Proceedings of the 9th International Conference on Structural Dynamics, EURODYN 2014
Porto, Portugal, 30 June - 2 July 2014
A. Cunha, E. Caetano, P. Ribeiro, G. Müller (eds.)
ISSN: 2311-9020; ISBN: 978-972-752-165-4

Structural health monitoring of the reinforced concrete plug joint system for existing concrete bridges

Yuichi Ishikawa[1], Eiji Iwasaki[2], Masatsugu Nagai[3]
[1] Assistant Manager, Road Engineering Department, Kanazawa Branch, Central Nippon Highway Engineering Nagoya Co.
3-7-1, Ekinishi-Honmachi, Kanazawa, Ishikawa, 920-0025, Japan
[2] Professor, Nagaoka University of Technology, Kamitomioka-cho, Nagaoka, Niigata, 940-2188, Japan
[2] Emeritus Professor, Nagaoka University of Technology, Kamitomioka-cho, Nagaoka, Niigata, 940-2188, Japan
Email: y.ishikawa.a@c-nexco-hen.jp, iwas@nagaokaut.ac.jp, nagaimasatsugu@gmail.com

ABSTRACT: The use of deicing salts in heavy snowfall area in Japan has been increased since the 1990s. The purpose of using deicing salts is to ensure the road safety during the winter season. However, as a trade-off, the highway bridges are deteriorated by salt attack due to the deicing salts. Thus, this study examines the number of water leakage from bridge joints in the Hokuriku Expressway in Japan. This survey was conducted to investigate the relationship between deteriorations at the girder ends due to the salt attack by deicing salts and the water leakage from the bridge expansion joints. It is found out that the water dissolved with salts from deicing salts has accelerated the damage of the reinforced concrete (hereafter RC) structures at the girder ends. Therefore, as a preventive measure, a new highly durable jointless system named RC plug joint system (hereafter RC plug joint) for existing concrete bridges are being proposed. The RC plug joint connects the girder end to the abutment's backwall using anchor reinforcing steel bars (hereafter rebars) and fiber reinforced concrete. The analysis of live load influence, a temperature change and the seismic influences using a finite element analysis are conducted. The experiment model in the case of huge earthquake occurrence had already grasped the destruction form of the RC plug joint. From this analysis, it is recommended that the RC plug joint should be applied to an existing concrete bridge with the bridge lengths less than 40 meters. In addition, to monitor the structural health of the RC plug joint, assessment of 85 locations of installed RC plug joint confirm the modeling analysis results. As a result, the RC plug joint can prevent water leakage and allow for a smooth ride of vehicles at the joint. In conclusion, RC plug joint is proposed as a method that can improve the durability of existing concrete bridges.

KEY WORDS: Expansion joint, Reinforced concrete plug joint, Finite element analysis, Structural health monitoring

1 INTRODUCTION

Hokuriku region is a heavy snowfall area in Japan. Figure 1 shows the position of Hokuriku region. For 3 – 4 months in the winter season, snow or water freezing on the expressway road surface tends to make the road slippery. Deicing salts have been generally used as the preventive measure [1]. However, it caused many bridge structures to deteriorate from salt attack [2]. Moreover, an investigation on current status of water leakage targeting about 1052 bridge expansion joints in the Hokuriku Expressway had been carried out. This survey was conducted to investigate the relationship between deterioration at the girder ends due to the salt attack by deicing salts and the water leakage from the bridge expansion joints. It is found out that the aged bridge expansion joints with the deteriorated waterproof function allow the remnants of dissolved deicing salts, rainwater and melted snow to drop down to the girder ends. As a result, many reinforced concrete (hereafter RC) girders, abutments and piers have been damaged by salt attack. Figure 2 show the typical damage of a RC girder ends with pier and abutment due to leakage from the aged expansion joints [3].

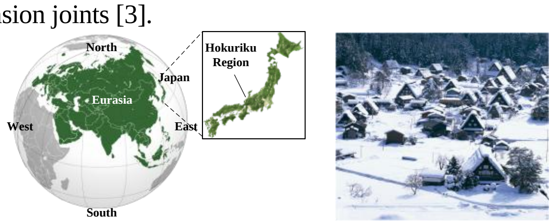


Figure 1. The position of Hokuriku region in Japan.

Therefore, we developed a new highly durable jointless system, named RC plug joint, for existing concrete bridges. The RC plug joint connects the abutment's backwall to the girder using reinforcing steel bars (hereafter rebars) and fiber reinforced concrete. The analysis of live load influence and temperature changes by three dimensional finite element analysis (hereafter 3D-FEA) has been conducted. In order to design RC plug joint and the scope of application, the comparison has been done between analysis frameworks that considering the seismic influences with the experimental loading test in the laboratory. Furthermore, monitoring about 85 locations of installed RC plug joints in the Hokuriku Expressway had been conducted. The results confirmed that the RC plug joint is possible to improve the durability of the existing concrete bridges.

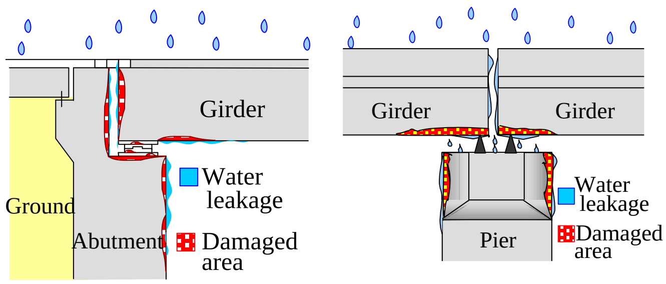


Figure 2. Schematic view of typical damaged RC girder ends with pier and abutment due to salt attack.

2 INVESTIGATION OF THE AGED EXPANSION JOINT

2.1 Investigation of water leakage from the joints

Table 1 shows the results of water leakage investigation from the bridge expansion joints. Water leakage survey from the bridge expansion joints is conducted by visual observation. As shown by Figure 3, water leakage occurs when the abutment surface looks wet after rain. From 1052 locations of bridge expansion joints in the Hokuriku Expressway, water leakage is confirmed from 607 locations. The proportion accounted for 58% of the total locations. The quantity of expansion and contraction due to annual temperature changes of less than 50mm was the most commonly occurred. In addition, a significant water leakage occurred in the small and medium-sized concrete bridges.

2.2 The Relationship of the girder ends degradation with water leakage from the joints

In the Hokuriku Expressway, regular sodium chloride is being used as deicing salts in the winter period. Figure 4 shows a typical example of the existing concrete bridge girder ends degradation due to salt attack in the Hokuriku Expressway. The degradation of concrete bridge girder ends also lead to the corrosion of rebars.

Approximately 85% of bridge girder ends that were deteriorated by salt attack showed water leakage from the bridge expansion joint, as shown by Figure 5. Thus, there is a high correlation between water leakages in bridge expansion joints with delaminated girder ends due to salt attack. Salinity of deicing salts is attached in the water leakage of the girder end, front of abutment, and concrete surface of the bridge pier, thus lead to degradation of RC structure locally.

3 OUTLINE OF REINFORCED CONCRETE PLUG JOINT

3.1 Basic concepts

Figure 6 shows the side view of the RC plug joint. In this system, the aged bridge expansion joint is removed completely, and fiber reinforced concrete fills the gap. Then, a waterproof membrane is applied on the surface of the fiber reinforced concrete. Lastly, a new layer of asphalt pavement is completed.

Table 1. Water leakage from the joint on the abutment pier

Quantity of expansion and contraction	Total locations	Water leakage	Ratio
Less than 50mm	949	582	62%
50mm to100mm	93	24	26%
More than 100mm	10	1	10%
Total	1052	607	58%

Figure 3. Water leakage from the joint.

Figure 4. Degradation of the girder ends.

3.2 Structural Characteristics

The RC plug joint connects the abutment's backwall (i.e. parapet) to the girder using fiber reinforced concrete. This jointless system is applied to existing concrete bridges whose length is less than 40 meters. As a result, the prevention of leakage, in addition to create a smooth ride for vehicles at the bridge expansion joints, is achieved. Therefore, the superiority of this system compared to the previously used bridge expansion joint systems is quite clear.

3.3 Details of reinforced concrete plug joint

A detailed view of the RC plug joint is shown in Figure 7. The RC plug joint completes the gap between the girder and abutment with fiber reinforced concrete for the main purpose of preventing water leakage at the bridge expansion joint. In addition, the waterproof membrane and the road asphalt pavement are applied on top of the RC plug joint. This double protection system guarantees increased waterproof protection in comparison with the previously used type of expansion joint systems. A concrete adhesive material is applied to the interface of the concrete to ensure bonding and cohesion of both the old and new concrete with the anchor rebars.

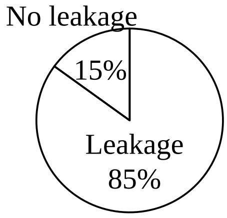


Figure 5. Leakage situations of deteriorated girder ends.

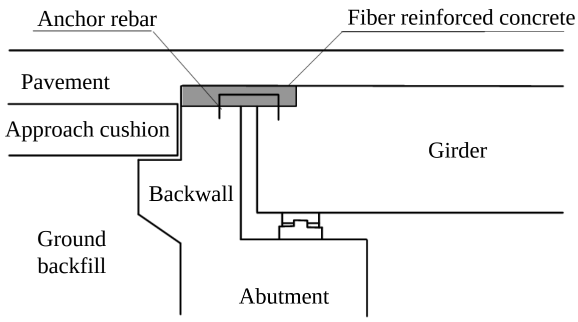
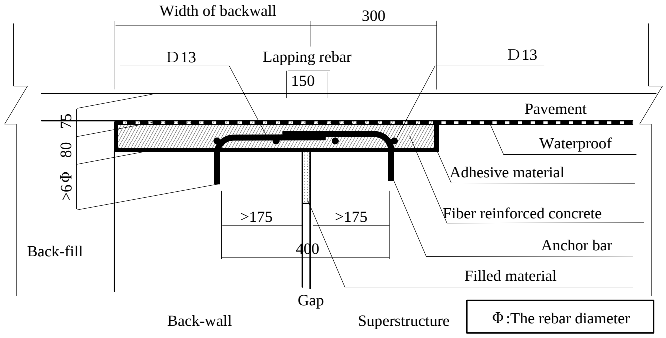


Figure 6. Side view of the RC plug joint.



(Unit: mm)

Figure 7. Details of the RC plug joint.

4 TRIAL DESIGN OF REINFORCED CONCRETE PLUG JOINT

4.1 Analysis of live load

The 3D-FEA model is made for two consecutive span of 31 meters long RC hollow slab bridge. In this model, the effect of abutments with RC plug joint is installed, was analyzed by giving 200KN live load. As shown by Figure 8 the concrete material is modeled with solid elements. The result of 3D-FEA shows that girder and abutment are united and behave together as a rigid frame.

4.2 Analysis of temperature change

The effects of girder expansion and contraction due to annual temperature change were analyzed with 3D-FEA by providing a forced displacement to the girder ends. FEA results show the abutment is deformed. As shown in Figure 9, this behavior is a response to the expansion and contraction of girder due to temperature change. Figure 10 shows the distribution of the maximum principal stress due to temperature changes of the RC plug joint in the case of hard rock support the abutment. The abutment is deformed to follow the response of the expansion and contraction of the girder due to temperature changes. Stress concentration of the maximum principal stress is generated due to the fact that it is hard to deformed wings. In the case of abutment supported by the hard rock, it can be seen that the application of RC plug joint is difficult.

Figure 11 shows the analysis result of the connecting part RC plug joint. In this analysis, the anchor rebars of connecting part were set with 13mm diameter and 250mm spacing between rebars. The influence of abutment height and the girder length was also studied. If the abutment height was increased, the axial force generated in the connection part of the RC plug joint decreased. Moreover, if the girder length was increased, the axial force generated in the connection part of the RC plug joint also increased.

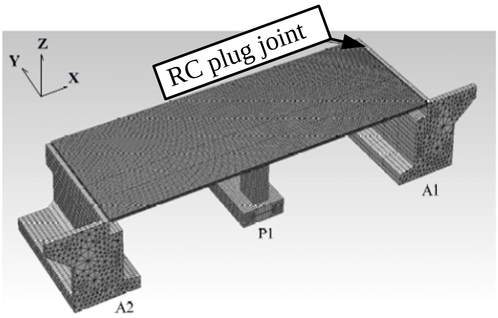


Figure 8. 3D-FEA model used with live load influence.

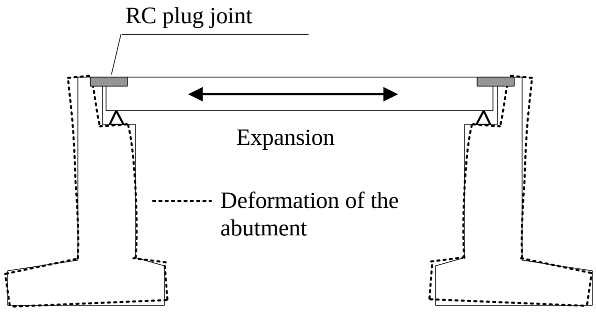


Figure 9. The abutment deformation due to temperature change.

4.3 Analysis of earthquake influence

(1) Outline

The safety of bridges installed with RC plug joint was evaluated in the case of the occurrence of an earthquake. In framework analysis, as shown in Figures 12 and 13, RC plug joint were modeled with a bar element to calculate the cross-sectional force by the action of inertial force of the girder due to an earthquake. The horizontal seismic coefficient of the earthquake is assumed to be 0.3. The ground spring is also considered to give a support to the abutment.

(2) Parameters

Table 2 shows the analysis parameters on this research works. These parameters are based on existing concrete bridge data of Hokuriku Expressway. In this study, the bridge types, length of span, number of span and abutment height are considered.

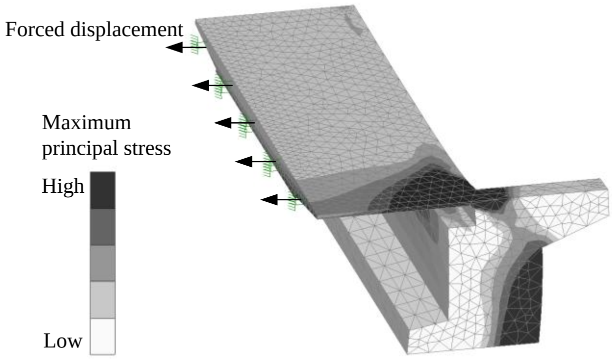


Figure 10. Maximum principal stress of the RC plug joint due to temperature change.

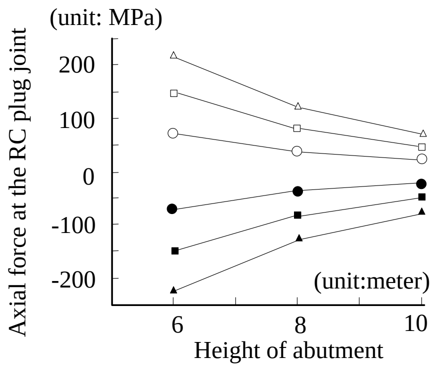


Figure 11. Axial force of the RC plug joint by frame analysis.

Table 2. Analysis parameters.

Parameters of the girder type	Length and number of span	Rigidity of girder
RC bridge	20m×1 span	0.07 m^4/m
	20m×2 span	
Pre-stress concrete bridge	20m	0.03 m^4/m
	30m	0.10 m^4/m
	40m	0.30 m^4/m
Parameters of the substructure	**Abutment height**	**Abutment stiffness Ic**
T shaped abutment, On the ground	6.0m	0.23m^4/m
	8.0m	
	10.0m	

(3) Results

Figure 14 shows the ultimate bending moment of the parapet in the Hokuriku Expressway. The result calculated the ultimate bending moment which the rebar of the parapet yielded. It shows that the ultimate bending moment of the parapet, with the height around 1.0 meter, is around 150KN・m/m. Based on this result, in the occurrence of an earthquake, the axial force generated in the RC plug joint should be limited to less than 150KN/m. Table 3 shows the axial force generated in the RC plug joint that occurs in an earthquake. The bridges with length up to 40 meters show the axial force under 150KN/m.

4.4 Experimental study on huge earthquake

(1) Overview and experimental tests

Forced displacement occurred in the bridge gap due to the earthquake possibly destroying the RC plug joint. In this experiment, the specimens were simulated to understand the load, displacement, and fracture morphology in ultimate conditions. The specimens are placed as shown in Figure 15.

Table 3. Axial force generated in the RC plug joint that occurs in an earthquake. [Unit: KN/m]

Bridge type	Length and number of span	Height of an abutment		
		6.0m	8.0m	10.0m
RC bridge	20m×1 spans	59.1	57.6	57.4
	20m×2 spans	117.9	114.9	114.7
Pre-stress concrete bridge	20m	36.6	35.7	35.5
	30m	76.9	75.0	74.8
	40m	146.6	142.8	142.4

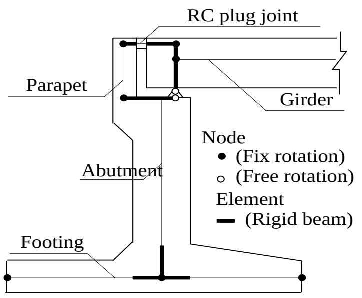


Figure 12. Frame model of the RC plug joint.

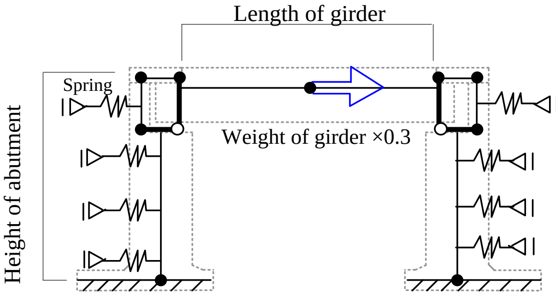


Figure 13. Seismic horizontal inertial force and restraint condition from an earthquake.

The specimen is placed between two 1500KN oil jacks. The loading system will give the forced displacement to the gap of the bridge. Four types of specimen are made with variation in the anchor rebars of the RC plug joint. The variations are applied in the anchor rebars shape and embedment length. Table 4 shows the types of specimen, while Figure 16 shows the schematic view of anchor rebars connection.

(2) Outline of the experimental results

Figure 17 shows the relation between load and the extension value of the gap. In addition, Figure 18 shows the ultimate condition of the specimen. When the loading started, initially it broke the bond between concrete of the RC plug joint and the concrete specimens (Figure 17 in the A zone). After that, extension value is increased by leaving the load. As a result,

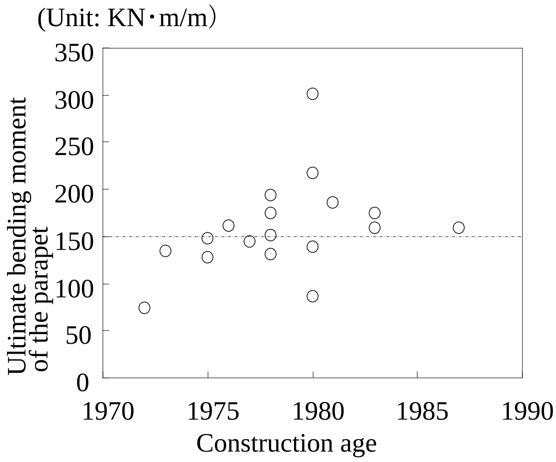


Figure 14. The parapet bending moment.

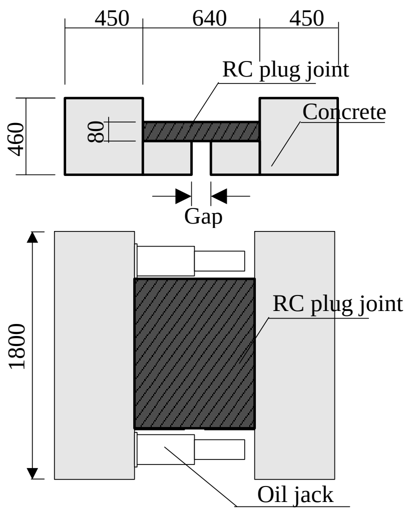


Figure 15. Schematic view of the specimen.

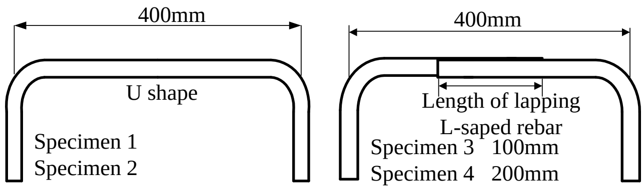


Figure 16. Type of anchor rebars.

the cracks begin to occur in the concrete around the embedded rebar. As the load continues to be applied, the connection rebar is pulled out. At that point, the load reaches the ultimate condition (Figure 17 in the B zone). After that, the surface between the specimen and concrete of RC plug joint is detached and sliding. The width of crack is enlarged in the concrete around the embedded rebar. After the surface is detached, the extension value is increased (Figure 17 in C zone).

a) Effect of embedment length of anchor rebars

The comparisons of maximum load on the specimen type1 and 2, which have different embedment length of the anchor rebars, were conducted. The results show that the longer embedment length will provide the largest maximum load. Therefore, the maximum load of the RC plug joint is significantly affected by the embedment length of anchor rebars connection.

Table 4. Types of specimen.

Specimen type	Rebar's shape	Rebar's diameter	Embedment length	Lapping length	Fiber-reinforced
1	U	13mm	40mm	-	Yes
2	U	13mm	60mm	-	Yes
3	L	13mm	40mm	100mm	No
4	L	13mm	40mm	200mm	No

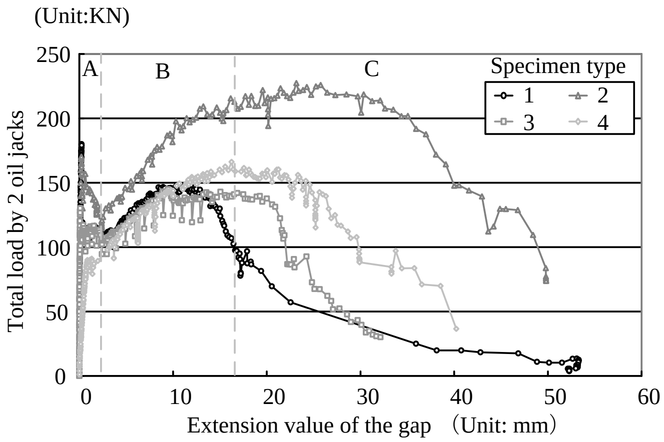


Figure 17. Loading experiment results.

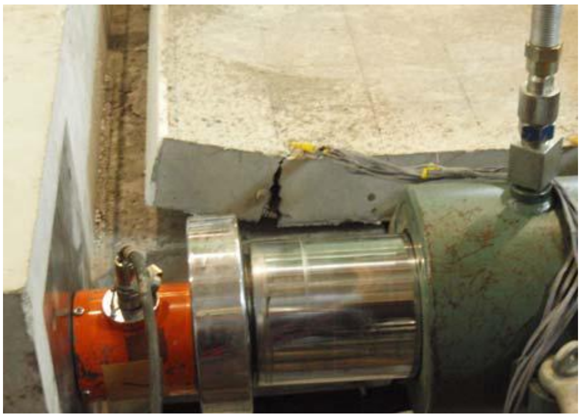


Figure 18. Ultimate condition of the specimen.

b) The difference in the shape of anchor rebar

As for the difference in the shape of anchor rebars, the results from specimen type1 and 3 show almost the same maximum loading. Thus, the difference in the shape of anchor rebars only gives a little influence to the maximum load. Moreover, for difference in the lapping length, small difference in the maximum loading could be seen in specimen type3 and 4. It shows that strength of RC plug joint was affected by the lapping length.

(3) Discussion of the experimental results

Theoretically, fracture morphology in the ultimate experiment was mainly form cone destruction by the pull-out of the anchor rebars. In order to confirm this theory, analysis using software DIANA is performed. Figure 19 shows the principal stress distribution of the analysis which forced displacement applied at RC plug joint. The vertical stress (Y-direction) is generated in the embedded rebar by applying the horizontal force (X-direction) to the anchor rebars. The axial force in the horizontal direction acting on the rebar converted into axial force in the vertical direction at the embedment side is confirmed. In addition, it can be seen that the deformation in the Y-direction occurs at the embedded rebar. From this analysis, it could be concluded that the fracture morphology is considered to be singular events.

5 STRUCTURAL HEALTH MONITORING OF THE REINFORCED CONCRETE PLUG JOINT

5.1 *Leakage assessment*

As of 2012, we have replaced the existing joints with the RC plug joints at 85 locations within the area under the supervision of Kanazawa Branch, Central Nippon Expressway Co., Ltd. Figure 20 shows the number of installed RC plug joints and results of leakage assessment. Unfortunately, the water leakage from the RC plug joints was found at three locations. The faults of RC plug joints occurred due to the detachment of the existing surface concrete. After much discussion over this fault, the use of an adhesion material (i.e. epoxy resin) on the existing surface concrete for future repairs was decided.

There has been no subsequent pavement damage such as potholes, cracks or leakage from the RC plug joints. From these findings, it is confirmed that the reliability of the RC plug joint proves thus far successful. Until now, the performance of the RC plug joint still observed.

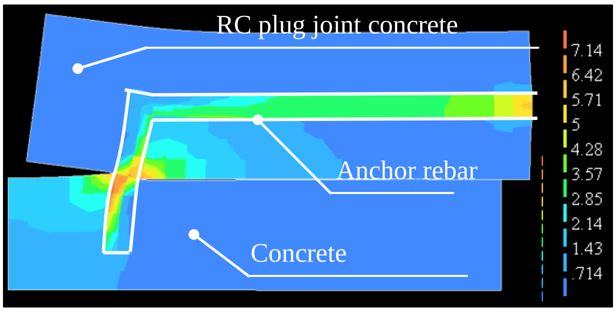


Figure 19. The Result of ultimate condition of RC plug joint.

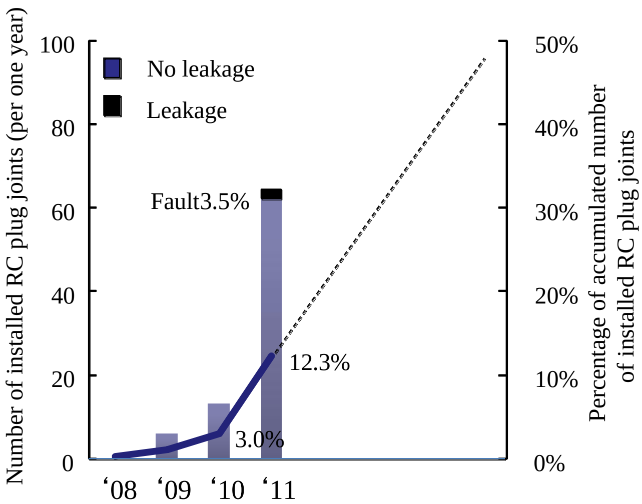


Figure 20. Leakage assessments of RC plug joint.

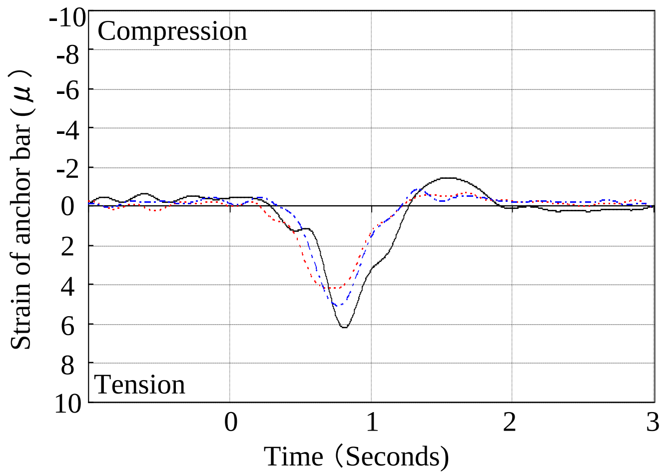


Figure 22. Measured strain induced by test cars.

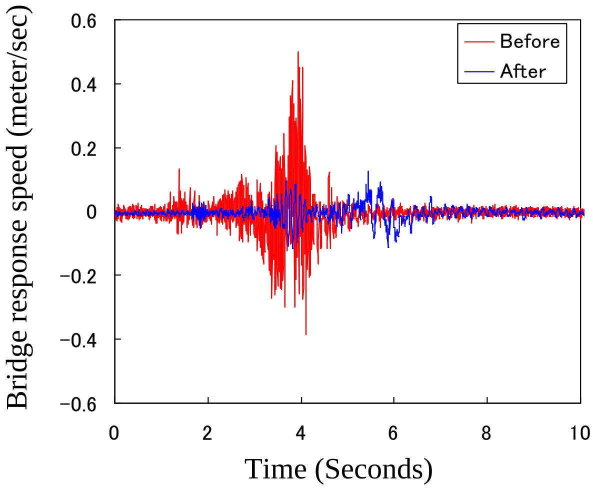


Figure 21. Velocity response of the bridge caused by test car.

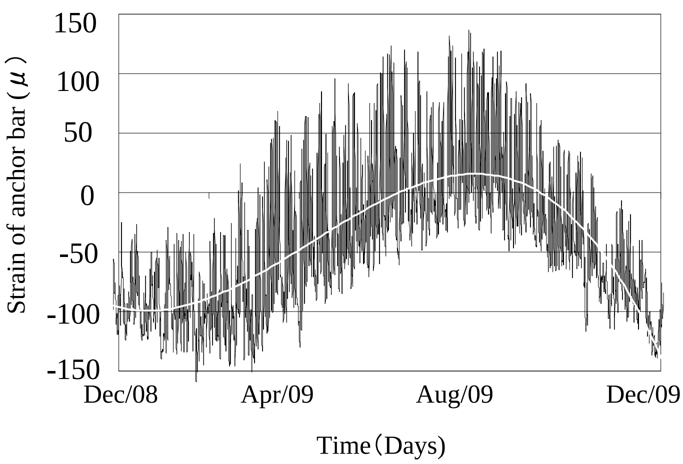


Figure 23. Measured strain due to temperature change.

5.2 *Travelling performance*

In order to assess the effect of vibration reduction due to the traffic loading after the installation of a RC plug joint, the vibration response of both, the bridge and test car was measured. Figure 21 shows the reduction effect of the bridge response before and after the installation of the RC plug joint. These results show that the RC plug joint have greatly reduced the effect of the bridge's vibration. After comparing the results before and after the RC plug joint was installed, it is observed that a smoother passage for vehicles was also achieved.

5.3 *Measurement of strain of anchor rebars*

Figure 22 shows the measured strain of anchor rebars under traffic loads. Figure 23 shows the strain of anchor bars due to seasonal temperature change. It was concluded that the strain due to temperature change was 50 times higher than that caused by the traffic loading. As a result of this discrepancy, future attention must be paid to the temperature change during the design phase. Furthermore, a structural analysis on the effect of temperature change using a frame model concluded that the permissible expansion and contraction of the RC plug joint should be limited to 20mm for bridge lengths less than 40 meters.

6 CONCLUSIONS

This paper discusses the development of the RC plug joint as well as analyzes the results of the investigations conducted. The results confirmed the structure characteristic of the bridge installed with RC plug joint by 3D-FEA. In addition, the ultimate condition of RC plug joint test confirmed that the emergency vehicle still could pass the bridges when a huge earthquake occurs. For these reasons, the safety of RC plug joint is verified.

Moreover, field surveys and structural health monitoring of the RC plug joint RC plug joints were carried out. The results confirmed that the RC plug joint is possible to improve the durability of the existing concrete bridges

REFERENCE

[1] Carl-Gustaf Wallman, Henrik Astrom: Friction Measurement Methods and the Correlation Between Road Friction and Traffic Safety, VTI meddeland 911A, ISSN 0347-6049, pp.34-42, Swedish National Road and Transport Research Institute,2001

[2] Robert R. Blackburn, Karin M. Bauer, Duane E. Amsler, S. Edward Boselly, A. Dean McElroy: Snow and Ice Control: Guidelines for Material and Methods, National Cooperative Highway Research Program Report 526, Transportation Research Board, ISBN 0-309-08799-6, 2004

[3] Yuichi Ishikawa: A Study on the Durability Enhancement of the Japan's Expressway Existed Bridges Damaged by De-icing salts, (Unpublished doctoral dissertation), Nagaoka University of Technology, 2013.9,(in Japanese)