this section of the thesis, we report the results of the primary plate inspection on Michinoku Bridge which was conducted as a detailed inspection in the Nasu jurisdiction in the 2006 fiscal year.

3.1.2 *Methods*

A detailed inspection is conducted to evaluate the soundness of the structure by inspecting the status of each structure in detail with close visual observation and sound wave reflection test etc. However, since there was a difficulty of close inspection by using inspection isles and scaffolding on Michinoku Bridge, we decided to conduct a distant visual observation with field glasses. Concerning the sound wave reflection test, we conduct a sound wave reflection test in the range which we can approach from the inspection isle to grasp the exfoliation of the structure, looseness of the bolts, etc. Table 2 shows the division to judge the change status in the detailed inspection.

Table 2-Division to judge the change

Division to judge		General status
Assessment of the change status	AA	The change is extreme and highly influence the performance deterioration of the structure.
	A1	The change is progressed and highly influenced to the performance deterioration of the structure.
	A2	The change is progressed but influenced little to the performance deterioration of the structure.
	A3, B	The change is recognized but it doesn't influence the performance deterioration of the structure.
Impossible to judge the change status	R	Investigation has to be conducted to judge the change status.

3.1.3 *Results*

（1）Free lime

We conducted research for the occurrence status of free lime from the bottom of the deck. Table 3 shows the results and Picture 1 is a photograph of the inspection work. Compared with the primary plate of the other bridges, there were more Assessment A free limes on the primary plate of Michinoku Bridge. Inspections of each panel revealed, free lime had developed on 54 panels out of 378 panels.

（2）Exfoliation, floating, exposure of reinforcing bars, cavity, honey comb

We conducted research for the occurrence status of exfoliation, floating, exposure of reinforcing bars, cavity, and honey comb on the primary plate. Table 4 shows the results. And Picture 2 is a photograph of the research work. Compared with the primary plates of other bridges, there was more exfoliation and floating on the primary plate of Michinoku Bridge. Concerning the reasons, we considered that the anti-freezing agents got in the cracks, which occurred because of the curbstone above the G4 girder, and brought on salt damage.

Picture 1-Free lime on the primary plate (assessment A3)

Table 3-Damage assessment of the free

Name of the bridge	Division of the lines	Assessment	Number of the spots	Amount(m²)
Mchinoku Bridge	Up line	A2	7	0.46
		A3	22	6.25
		B	39	25.38
	Down line	A2	8	0.74
		A3	12	5.22
		B	9	3.88

Picture2-Exfoliationon the primary plate (assessment A3)

Table 4-Damage assessment of exfoliation, floating, exposure of reinforcing bars, and cavity

Name of the bridge	Types of damage	Assessmen	Number of the spots	Amount(m²)
Mchinoku Bridge	Exfoliation	A3	14	1.74
		B	17	0.5
	Exposure of reinforcing bars	B	3	0.05
	Floating	A3	32	5.37
		B	7	0.16
	Cavity	A3	2	1.39

We were able to grasp the damage to the surface of Michinoku Bridge through this detailed inspection. However, since there is a limitation involving the close inspection from the inspection isle and by the distance visual observation with field glasses, we couldn’t clarify the relationship between the road surface damage, such as pot holes which occurred on the pavement, and the damage to the deck. Therefore, we had to conduct a detailed assessment of the damage on the increased deck and the established deck.

3.2 Structure repair research

3.2.1 Purpose

Based on the results of the detailed inspection mentioned above, concerning the damage status of the increased deck and the established deck, there was a possibility of interfacial peeling. Therefore, we conducted the 2006 structure repair research. In this section of the thesis, we report the damage on the deck which we detected with the non-destructive impact echo method.

3.2.2 *Method*

To clarify the damage status of the inside of the increased deck and the inside the established deck, we conducted a non-destructive inspection with the impact echo method. The impact echo is a method to ascertain the status of inside the structure from the amplitude responsive waveform on the surface, which was obtained by creating an impact directly to the surface of structures to generate stress wave. If there is any vacant space or cracks inside the concrete, a reflection of the sound will occur and the peak will be observed in the strength of the reflection frequency. In this research, we performed the impact echo method from the bottom of the deck to all the panels. We checked at least one spot per one panel, and we checked 389 spots in total.

3.2.3 *Results*

Figure 5 shows the comprehensive evaluation which is a superposition of the damage assessment with the impact echo method and the road surface repair history. As far as the results of this inspection, only 21 panels were evaluated as normal. This is about 11% of the 189 panels in total. We found 59 panels which have defective parts with damage in a wide range. This is about 31% of the 189 panels and they are located all over the bridge. Also, we found that not only the parts had road surface damage in the past, but also most panels had some form of damage. Though we tried to identify the status and the range of the damage by referring to the existing road surface data, it was not successful with the results of the impact echo method exclusively. To make the accuracy higher, it is necessary to conduct an advanced inspection, for example by conducting a sample taking or a full-scale inspection of the pavement, on the panels which were evaluated as damaged with the impact echo method.

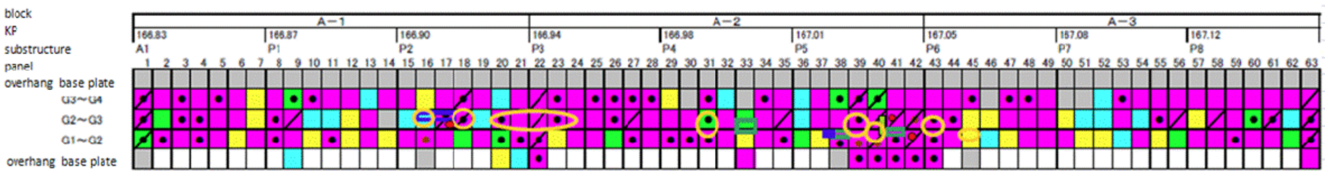


Figure 5- The total evaluation of damage

The list of total evalution results

			/		/			計	●	●/	●	●/	計
G3～G4	3	42	5	2	1	5	5	63	16	4	0	0	20
G2～G3	6	28	14	4	0	10	1	63	12	5	0	1	18
G1～G2	12	38	4	6	1	2	0	63	15	3	2	1	21
Subtotal	21	108	23	12	2	17	6	189	43	12	2	2	59
Total of the defective area	21	145				17	6	189	55		4		59
Overhang base plate	1	8	0	0	0	2	4	15	6	0	0	0	0

Legend

- Sound
- With defective areas
- There are both sound areas and defective areas
- Though there is no reflection wave from defective area, it cannot be judged as sound.
- Impossible to analyze
- ● The panel which has an area that doesn't have any reflection waves from the back side of the shocked side, and is assumed to have comparatively wide cracks.
- ● By the results of the probe of mirror face side
- Construction on the deterioration of steel fiber concrete
- No data of measurement
- Road surface repair･Pavement replacement
- Super rapid harden concrete・Pavement replacement
- Urgent repair history such as pot holes

3.3 Deck repair designing research

3.3.1 *Purpose*

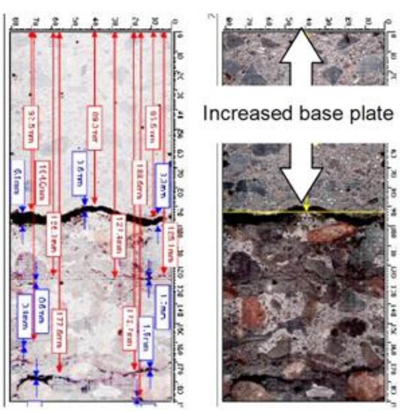
From the results of the structure repair research mentioned above, it is clear that damage has occurred in a wide range on the increased deck and the established deck. However, it was necessary to accurately guage the damage status of the deck such as cracks, mudification, stagnant water etc., to decide the repair range according to the damage status, to discuss the repair methods, or to make designs and construction plans. Therefore, we removed the pavement in Michinoku Bridge deck repair designing inspection in 2008, and we conducted the soundness research of the increased deck, monitoring research of inside the deck with a stick scanner, and salinity measurement research.In this section of the thesis, we report the results of monitoring inside the deck and the salinity measurement, which were conducted after we removed the pavement.

3.3.2 *Method*

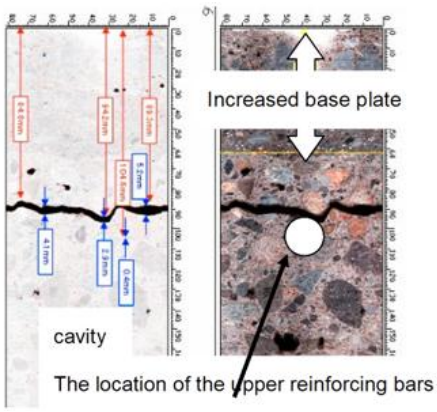
Based on the results of the impact echo research on the structure repair examination mentioned above, we selected 22 typical spots, such as to which part is considered to have severe damage, the part in which pot holes frequently occur, and so on. Also, to compare the results of the research, we conducted research on the spots where were evaluated as sound in past inspections. We removed the pavement for a range of 100cm×100cm, and conducted a visual observation and soundwave reflection test of the increased deck.If the increased deck is satisfactory, we take a small core with Φ＝25mm from the increased deck to the established deck and conduct a salinity measurement with fluorescent X-ray analysis and observation of inside the deck with a stick scanner. Concerning the salinity measurement, we measured it in the direction of depth at 10 spots at intervals of 2cm.

3.3.3 *Results*

Picture 3 shows the core of the cruising lane of P2-P3, and Picture 4 shows a core of the cruising lane of P3-P4, which are evaluated as “having damaged areas” in the impact echo inspection mentioned above. In Picture 3, which was taken by the stick scanner, we found a 6.1mm horizontal crack at 92.8mm from the surface and a 1.7mm horizontal crack at 126.3mm from the surface. Since the thickness of the increased deck is 93mm, it turned out that the horizontal crack on the surface side occurred on the boundary of the increased deck and the established deck. Concerning the horizontal crack on the bottom side, since it is located at about 180mm from the deck surface, it can be considered that it exfoliated somewhere around the reinforcing bars on the bottom side. Also, there was a horizontal crack in the idle of the established deck at 126.3m from the surface of the deck.From Picture 4 which was taken by the stick scanner, we found a 5.2mm horizontal crack at 89.4mm from the surface side, and a 10.4 horizontal crack at 104.6mm from the surface side. Since the thickness of the increased deck is 62mm, it turns out that the upper horizontal crack occurred on the upper reinforcing bars in the established deck. Also, we found out there is a cavity in the deck.As well as in the results of other observations, we found horizontal cracks around the boundary of the increased deck and the established deck in 5 spots out of 22 spots. The reason can be considered that the increased deck and the established deck didn’t unite properly because of the grinding, cleaning, and compaction were not good enough when the increased deck was positioned in 1996. Also, there are 10 spots out of 22 spots in which we found horizontal cracks in the established deck. The reason for these cracks can be considered that micro cracks occurred in the established deck because of the concrete breaker when the increased deck was positioned in 1996, or erosion of the reinforcing bars because of salt damage. Also, we found a water effusion in the deck, though we performed water proof processing when the increased deck was positioned. The reason could be that water entered from the damaged curbstone and joints of the road surface and remained. Also, the infelicity of the selection of water proof processing for the deck or the methods of surface processing, and the malfunction of water proofing in the deck because of external influences such as the aggregate and the weight of the traffic etc, could be another reason to find stagnant water inside.



Picture 3-A photograph of the core(P2-3)



Picture 4- A photograph of the core(P3-4)

Figure 6 shows the results of the salinity measurement with a portable fluorescent X-ray in P2-P3 of the cruising lane. Since we added the data for horizontal cracks which were obtained from the inspection with a stick scanner, the relevancy of the salinity can be observed in the graph. The results of the salinity measurement show that the salinity is high on the boundary of the increased deck and the established deck and around the horizontal cracks. It is because the water which includes anti-freezing agents entered from the damaged parts of curbstones and wheel guards, and spread to the boundary of the increased deck and the established deck, and the horizontal cracks in the deck, we concluded.Also, the horizontal cracks which occurred in the spots with high salinity have a high possibility that the reason is an erosion of the reinforcing bars because of salt damage.

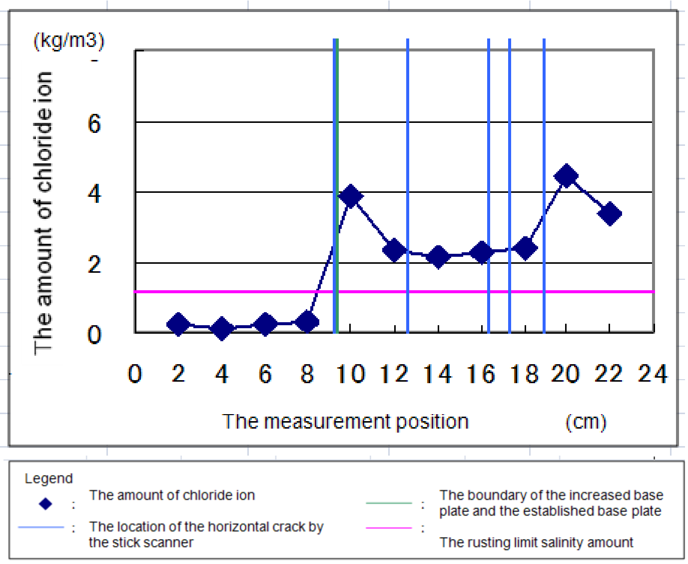


Figure 6-The results of salinity measurements

3.4Prior inspection

3.4.1 *Purpose*

Since we found horizontal cracks in the boundary of the increased deck and the established deck and inside the established deck in the deck repair design inspection mentioned above, we decided to perform the punching out of the increased deck and the established deck. Therefore, we conducted a prior inspection to make the final decision of the punching out range.

3.4.2 *Method*

We conducted a close visual observation, sound wave reflection test, and salinity measurement by positioning hanging scaffolding on Michinoku Bridge. In the close visual observation and sound wave reflection test, we grasped the soundness of the structure by checking the sound with designated hammers. We conducted the salinity measurement in 5 spots across the damaged range and the sound range. We measured salinity at the interval of 100mm, at every 20mm in the direction of the depth until 100mm. We conducted these inspections in 22 spots.

3.4.3 *Results*

Different from the detailed inspection, since we could inspect the bottom of the deck by the close visual observation from the hanging scaffolding, we were able to find new damage.

Figure 7 shows the results of the salinity measurement research. From the damaged area to the sound area, the concentration of salinity tends to decrease. Also, it is clarified that if we decide the punching out range for +200mm from the damaged area toward the sound area, the Chloride ion concentration goes below 2.4kg/㎥ (this standard is the occurrence limit line which is referred from the bridge repair construction which NEXCO East has conducted thus far). The same results were obtained in the other inspection spots, too. Seeing the salinity concentration at each depth, revealed that the salinity concentration in the damaged area is higher in the bottom area, and it goes lower toward the middle of the deck. Before this research we set the punching out range on the deck of Michinoku Bridge for 184 ㎡, but we decided to set it for 283 ㎡, which is 100 ㎡ more than the original plan, according to the results of this research. (Figure 8)

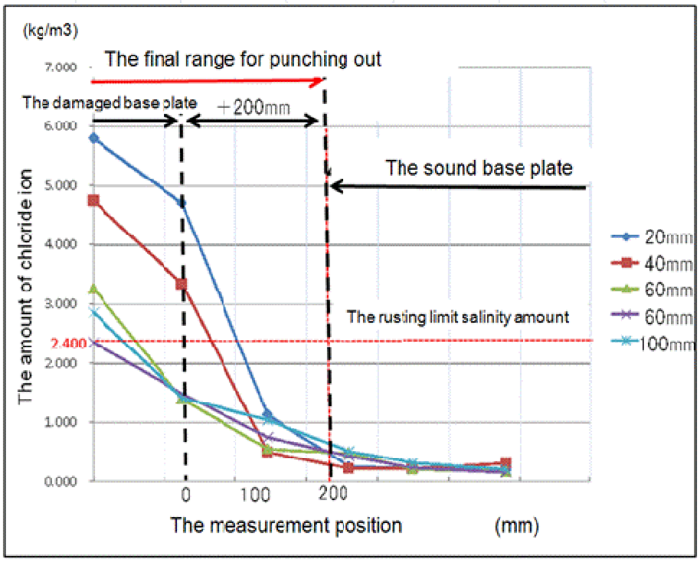


Figure 7-The results of salinity measurements (P5)

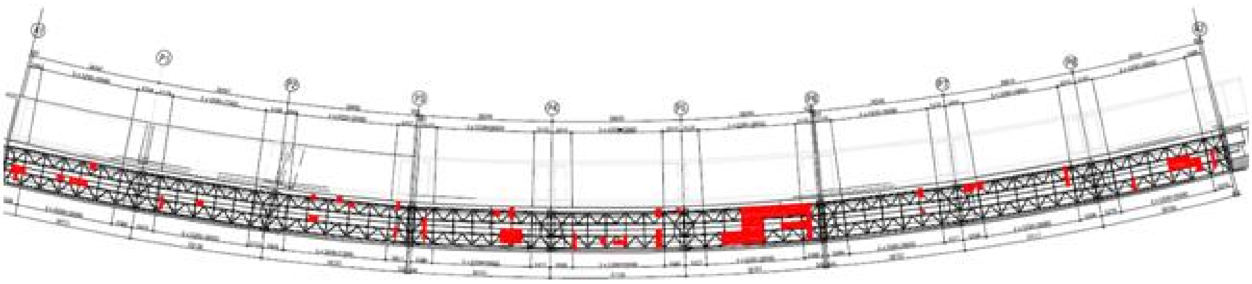


Figure 8-The range of punching out on the base plate (the red part)

4. OUTLINE OF THE CONSTRUCTION

Through the researches thus far, we found many horizontal cracks on the increased deck and the established deck. Therefore, we conducted a man-powered chipping with a breaker for the entire part of the increased deck (2370 ㎡), and a water-jet chipping for the top 30mm of the established deck. When we first positioned the increased deck, we tried to unite the decks by performing a surface finishing through shot-blasting on the established deck. But in this construction, we tried to unite the decks by chipping the top 30mm with water jet to remove the weaken and damaged part. Also, we conducted a replacement in the area in which a high salinity in the deck was recognized in the horizontal crack and salinity measurement research, including the established deck (283 m^2). Concerning the punching out part, after cutting the pavement with a cutting machine, we conducted chipping with water jet in the 200mm range of the punching out part so as not to create micro cracks in the structurally sound established deck. Concerning the punching out in the deck area, after pouring super rapid hardening concrete, we inserted the joint glue and positioned SF concrete to pave it. (Picture 3 – 14).Also, as the results mentioned in 4.3.3 above shows, since there was the possibility of water effusion from curbstones to the deck, we set-up an edge water conveyance in the curbstone part, after we fixed the deck and pavement. (Figure 9)The water which dispersed to the edge will be guided to the catch basin of the bridge, through the edge water conveyance. Picture 15-17 are photographs of the construction.

Picture 3- Cutting the road surface

Picture 4- Sound inspection

Picture 5-Man-power chipping

Picture 6-Stagnant water
in the established base plate

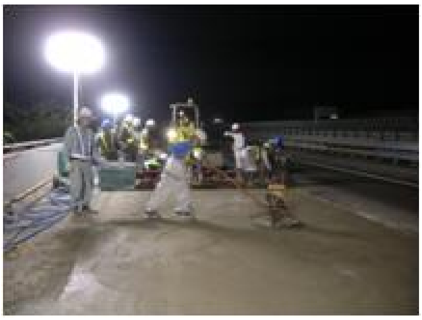
Picture 7-Base plate goes
into sand state

Picture 8- Defect of reinforcing bars

Picture 9-Horizontal crack

Picture 10-Chipping by water jet

Picture 11-The punching out part on the base plate



Picture 12-Applying joint glue

Picture 13-Pouring steel fiber concrete

Picture 14-Paving

Picture 15-The positioning status of the edge water

Picture 16-Connection to the bridge drain

Picture 17-Paving

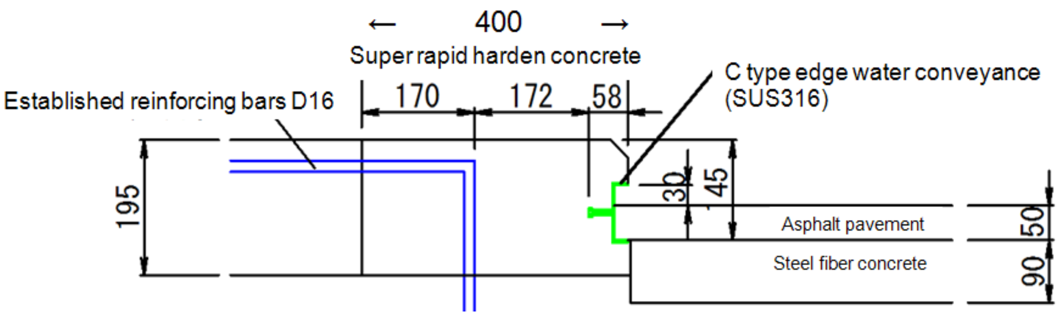


Figure 9-Section c

5. CONCLUSION

This thesis reported the methods to assess the damage status of the RC deck because of salt damage deterioration in a snowy-cold region, and its countermeasures. Since we found significant damage on the increased deck and the established deck, the entire replacement of the deck was one of the choices. However, considering the social impact of traffic closure, an increase of traffic accidents for one way traffic, and economic efficiency, we selected the chipping of the whole part of the increased deck, and the total replacement in cases where there is damage to the established deck.Through the nondestructive inspection and the prior inspection, we found cavities, stagnant water, horizontal cracks etc. inside the decks, though they were evaluated as structurally sound from their appearance. Since there are significantly many horizontal cracks in the position of the reinforcing bars in the established deck and the salinity is extremely high there, it can be considered that anti-freezing agents, which were sprayed during winter, seeped into the increased decks and the established deck through the pierced cracks and eroded and expanded the reinforcing bars to promote the horizontal cracks. Also, since many highway bridges in Japan have already been deteriorated, the salt damage deterioration caused by anti-freezing agents might decrease the load bearing capacity and durability with fatigue greatly. Therefore, it is necessary to assess the inside damage of the deck quickly and accurately. So, it is necessary to evaluate the structurally soundness by visual observation from the surface and bottom side of the deck, and by a sound wave reflection test, non-destructive inspection, salinity measurement research, etc. Concerning the detailed inspection, which is mentioned in this thesis, we used to depend on the visual observation from a distance with field glasses because of the structural problems and economic efficiency. However, since we conducted a close visual observation, sound wave reflection test, non-destructive inspection, salinity measurement, etc., from the hanging scaffolding which we positioned in the prior inspection, we were able to assess the damaged range more accurately. From these results, it must be important for the maintenance and management of the highway bridge in snowy-cold regions to build inspection isles and scaffolding to periodically evaluate the total soundness of the deck, even when the bridge is being built. Also, since we consider that one of the reasons for the deck damage is water including anti-freezing agents, which entered from curbstones and reached the deck, as a countermeasure, we positioned the edge water conveyance, which guides the water on the edge to the catch basin, on the curbstone part.

In the end, the construction was completed on February 14, 2013, under various restrictions on the TOHOKU Expressway, which experiences a lot of traffic, without any accidents or any disasters. We would like to express our deepest gratitude to everybody who supported this construction.

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