STUDY ON GROUT CONDITIONS OF EXISTING PRESTRESSED CONCRETE BRIDGES

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Abstract

Against the background of recent cases of deficiencies attributed to insufficient grouting of prestressed concrete (PC) bridges, we conducted a study of conditions of grouting for existing PC bridges demolished due to obsolescence, remarkable defects or other reasons.

This paper presents the results of our grout condition surveys from the section cuts, using non-destructive testing methods and dissection of some demolished PC bridges, and examines the influence of grout condition on corrosion of prestressing cables.

The results of the study confirmed that where there is sufficient grouting inside the duct, PC cables are nearly always well protected even in severe or harsh environments.

Introduction

Prestressed concrete (PC) bridges in which cracking is mitigated by prestress, are generally considered to be highly durable. On the other hand, deteriorations such as strength and durability losses occurs in some PC bridges due to corrosion and breakage of prestressing cables which results from insufficient grouting and/or chloride attacks from airborne salts , the use of deicing salts, or even the use of sea sand in the concrete. Recently, there have been increasing reports about insufficient grouting in prestressed concrete bridges . For those bridges, water including sea salt or de-icing salt can seep into the ducts to cause corrosion of prestressing cables.

Figure1. Corroded and Broken Cables in Precast Segment Box Girder Bridge

Figure 1 shows corroded prestressing cables in a precast segment box girder bridge. An thorough investigation found that grout was not properly filled in the most of ducts. Many cables were already broken.

Against the background of recent cases of deficiencies of PC bridges, we conducted a "clinical study by using actual demolished bridges". The final goal of the study is to establish evaluation methods for

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deteriorated bridges.

In this paper, recent cases of PC bridge deficiencies due to insufficient grouting and CAESAR's research activity utilizing decommissioned bridges are presented.

Transition of Technical Standards in Japan (Anchor of PC Cables)

Figures 2 and 3 are conceptual drawings showing the anchor on the upper surface, and transition of cable anchorages at T-Shaped Post Tension Girder, respectively.

In addition, Table 1 shows a transition of anchorages in the standard T-shaped post tension girder established by the Ministry of Construction (MOC).

From 1969 when the original standard was established by MOC, to 1979, half the prestressing cables were anchored on the upper flange regardless of span length.

Before 1993, lots of multi-wire cable (e.g., 12 ϕ 5, 12 ϕ 7) were usually used by anchoring both on the end of girders and the upper surface, because of weak tensioning force.

Nowadays, use of multi-strand cables (e.g., 12S12.7, 12 S15.2) have improved the tensioning by expansion of the cross sectional area and all cables are anchored at the ends of girders.

Although the area around the anchorage zone on the upper flange is usually filled by non-shrinkage concrete at the time of construction, water on the road surface may seep into the ducts through these anchorages. And if the ducts are not grouted properly, the water causes corrosion and breakage of wires.

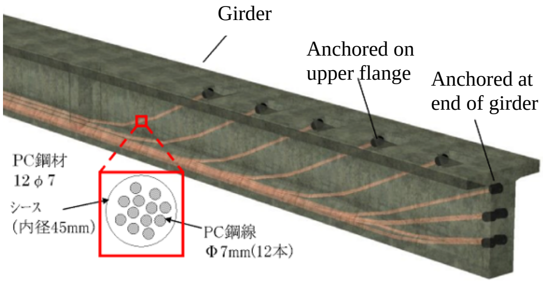


Figure2. Conception of anchor on the upper surface of T-Shaped Post Tension Girder

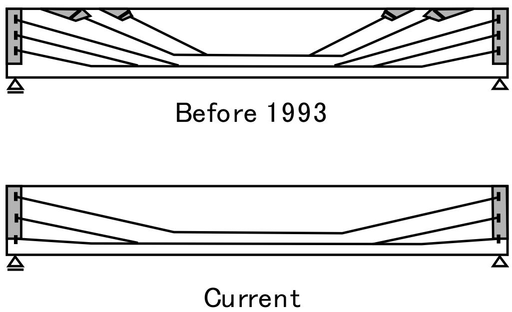


Figure3.Transition of anchorages of T-Shaped Post Tension Girder

Table1. Transition of anchorage of T-Shaped Post Tension Girder
(Standard design established by the then Ministry of Construction)

1969	1980	1994
Half of cables are anchored on the upper flange	(27m or less) Half of cables are anchored on the upper flange	All cables are anchored at the end of girder
	(28m or more) All cables are anchored at the end of girder	

Grout condition survey by demolished PC Bridges

To clarify relations between corroded or broken cables and insufficient grouting, we conducted a grout condition investigation using demolished bridges.

Table 2 shows the dimensions of demolished bridges due to obsolescence, remarkable defects such as salt damage, et al.

Table2. Dimension of demolished bridges

Bridge	Year built	Type of bridge	Structural type	Maximum span	# span/ # girder	Influence of salt damage	Anchored on the upper surface	Grout condition	Broken Cables	Case
A	1965	Road bridge	T-Shaped Post Tension Girder	39.9m	5 / 6	By coast	Yes	Not filled	Yes	-
B	1972	Pedestrian bridge		29.2m	3 / 2	60m from coast				-
C	1967	Road bridge		27.3m	5 / 5	80m from coast	No	Partially void		Case2
D	1972	Pedestrian bridge		23.2m	2 / 2	90m from coast	Yes			Case3
E	1965	Road bridge		22.8m	5 / 3	No influence		Not filled	No	Case1
F	1961			18.3m	2 / 5					

These bridges were built and grouted based on the "PC grout guidance" established in 1961 by the Japan Society of Civil Engineering. PC bridges constructed before 1961 were simple beams with usually, spans of less than 30m.

However from 1960’s through 1970’s, the quality control of grouting showed only paying attention as follows might not catch up with construction technology of PC bridges that bring long span bridges. The requirement in “PC grout guidance” Article 8 is “Must perform continuous grouting without stopping until grout of equal consistency flows out from all outlets”.

For this study, several bridges shown in Table 2 can clarify the influence of grouting conditions inside a duct on the corrosion process are described in the following chapters. Bridge A and B, both mainly influenced from salt damage were excluded.

Case 1 (E bridge)

The E Bridge was a 5-span simply-supported prestressed concrete bridge with T-shaped post tension girders (Figure 4), constructed in 1965. Although the bridge had no remarkable defects, it was demolished to make way for a new bridge to be built because the original narrow bridge deck was not safe for children commuting to school. In the demolition work (Figure 5), each girder was cut into three pieces longitudinally.

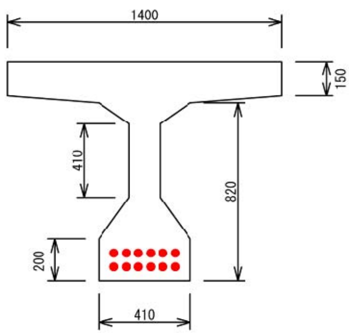


Figure4. Cross-sectional configuration of E bridge

Table3. Classification of grout condition

Class	Grout condition		Remarks
Level 1	Sufficient fill		Sufficient rust-proofness and bonding of cables
Level 2	Partial void		
Level 3	Insufficient grouting and cables are exposed		Insufficient rust- proofness and bonding of cables
Level 4	Not Filled		

Figure5. Demolition Site of E Bridge

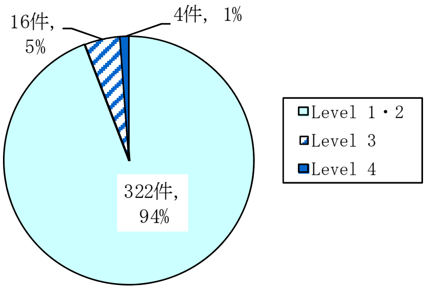
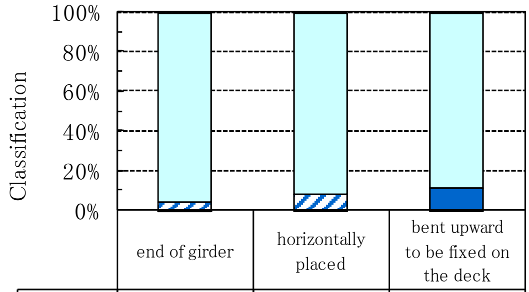


Figure6. Grout condition of E Bridge



	end of girder	horizontally placed	bent upward to be fixed on the deck
Level 1・2	229件	78件	15件
Level 3	9件	7件	0件
Level 4	2件	0件	2件

Figure 7. Grout condition classified in every part

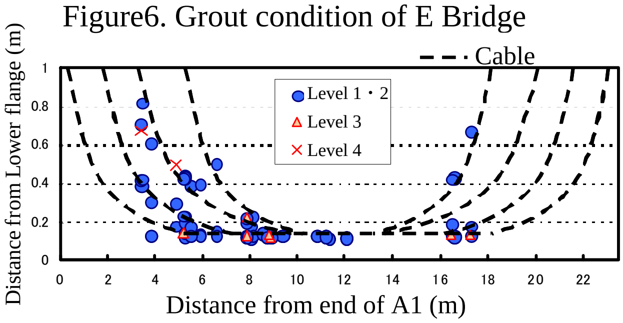


Figure8. Grout condition of cables anchored on the upper flange

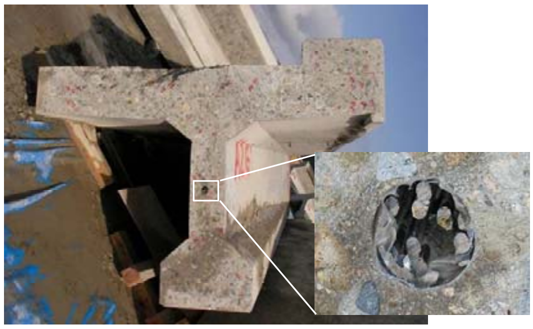


Figure9. Example of Not filled grouting at web (Level 4)

The grout condition survey was conducted from the cut sections. Grouting condition of each duct was classified by Table 3.

In 342 cross sections of ducts, 4 were not grouted (Figure 6). These empty or void ducts were found only in webs where cables were bent upward to be fixed on the deck (Figure 7, 8 and 9). Similar surveys were conducted in other bridges. Insufficient grouting was found in similar ducts. Also it was found that though there were some ducts with insufficient grouting, these had not corroded and there was no trace that water invaded into the duct.

Case 2 (C bridge)

C Bridge was a 5-span simply-supported prestressed concrete girder bridge (Figure 10) constructed in 1966. This bridge was located at the northeastern coastline of Japan where current Specification for Highway Bridge stipulates special treatment against chloride-induced deterioration. Over its service life, the bridge was repaired three times. However, chloride-induced deterioration could not be halted and the operator decided to close the service to traffic in September 2010, then to demolish the bridge. Figure 10b) and 10c) show large cracks found in the lower flange of a girder and the situation after chipping, respectively. Some broken cables were found. The girders are T-shaped post tension girder and used four 24 ϕ 7 multi-wire cables (Figure 11). For its almost double cross sectional area than 12 ϕ 7 multi-wire cable which mainly used in the past, only four cables per girder were anchored just at the end of the girder.

a) C Bridge

b)Pre chipping (A1-P1:Girder-3)

c)Post chipping (Same as on the left, Cable 3 was broken)

Figure10. External appearance of C Bridge before demolition work

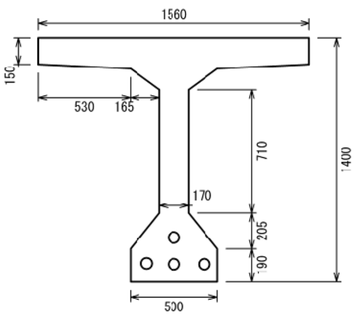


Figure11. Cross-sectional configuration of C Bridge

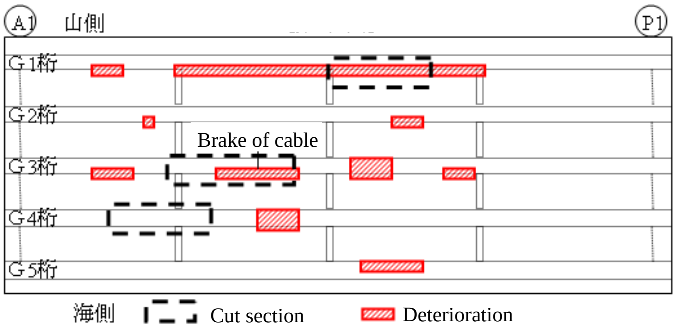


Figure12. Distribution of damage at lower flange of main girder and cutting area of C Bridge

In demolition work, each girder was cut into six or seven pieces and grout condition survey was conducted using the cut sections. Also corrosion investigation of cables was conducted focusing on external damage level of lower flange. Girder 1 at A1-P1 (Almost half the wire's cross section had decreased from corrosion), girder 3 at A1-P1 (Each cable decreased a part of the cross section and some had broken by corrosion), girder 4 at A1-P1 (No history of remedial works. First deterioration was found after 40 years of service)

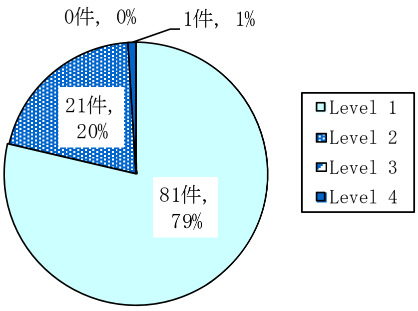
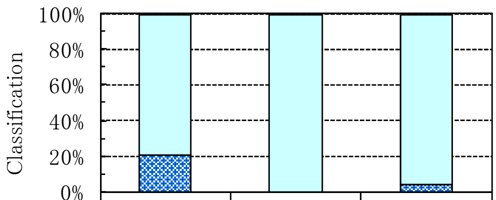
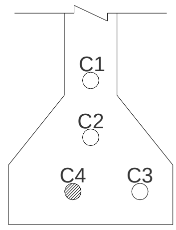


Figure13. Grout condition of C Bridge



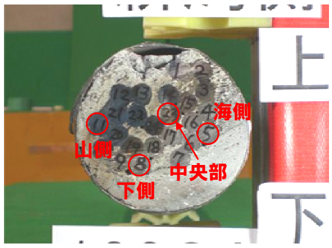
	A1-P1	P3-P4	P4-A2
Level 1	81件	20件	42件
Level 2	21件	0件	2件
Level 3	0件	0件	0件
Level 4	1件	0件	0件

Figure 14. Grout condition for each span



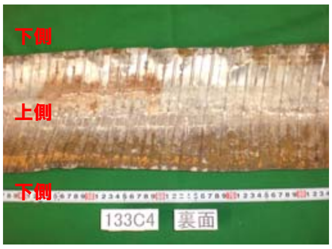
a) Grout of duct inside

b) Cable into duct

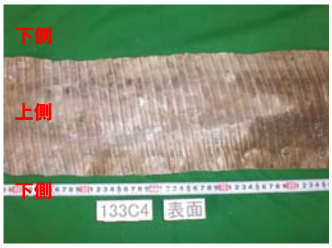


c) Cross section

d) Steel wire



e) Inside of duct (Rust)



f) Outside of duct

Figure15. Anatomical investigation of Cable 4, Girder 3 at A1-P1

from completion), and girder 4 at P4-P5 (Damage was remarkable next to girder 1) were selected.

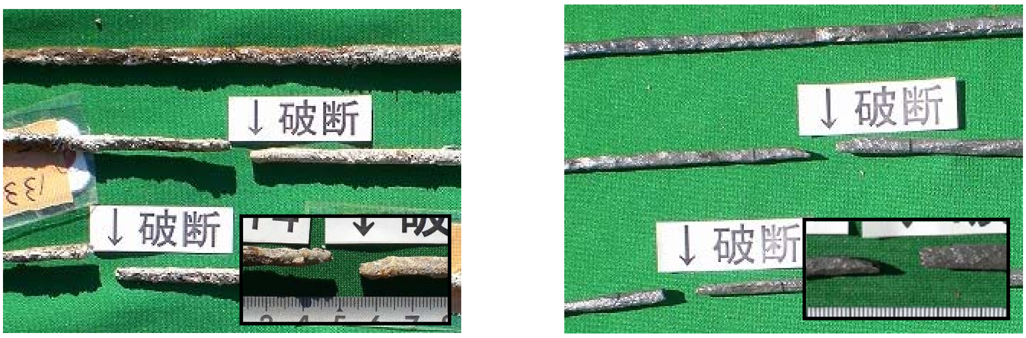
Figure 12 shows distribution of damage at lower flange of main girder and cutting area of C Bridge. Each girder was cut along dotted line shown in Figure 12.

In 103 cross sections of ducts at A1-P1, 102 sections were first separated into Level 1 or 2 (Figure 13 and 14). Nevertheless, 1 section was not grouted and classified into Level 4. These grout void ducts were found near girder 3 where Cable 3 was broken as shown in Figure 10c).

Figure 15 shows the anatomical investigation of Cable 4 extracted as a whole duct with cable and grout from girder 3. As for the duct, slight corrosion is seen in a part.

Although cables were covered with grout, the grout filled at upper sectional part in the duct is breakable and seem to show remains of air bubbles and bleeding. Nevertheless this Cable 4 was extracted near cable 3 which broke, only a little corrosion was confirmed on the cable. That is, it is considered to be able to suppress the corrosion of cable, if well but not completely grouted in the duct even if under severe environment conditions such as chloride attack from the sea.

In addition, the reason why inside of ducts corroded more than outside is considered to be attributed to remaining water which was used for flushing inside of ducts before grouting, from the fact that a few wires at bottom section of duct were corroded.



(a) Before removal of rust

(b) After removal of rust

Figure16. Corrosion condition of wires

Here too cable corrosion survey was conducted. Figure 16 shows conditions of cable decreased by corrosion. Here, we defined “Decrease ratio of cable weight” as the ratio of decreased weight to nominal weight of wire.

Figure 17 shows “Decrease ratio of cable weight” at cable 1 to 4, girder 3, A1-P1. The ratio of cable 3 in which 13 wires were broken is higher than 35%, however others come to less than 10% and no broken wires.

Figure 18 shows “Decrease ratio of cable weight” focused on same cover thickness with cable 3, girder 3, A1-P1. The ratio exceeded 10% only cable 3, girder 3 (the most remarkable damage) and cable 3, girder 1 (the second most noted damage), at which

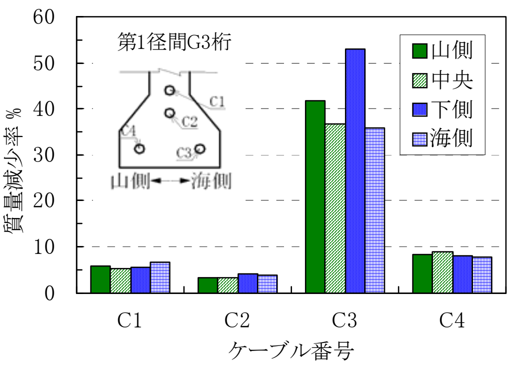


Figure 17. Decrease ratio of cable weight at cable 1 to 4, girder 3, A1-P1

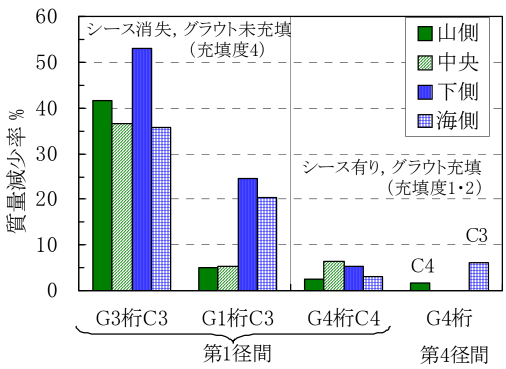


Figure 18. Decrease ratio of cable weight focused on same cover thickness with cable 3, girder 3, A1-P1

remarkable crack like Figure 10b) was observed. Also the ratios of wires at minor defects like longitudinal cracks of lower flanges shown in Figure 19 were 4% on average.

Figure19. Deterioration of Concrete surface

Case 3 (D bridge)

D Bridge was a 2-span simply-supported prestressed concrete girder bridge for bikes (Figure 20, 21). It was constructed in 1972, and demolished in 2011. This bridge was located in the northeastern coast of Japan.

By investigation, some deterioration such as crack, delamination, and spalling appeared over the whole of the girder and 2 in the total of 8 PC steel wires were broken (Figure 22).

Figure20. D Bridge in service

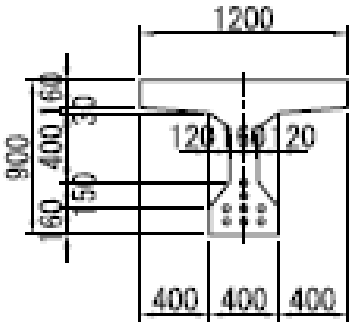


Figure21. Cross-sectional configuration of D Bridge

Figure22. Deterioration of lower flange at D Bridge

Figure 23 and 24 show X-ray inspection system and results of grout condition by the system, respectively. Although partial voids due to lack of “Consistency flow during grouting as the result of duct inclination” was confirmed, grouting is relatively well done throughout. While on the one hand, we were able to get a clear image by almost 3 minutes of X-ray irradiation if web thickness was around 160mm. On the other hand, it was not possible to get a desired clarity of images at the end of girders where web thickness was 400mm even if X-ray irradiation took place for more than 60 minutes.

a) X-ray generator (300kV) b) Imaging plate

Figure23. X-ray inspection system

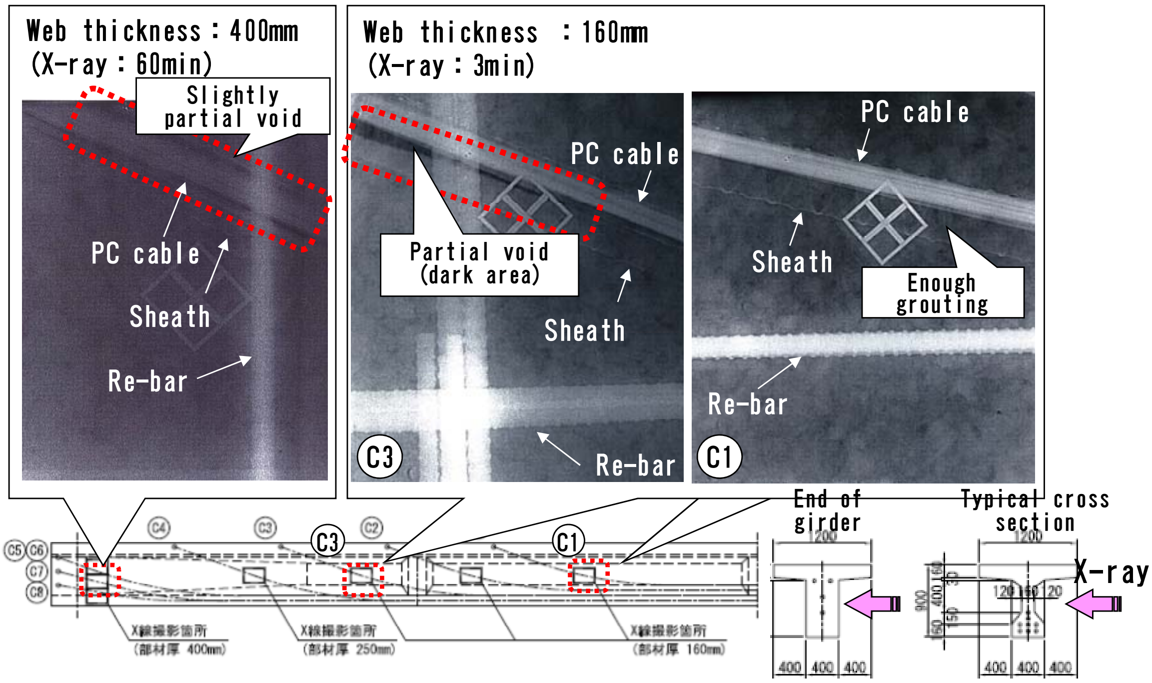


Figure24. Result of grout condition by X-ray inspection

Figure 25 shows relation between decrease ratio of weight and that of cross sectional area for 12 steel wires sampled from the cable in which broken wires were found.

Here, “Decrease ratio of cable cross sectional area” is the mean of areas measured every 50 mm along wires.

All the broken wires were found in the end of the girder, and limited to PC5, 8 (The mountain side) and PC6 (sea side exposure).

The decrease ratios of PC8 with intermittently broken wires were 40-70%. Except a broken steel wire in PC5, the decrease ratios of PC5 and 6 are approximately 10%.

Figure 26 shows relationship between X-ray results and cut section. Compared with 3 sectional area (C3-4, C4-5, C4-6), the result of the X-ray gave good agreement with the actual grout conditions seen in cut sections. It is considered that the X-ray inspection were quite precise.

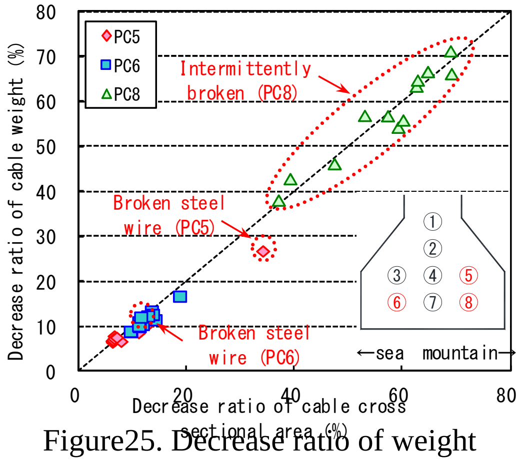


Figure25. Decrease ratio of weight and cross sectional area relationship

Void ducts were found only in webs where cables were bent upward to be fixed on the deck, and this is the similar tendency as in Case 1 (Figure 8).

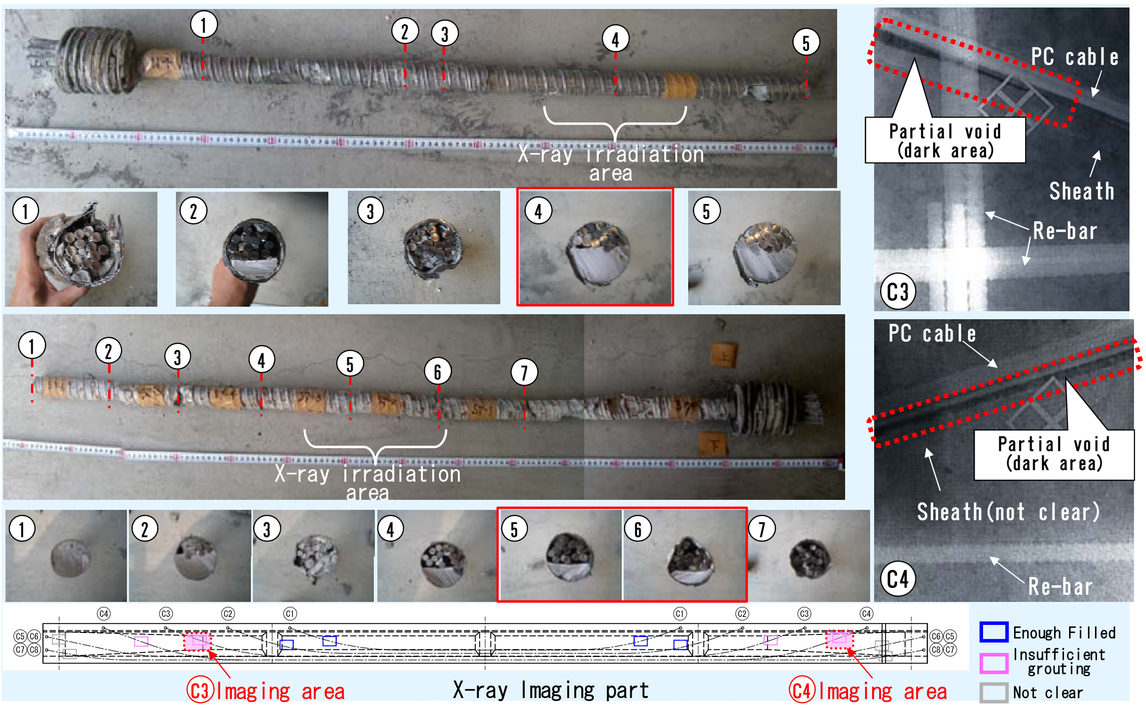


Figure26. X-ray inspection and cut section relationship

Consideration

In this study of grout conditions, it was found that most ducts were grouted sufficiently excepting some cables that were placed in web and bent upward to be fixed on the deck. The cause is considered to be, "Consistency flow during grouting occurred by duct inclination" (Figure 27). It may allow residual air in the duct. And if water invades from construction joints or cracks into these voids, it may cause corrosion or breakage of wires.

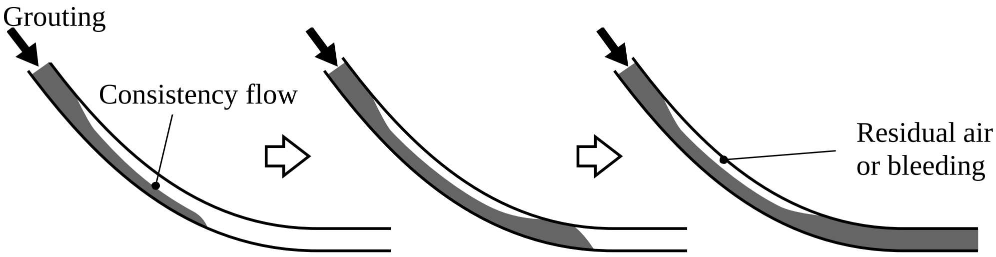
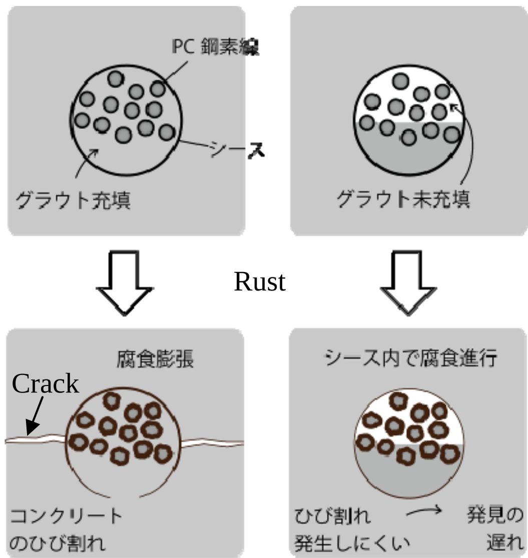


Figure27. Image of consistency flow during grouting

Moreover, while signs of deterioration, such as cracks or leakage of rusty water, may appear on the surface of the concrete in typical chloride-induced deterioration, it is difficult to find signs in this type of deterioration since corroded metal, such as ducts or prestressing cables, can freely expand inside of void ducts and may not damage surrounding concrete.

Figure 28 illustrates the mechanism of cracking due to corrosion in the duct. As the duct corrodes, the volume of corrosion products rises to around 3 times the original duct volume. If fully grouted in the duct (Figure 28a), this increase in volume generates radial expansive pressure on the surrounding concrete and cause cracking. On the other hand, the radial expansive pressure in an insufficiently grouted duct is lower than that in fully grouted ducts, because the voids are present in the ducts (Figure28b)).

Therefore, cracks are observed in a fully grouted duct earlier than in insufficiently grouted ducts. Moreover, it is noteworthy that re-bars adjacent to prestressing cables remained in nearly intact condition.



a) Enough filled b) Insufficient grouting

Figure28. Mechanism of cracks due to corrosion

Conclusions

From the result of this study, the following conclusions can be drawn:

(1) It is possible to suppress the corrosion of cables if the duct is nearly completely grouted even under severe environmental requirements such as chloride attack from the sea.

(2) Even in ducts with insufficient grouting, it was found that the wires in the ducts were not corroded under the condition of no water intrusion.

Acknowledgments

CAESAR's research activity utilizing decommissioned bridges was able to be conducted using demolished bridges provided from municipalities along with cooperation agreement with the Japan Prestressed Concrete Contractors Association (JPCCA). We thank them for their corporation.

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