Characteristics of Bridge Deterioration based on inspection data in Japan

Kazuaki OKUBO [a], Pang-jo CHUN [b], Shingo ASAMOTO [c]

[a] *Center for Disaster Management Information Research, Ehime University, 3 Bunkyo-cho, Matsuyama, Ehime, 790-8577, Japan*
[a] *E-mail: okubo@cee.ehime-u.ac.jp*
[b] *Department of Civil and Environmental Engineering, Ehime University, 3 Bunkyo - cho, Matsuyama, Ehime, 790-8577, Japan*
[b] *E-mail: chun@cee.ehime-u.ac.jp*
[c] *Graduate School of Science and Engineering, Saitama University, 255 Shimo-okubo, Sakura-ku, Saitama, 338-8570, Japan*
[c] *E-mail: asamoto@mail.saitama-u.ac.jp*

Abstract: Grasping the characteristics of bridge deterioration provides valuable information for efficient maintenance, repair and rehabilitation plan. The information is more valuable especially in rural areas, which are expected the population decline and limited budget constraint. We analyze characteristics of bridge deterioration of each bridge type, bridge member based on inspection data in Ehime prefecture, Japan. We found that the distance from coastal line have significant impact on main girder of RC bridges compared to other bridge types and bridge members. And we also pointed out the thickness of concrete coverage of main girder in RC bridge may be one of main reasons of deterioration. We also found correlation between failures, for example, crack and water leakage and free lime.

Keywords: Bridge deterioration, Inspection Data, Regional characteristics

1. INTRODUCTION

Deterioration of bridges has been a serious problem in Japan. There are over 700,000 bridges, whose spans are longer than 2 meter, in Japan. Many bridges were constructed in the Japanese rapid economic growth from 1960s to 1970s. They will exceed the average lifetime, which is about 50 years-old, until 2030 and should be appropriately repaired or reconstructed to maintain satisfactory performance of transportation networks. The increase in the repair and reconstruction cost is expected. The problem is serious, especially in rural areas in Japan. Populations in rural areas are decreasing and the budget constraints of the municipalities are decreasing and limited. Therefore, efficient maintenance, repair and rehabilitation have to be carried out to maintain reliability of service level and safety within limited budget.

Increasing the importance of maintenance, repair and rehabilitation plan, inspection data of bridge conditions is accumulated by agencies responsible for bridges. The inspection data contains large amount of information; condition rating of each bridge member, such as main girder, bridge deck, beam and failure types, such as corrosion, crack. Some studies have used the numerous data to build deterioration models of structures. Kobayashi *et al.*(2012) develops deterioration forecasting model based on the latent Markov decision process by correcting measurement error and selection biases and predicts the road rutting deterioration. The study develops model based on Markov Chain model to describe deterioration process and use inspection data to estimate transition probability.

The data is also used in the road network plan of maintenance, repair and rehabilitation. Hu *et. al* (2015) developed a framework to determine optimal maintenance plans for large networks. They applied their framework to highway network of the San Francisco Bay Area and considered bridge deck failures to examine the increase in the user cost of that highway network and used inspection data to describe the deterioration process of bridge deck.

The study takes into account failures on road surface, such as road rutting deterioration and spalling in bridge deck. Bridges are composed of many members, such as main girders, under structure and bridge bearing. Failures in these members may increase the social cost. Our study focus on the deterioration of the bridge members. Some relationship among failures are investigated, for example a certain failure may cause another failure.

Some papers also reported the characteristics of deterioration. For example, Koike and Nagai (2015) explains the aging deterioration trend by grouping bridges into the same bridge type and age in Niigata prefecture, Japan. They characterize the bridge deterioration from the viewpoint of bridge age, length and failure type. They found steel bridges deteriorate faster than concrete bridges, such as PC (Pre-stressed Concrete), RC (Reinforced Concrete) and Box culverts. They also found the average soundness level of RC bridges is scattered more widely than other bridge types. Yoshida *et al.* (2016) pointed out that the differences in specifications used for the construction are an important factor to characterize the number of bridge damage. They focused on the number of damages in the superstructure of steel bridges.

The objective of our paper is to investigate bridge type and bridge member which are likely to deteriorate from the inspection data, Ehime prefecture, Japan. We consider 3 bridge types, RC, PC and Steel bridges, and investigate 3 bridge members, main girder, under structure and bearing. We also check the spatial distribution of bridge damages to check the effect of regional environment on the deterioration. Our main objective is to show the hypothesis to test in the future research from the inspection data, Ehime prefecture, Japan.

Section2 represents the abstract of available data. Deterioration of each bridge type for each bridge member is presented in section 3. Finally, in section 4, some conclusions and directions for future research are presented.

2. Available DATA

2.1 Bridge attributes

We use the inspection data of road bridges, which are managed by the ministry of Land, Infrastructure and Transport and Tourism (MLIT), in Ehime prefecture, Japan. There are 172 bridges, 31 steel bridges, 61 Reinforced Concrete (RC) bridges, 57 Pre-stressed Concrete (PC) bridges. The data contains, bridge names, built years, structures, geographical information, standard specifications for construction and condition ratings of each bridge member. Figure 1 shows the distribution of built years. Almost 67% RC bridges are constructed in 1950s. 14 steel bridges are constructed in 1970s, which is about 47% of the total steel bridges. Figure 2 shows the distribution of bridges' age at 2016. PC bridges are relatively newer than the other bridge types. On the other hand, more than one-third of RC bridges are over 50 years-old. It is said that the average design life of a bridge is 50 years old. Figure 3 shows the distribution of bridge length. Bridge length of the bridges are mostly shorter than 30 meter. The length of RC bridges are shorter than those PC bridges while steel bridges are relatively longer length.

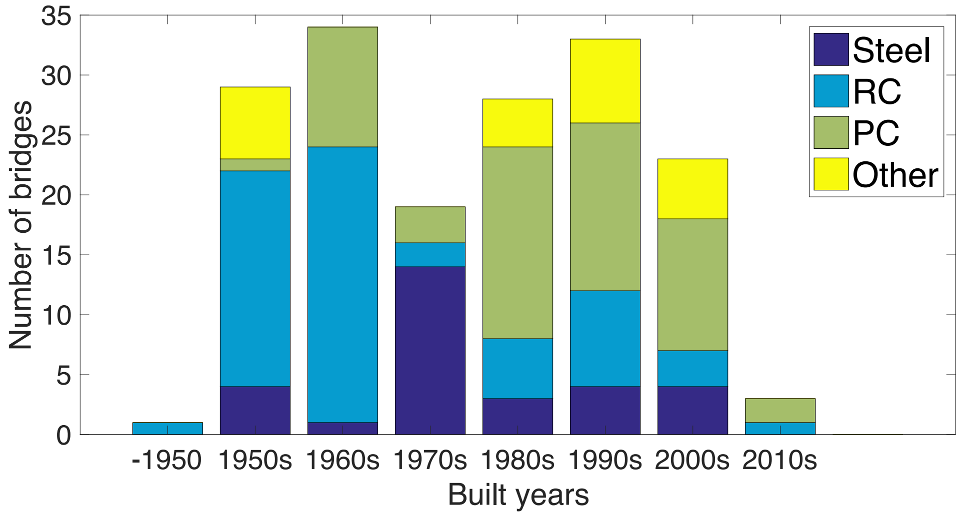


Figure 1. Distribution of built years (Steel, RC, PC and Other bridge type)

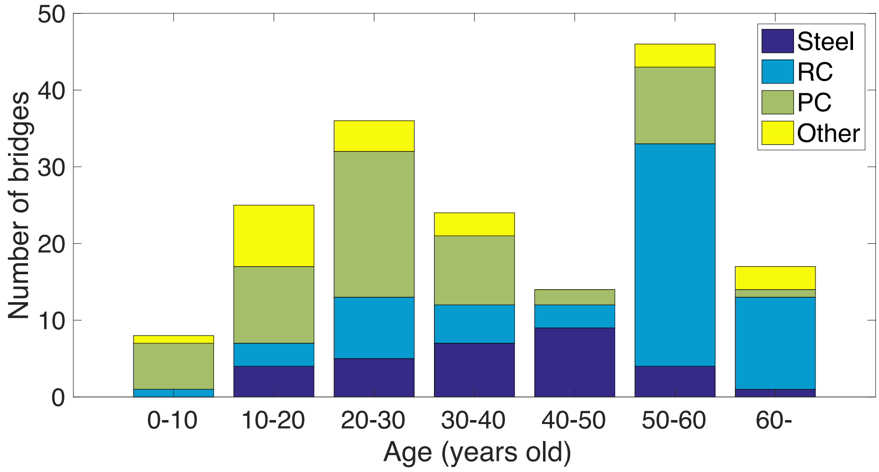


Figure 2. Distribution of bridge age (Steel, RC, PC and Other bridge type)

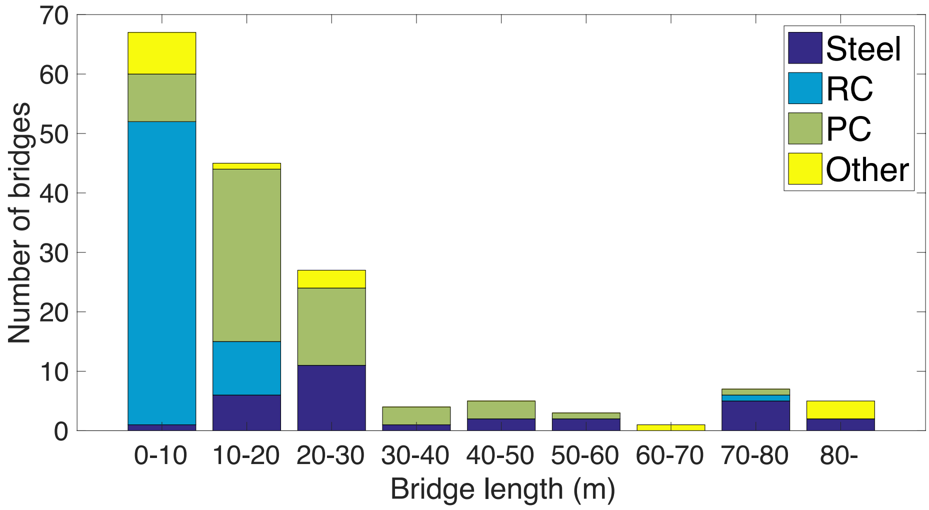


Figure 3. Distribution of bridge length (Steel, RC, PC and Other bridge type)

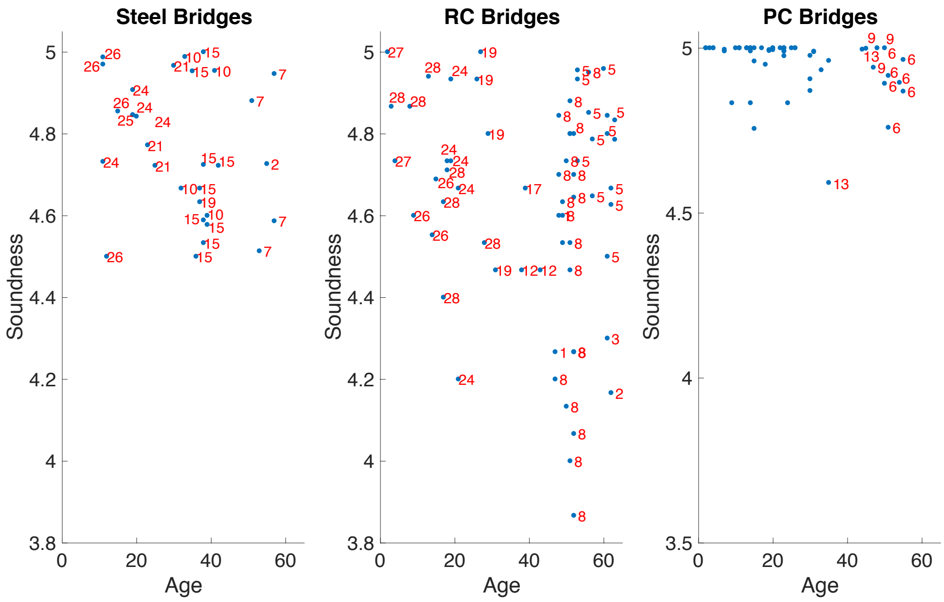


Figure 4. Average condition rating of Main girders (Steel, RC and PC bridges)

2.2 Bridge inspection condition rating

The inspection data contains the condition ratings of bridge members, such as main girders, bridge decks, bearing and so on. The deterioration of each member are classified into 26 types, such as corrosion, cracks and so on, and each condition is evaluated by condition rating index. The index takes integer values between 1 and 5, according to bridge maintenancemanual established by MLIT. The condition rating 1 shows the worst condition and 5 means the sound condition without any deterioration. The condition was rated in each span and member.

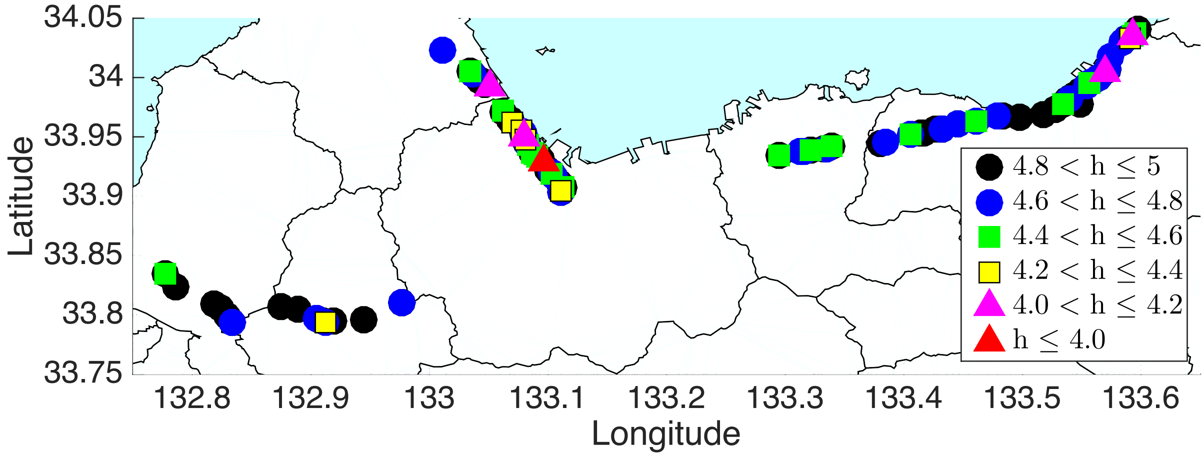
3. Characteristics of deterioration of each bridge type

3.1 Deterioration of main girders

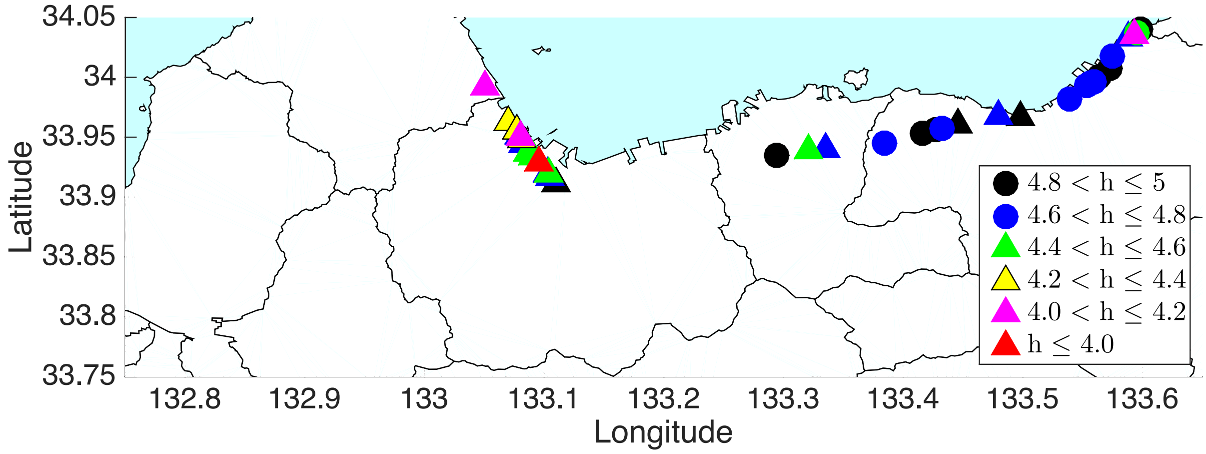
Figure 4 shows the relationship between bridge's age and the average condition rating of main girder of each bridge type. The average condition rating was obtained by averaging the conditions of all spans and members for each bridge as shown in figure 4. We also investigate the specification standards, which were used for each bridge construction, by describing an index near each plot in figure 4. The average condition rating is likely to decrease with aging. The decrease of the RC bridge's rating is larger than those of the Steel and PC bridge's.

3.1.1 Main girders of RC bridges

It is found that the main girders of RC bridges over 50 years old deteriorate significantly. These bridges were built based on the standard specification for concrete structure 1951(Index 5) and 1958 (Index 8). The condition ratings of RC bridges, based on the standard specification 1958, are greatly scattered. However, the condition scattering of the RC bridges, which were built based on the standard specification for concrete structures 1951, is relatively small. For other old RC bridges, which keep better condition rating, it is indicated that they had been already repaired.



(a) All bridges



(b) Bridges, which are built based on the standard specification 1951 and 1955

Figure 5. Spatial distribution of bridges and average condition ratings

There are two possible reasons to explain the worse condition of RC bridges, which are over 50 years old. First, it might be caused by the different construction design. Many RC bridges were built in 1950s and 1960s as shown in figure 1. The technology to ensure an adequate thickness of coverage was not clearly established in these years. In other words, the distance between concrete surface and inner reinforcing bar are insufficiently small. Table 1 shows the main deterioration of bridges which have lower condition ratings. The main deterioration in RC bridges' main girders are crack, loose part of concrete, spalling and rebar exposure. These deterioration is caused generally by the insufficient concrete cover thickness.

Second, we can also point out the effect of surrounding environmental conditions on the bridge deterioration. Figure 5 (a) shows the spatial position and the average condition ratings of all bridges, including Steel, RC, PC and other bridge types. And figure 5 (b) shows the constructed position of RC bridges, which were constructed based on the specification 1951 and 1958. Triangle plots represent the RC bridges, which were built based on the specification 1958. Brighter color plots indicate lower condition ratings. For example, red triangles represent the bridges whose main girder's average condition rating is smaller than 4.2. It is clear that the worse condition bridges are concentrated on the north coastal region by comparing figure 5 (a) and (b). The condition rating is relatively low in the north central coastal region; this area is flat region and it might be vulnerable to the impact of salt attack.

Next, we discuss the deterioration characteristics by focusing on relationship between

Table 1. Major deterioration of Main girders and its average condition rating

Bridge Type	Steel	RC	PC
Crack	5.00	4.02	4.93
Loose part	5.00	4.20	5.00
Spalling and Rebar Exposed	5.00	4.46	4.87
Deterioration of Anti corrosion coating	2.75	5.00	5.00
Corrosion	4.74	5.00	5.00
Joint Gap abnormatrity	4.93	4.95	5.00

Table 2. Correlation matrix among failures (RC bridges)

Failure Type	Crack	Loose part	S/R exposed	Failures in R&R	WL/SW	WL/FL
Crack	1.00	-0.02	0.07	-0.15	0.13	0.25
Loose part		1.00	0.27	0.25	0.16	0.16
Spalling and Rebar Exposed			1.00	-0.09	0.36	0.19
Failures in Repair and Reinforcement material				1.00	-0.05	0.03
Water Leakage/Stagnant Water					1.00	0.13
Water Leakage/Free Lime						1.00

Table 3. Correlation matrix among failures (Steel bridges)

Failure Type	Deterioration of Anti-corrosion coating	Corrosion	Joint gap abnormality
Deterioration of Anti-corrosion coating	1.00	0.32	0.09
Corrosion		1.00	0.26
Joint Gap Abnormality			1.00

deterioration types. Table 2 shows the correlation coefficients between condition ratings of each deterioration. There is a strong correlation between Spalling/Rebar exposure and Water leakage/Stagnant. We can also find weak correlations between Crack and Water leakage/Free lime, Spalling/Rebar exposure and Loose part of concrete, Loose part of concrete and Failures in repair and reinforcing materials. It is concluded that the deterioration of RC bridge are not independent but dependent on each other as inspection date indicated. When a certain deterioration in the inspection items was observed, we should carefully examine or repair the correlated deterioration at the same time.

3.1.2 Main girders of Other bridge types

The condition ratings of steel bridges is more likely to decrease with aging than RC and PC bridges as shown in figure 1. The condition rating rapidly drops after 30 years old. Main deterioration in steel bridges are the deterioration of anti-corrosion coating, corrosion and joint gap abnormality. The deterioration is different from the main deterioration in case of RC bridges as shown in table 2. On the other hand, the deterioration rate of PC bridges is relatively slower than that of other bridge types, and the condition is kept relatively better with aging.

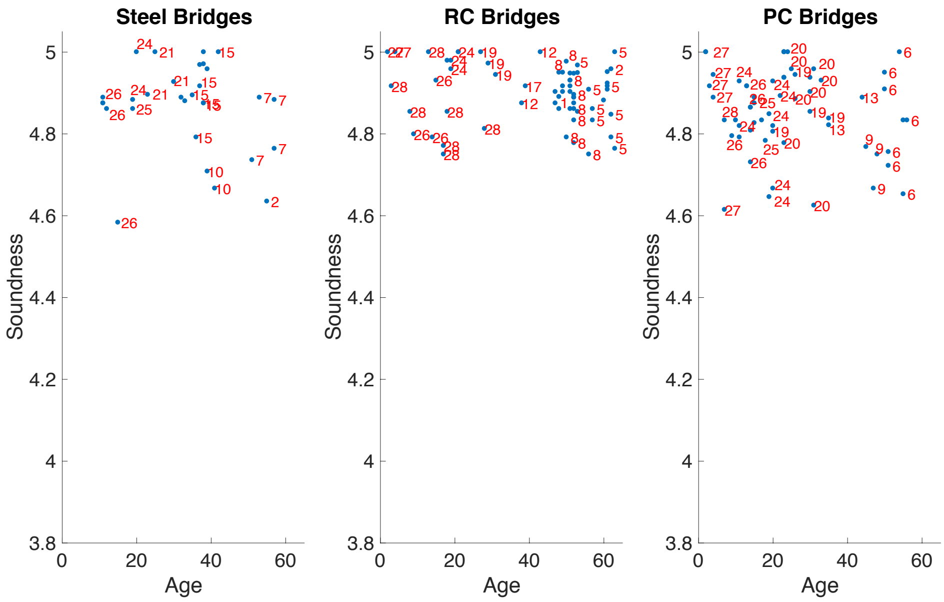


Figure 6 Average condition ratings of under structure

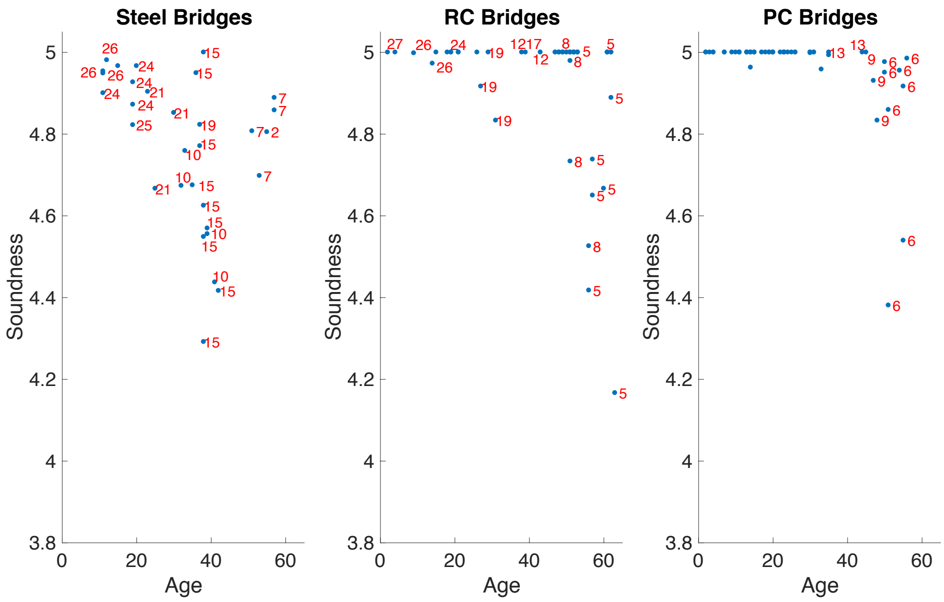


Figure 7 Average condition ratings of bridge bearing

Table 4 Major failures of bridge bearing and its average condition ratings

Bridge Type	Steel	RC	PC
Deterioration of anti-corrosion coating	3.72	3.82	4.92
Corrosion	4.57	4.07	4.94
Joint Gap	4.88	4.98	4.99
Crack	4.93	4.99	4.99

Main deterioration in PC bridges are almost the same as that in the RC bridges; Crack, Loose part of concrete and Spalling/Rebar exposition. However, the worst condition of PC bridges is different from that of RC bridges. Spalling/Rebar exposure is the most serious deterioration in

PC bridges.

3.2 Deterioration of under structures

Next, we discuss the deterioration of under structure. Under structure contains columns, wall, beam and so on. The condition is also averaged by all members of under structure. Figure 6 shows the condition ratings of each bridge type. The variances of under structure's condition are better (more sound) than that of main girders in cases of steel and RC bridges. This indicates that the deterioration of main girder is more serious than that of under structure. The under structures of RC bridges are less deteriorated than other bridge types, especially. It can because the sufficient concrete cover thickness might be kept due to the ease of casing concrete vertically in under structure rather than in main girder to cast concrete horizontally.

3.3 Deterioration of bridge bearing

Figure 7 shows the average condition ratings of bridge bearings. Bridge bearing contains not only bearing but also anchor bolt, mortar and structure to prevent bridge falling. The average condition rating of bridge bearing was obtained by averaging these components of the bearing

As shown in figure 6, the condition rating drops after a certain age in all cases. They rapidly drop at 30, 50 and 50 years old, in Steel, RC and PC bridge, respectively. The condition rating of steel bridge decreases earlier. The steel bridges are generally supported by pin bearing and the deterioration there can be found more easily and earlier even if it is small. On the other hand, in the case of RC and PC bridges, the rubber bearings are often used, which is difficult to find the deterioration by the visual inspection until the condition become worse.

Major deterioration of bridge bearing are shown in table 4. Major deterioration in RC and steel bridges are almost the same, as shown in table 4. The smallest condition rating is found in the deterioration of anti-corrosion function. The second smallest rating is corrosion. Strong correlation can be found between the corrosion and the deterioration of anticorrosion coating in all bridge types, especially RC and PC bridge type.

4. CONCLUDING REMARKS

This paper shows the characteristics of bridge deterioration to provide valuable information for efficient maintenance, repair and rehabilitation plan. We present the characteristics of bridge deterioration of each bridge type, bridge member. We found that the main girders of the RC bridges are likely to deteriorate than the other bridge members and bridge types. We also found that the main girders of RC bridges are deteriorate especially in coastal region. These damages may be caused by a) insufficient thickness of concrete coverage, b) salt impact from the ocean. And we also find correlation between failures, for example, crack and water leakage and free lime. Therefore, these damages may often occur simultaneously. This information hopes to provide useful information for not only developing the plan but also implementing the bridge inspection in the future.

REFERENCES

Hu, X., Daganzo, C., & Madanat, S. (2015). A reliability-based optimization scheme for maintenance management in large-scale bridge networks. *Transportation Research Part C*, *55*(C), 166–178. http://doi.org/10.1016/j.trc.2015.01.008

Kobayashi, K., Kaito, K., & Lethanh, N. (2012). A statistical deterioration forecasting method using hidden Markov model for infrastructure management. *Transportation Research Part B*, *46*(4), 544–561.
Koike, M. and Nagai, K. (2015), Analysing aging degradation trend using the bridge inspection data in Niigata Prefecture Municipalities, Proceedings of the Japan Concrete Institute, 37(2), 1339-44. (in Japanese)
Yoshida, S. and Inamura, H and Morichi, S. (2016)., Analysis of damage characteristics due to cumulative number of shaft center and design basis transition in Metropolitan expressway, *Proceedings of infrastructure planning*, Vol.54, CD-ROM.(in Japanese)