SLIPPAGE TEST OF FRICTIONAL HIGH STRENGTH BOLTED JOINTS WITH ADHESIVES FOR CORRODED DAMAGED STEEL MEMBERS

Y. TAMBA[1*], S. YUKITO[2†], T. YAMAGUCHI[3], H. SAKODA[1], A. HIGATANI[4] and A. TABATA[4]

[1]Planning & Research Department, Hanshin Expressway Technology Center, Japan

[2]Graduate Student, Department of Civil Engineering, Osaka City University, Japan

[3]Professor, Department of Civil Engineering, Osaka City University, Japan

[4]Engineering Department, Hanshin Expressway Company Limited, Japan

ABSTRACT

When the corroded steel member is repaired by adding steel patch plate, epoxy resin is usually used to make the corroded plate flat and to prevent from further corrosion. But it is not clear that how epoxy resin might influence on the slip resistance of the joint, so the current practical design code does not generally consider increase of slip resistance due to adhesive effect of epoxy resin. In order to clarify the relationship between the location of concavities with the epoxy resin and bolts, and an influence on the slip resistance by some concavities, a slippage test of the frictional high strength bolted joints with epoxy resin on some concavities has been executed.

Keywords: Slippage test, High strength bolt, Adhesives, Corrosion

1. INTRODUCTION

The frictional high strength bolted joints have been generally applied to connections of steel structures. In ordinal, the corroded steel member is repaired by the patch plate with high strength bolts and epoxy resin as shown in Picture 1. Some fundamental studies on mechanical behavior of bolted connection with adhesive and adhesively bonded joints for steel structures have been provided (J. Murakoshi 2008, P. Albrecht 1988, JSSC 1993 and so on). However it is unclear how the high strength bolted joints with adhesives for the corroded damaged steel member might influence on the slip resistance or decrease of bolt axial force. Therefore, the repair manual of Hanshin Expressway does not consider the

(a)Gluing epoxy resin **(b)After completion**

Picture 1: Repairing by a patch plate

---

* Presenter: Email: yoshio-tamba@tech-center.or.jp

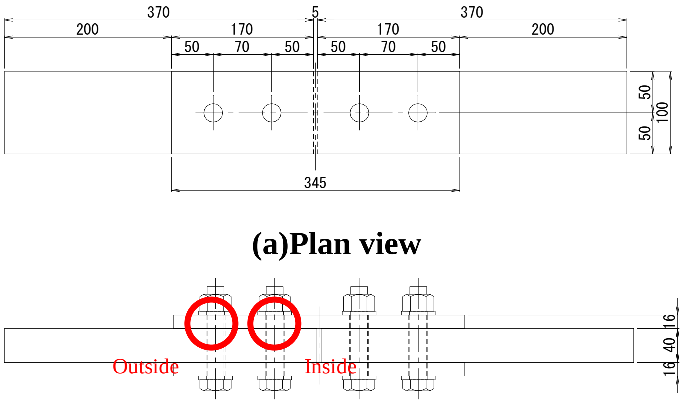
† Corresponding author: Email: yukito@brdg.civil.eng.osaka-cu.ac.jp

increase of slip resistance due to bolt axial force and adhesion of epoxy resin. In this study, discussed are the slip resistance of them through load-displacement curves obtained from the slippage tests focusing on geometrical configurations, such as the depth and the number of concavities which are the parameters for corrosion modeling.

2. SLIPPAGE TEST METHOD

2.1. Design of specimens

Geometrical configurations of the specimens are determined by the design code (Japan Road Association 2012) as shown in Figure 1. The thickness of the base plate and the splice plate of the specimen for the slippage test is 40 mm and 16 mm respectively. The steel material used is high tension steel HT590, which tensile strength is more than 590 N/mm^2, and bolts used are M20 (F10T). Considering corrosion damage of the cross section and strength of adhesives, are determined geometrical dimensions of the specimens which limit state is slipping, by referring to the recommendations for design of connections in steel structures (JSCE 2006). Slip to yield resistance ratio β_d of the standard specimen is about 0.25 by the equation (1) in which the slip coefficient assumes to be 0.4 and the adhesives is not considered.



(a)Plan view

(b)Side view

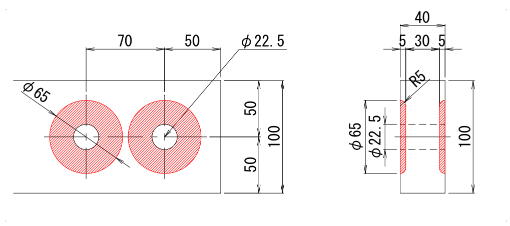
Figure 1: Dimensions and configuration of the specimen for slippage test (mm)

$$\beta_d = \frac{\mu \cdot m \cdot n \cdot N}{(W - d) \cdot t_1 \cdot \sigma_y} \quad (1)$$

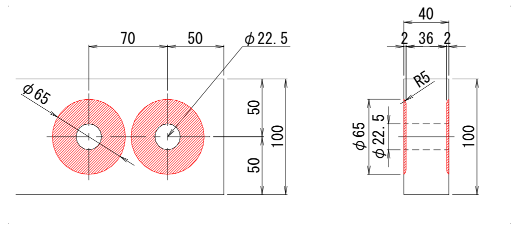
μ : slip coefficient m : number of the contact surface (=2) n : number of the bolt (=2)
N : design bolt axial force (165kN) W : plate thickness d : diameter of bolt hole
t_1 : thickness of the base plate σ_y : yield stress of the steel (specification)

The base plate used in this experiment has some various concavities as shown in Figure 2. The connected surfaces of the splice palates are painted by inorganic zinc-rich paint with 85~100 μm thickness after abrasive blasting (Ra:12.3μm) by realizing actual execution. The parameters varied are the depth, the numbers of the concavities and with/without adhesives. Summary of specimens are tabulated in Table 1. The influence of corrosion is investigated by comparing with CASE-C, D and E as shown in Figure 2. CASE-A is the reference specimen. CASE-B is the joint with adhesives and no corrosion damage. CASE-C has a concavity under the bolt. CASE-D and CASE-E have some concavities with adjacent the bolt holes. The concave depth of CASE-C, D, and E is 5mm or 2mm on one side. The number of concavities and those sizes are varied under the restrain in which the total areas of concavities of the specimen are constant.

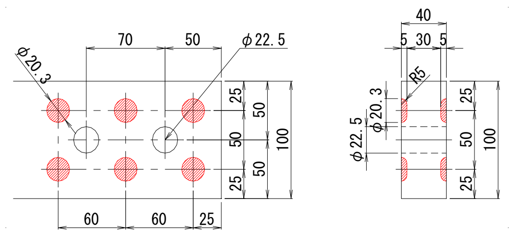
Fundamental mechanical characteristics of the adhesive are tabled in Table 2. The adhesives used is epoxy resin 2 liquid mixed type (product name:E258 made by Konishi Bond Corp.) which can work by gluing to the upward. As for making up the specimens, after gluing the adhesive, temporary bolts are fastened preliminarily by a spanner to exhaust the surplus adhesive on the surface. After hardening of the adhesive, a week, the temporary bolts were replaced and the original bolts are fastened by checking the bolt axial force through the strains glued on the bolt shank. The introduced axial force of all the bolts is 10% higher than the standard bolt axial force which is specified in JSHB(Japanese specifications for highway bridges).



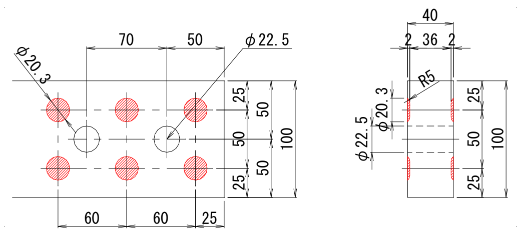
(a) CASE-C(No.3-1)



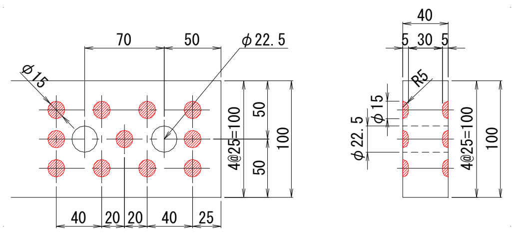
(b) CASE-C(No.3-2)



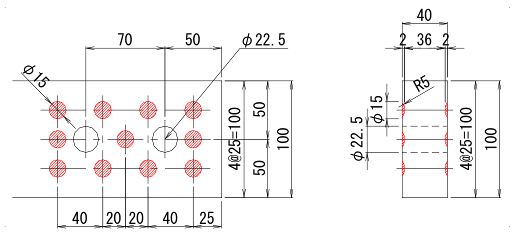
(c) CASE-D(No.4-1)



(d) CASE-D(No.4-2)



(e) CASE-E(No.5-1)



(f) CASE-E(No.5-2)

Figure 2: Configurations of the concavities

Table 1: List of specimens and parameters

CASE	Specimen No	Configurations and concavity of the specimen					Adhesives	Number of the specimen
		diameter (mm^{φ})	numbers (numbers)	depths (mm)	area of glue (mm^2)	area of concavity (mm^2)	Yes or No	
A	1-1	No			-	-	No	3
B	2-1	No			32,410	-	Yes	3
C	3-1	65φ	4holes	5mm	32,410	11,677	Yes	3
	3-2			2mm	32,410	11,677	Yes	1
D	4-1	20.3φ	12holes	5mm	32,410	3,882	Yes	3
	4-2			2mm	32,410	3,882	Yes	1
E	5-1	15φ	22holes	5mm	32,410	3,886	Yes	3
	5-2			2mm	32,410	3,886	Yes	1

18

Table 2: Fundamental characteristics of the adhesive

Main agent	Epoxy resin
Hardening agent	Polyamideamire
Mixture ratio	Main agent：Hardening agent ＝1 ：1 （Weight ratio）
The condition after	Paste
Working life	50min/20℃， 30min/30℃
Hardening time	48hrs/5℃， 12hrs/40℃
Tensile strength	25MPa （20℃， 7 days later）
Shear strength	24MPa （20℃， 7 days later）
Compressive yield strength	53MPa （20℃， 7 days later）
Compressive elastic	1200N/mm^2

2.2. Loading and measuring

The slippage test has been carried out about a week later after tightening bolts. The universal testing machine (1,000 kN) of Osaka City University is utilized for the slippage test. Applied tensile load, bolt axial force, and the relative displacement between the base plate and the splice plate are measured during the loading. Relative displacements are measured at the side edge of the base plate adjacent the outside and the inside bolt. Slip resistance is defined as the obtained maximum load in the test.

3. RESULTS AND DISCUSSIONS

3.1. Test results

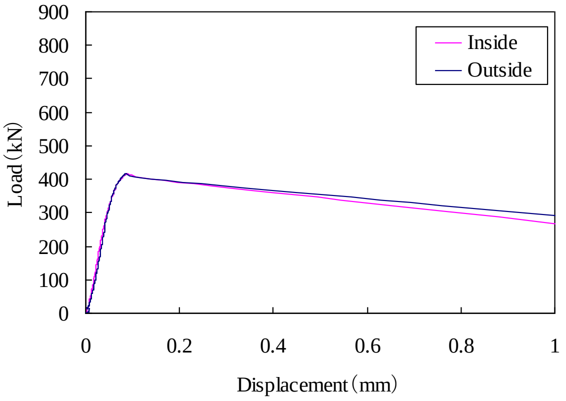
Summary of test results of all specimens is shown in Table 3. The axial force in Table 3 is the average value of the inside and the outside bolt axial forces where the slipping is occurred firstly.

Table 3: Summary of test results

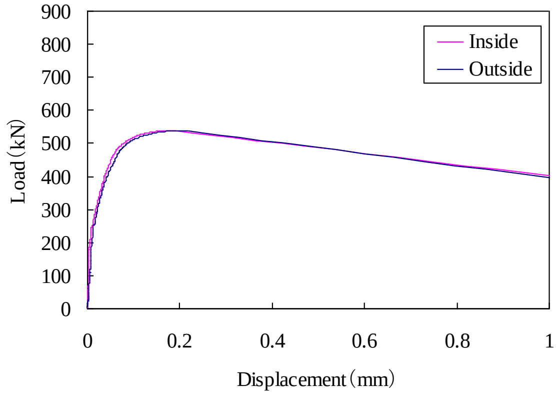
CASE	Specimen No.	Installed axial force	Axial force before test	Decreasing rate of the bolt axial force		Slip resistance	
		kN	kN	%	Ave	kN	Ave
A	1-1	183.4	170.2	7.2	6.2	415.5	426.8
		185.4	174.5	5.9		434.0	
		183.6	173.3	5.7		431.0	
B	2-1	191.8	178.4	7.0	6.0	538.5	551.0
		184.8	172.9	6.4		556.0	
		182.5	173.9	4.7		558.5	
C	3-1	183.2	162.4	11.4	11.5	481.5	487.7
		182.2	159.2	12.6		477.0	
		183.0	164.0	10.4		504.5	
	3-2	183.0	160.6	12.3	12.3	526.0	526.0
D	4-1	186.9	176.2	5.7	6.4	570.0	559.7
		183.8	171.4	6.8		573.5	
		183.6	171.4	6.8		535.5	
	4-2	182.1	170.9	6.1	6.1	579.0	579.0
E	5-1	183.3	172.2	6.0	5.9	479.5	532.5
		183.8	173.4	5.7		557.0	
		187.2	175.9	6.0		561.0	
	5-2	185.4	174.0	6.2	6.2	547.0	547.0

3.2. Load-Displacement relation

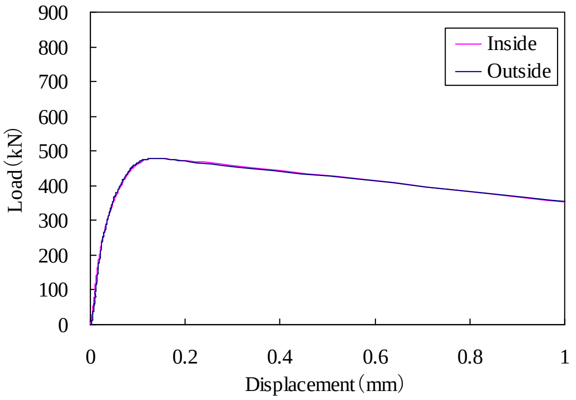
Typical examples of the relationship between load and relative displacement are shown in Figure 3. The load of all specimens is increasing until the major slip is occurred, that is, the maximum .load is obtained when the major slip is occurred. In this study, the slip resistance is defined as the maximum load as mentioned above. In order to clarify the influence of existence of adhesives, load-displacement curves of No.1-1 and No.2-1 are compared. No.2-1 shows non-linear behavior while No.1-1 shows linear behavior until the load reaches about 250 kN. As shown in Figure 2(b), the initial stiffness of No.2-1 is very high while the applied load is low, and then the stiffness gradually decreases until the major slip is occurred. It is caused by that the base plates and the splice plates are fixed due to adhesives on the connected surfaces. The relationships between load and displacement of other specimens with adhesives are almost same as that of No.2-1 without regard of the depth and the number of concavities.



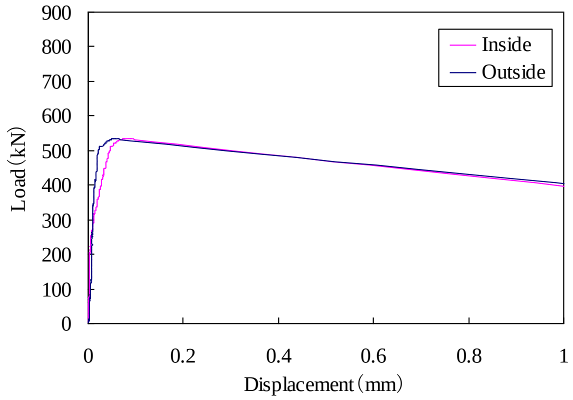
(a) No.1-1



(b) No.2-1



(c) No.3-1



(d) No.4-1

Figure 3: Relationship between load and displacement

3.3. Relaxation of bolt axial force

Figure 4 shows the decreasing ratio of the bolt axial force of each specimen in about a week later after tightening bolts. The relaxation of bolt axial force of No.1-1 and No.2-1 are both almost 6%. It means that there is almost no influence of the creep of adhesives since the adhesives is very thin. In addition, decreasing ratios of the bolt axial force of No.4-1, 4-2, 5-1 and 5-2 are almost same as that of No.2-1. It is understood that the depth, the diameter and the number of concavities does not influence on decreasing ratio of the bolt axial force if the bolts are not allocated near the concavities.

On the other hand, the decreasing ratio of the bolt axial force of No.3-1 and No.3-2 is both about 12%, which is larger than that of No.2-1. This high relaxation of the bolt axial force might be caused by the creep of the adhesive at the concavity.

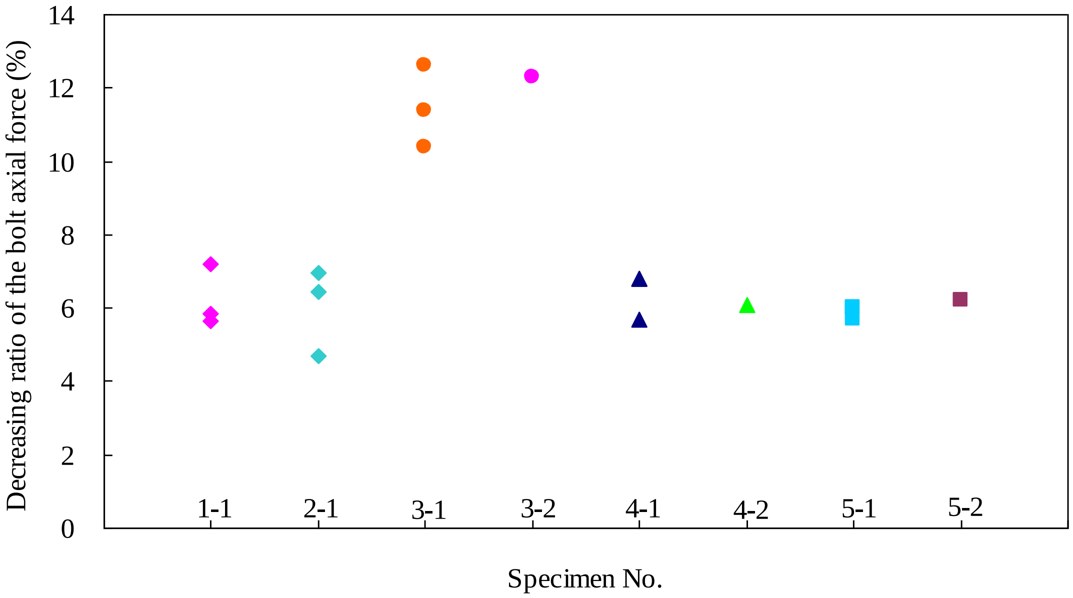


Figure 4: Decreasing ratio of the bolt axial force

3.3. Slip resistance

Comparing the slip resistances of all specimens is shown in Figure 5. The slip resistances of the specimens with adhesives are higher than the average slip resistance of No.1-1(427kN). It is found that the slip resistance of the specimen with adhesives is higher than that of the specimen of the frictional high strength bolted joint.

The slip resistances of No.3-1 and No.3-2 which have concavities under the bolts are 488 kN and 526 kN respectively, which is lower than that of other specimens with adhesives. The reason is considered that the decreasing ratio of the bolt axial force of No.3-1 and No.3-2 is about 12%, which is higher than that of the other specimens with adhesives. When the concavity doesn't exist under the bolt and the area of the concavity is constant, it is considered that the concave depth does not influence the slip resistance since the slip resistance of No.4-1, No.4-2, No.5-1 and No.5-2 is almost same.

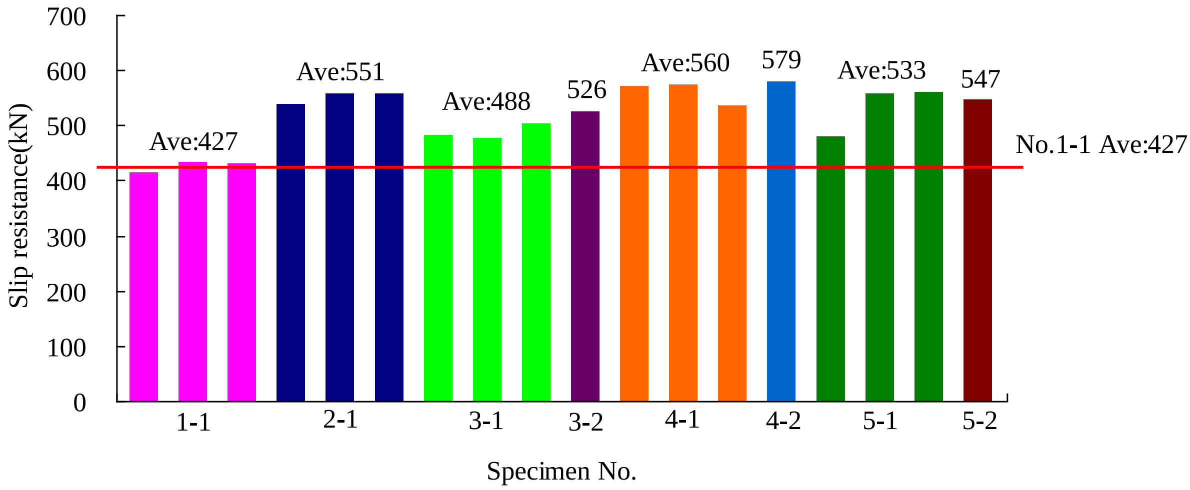
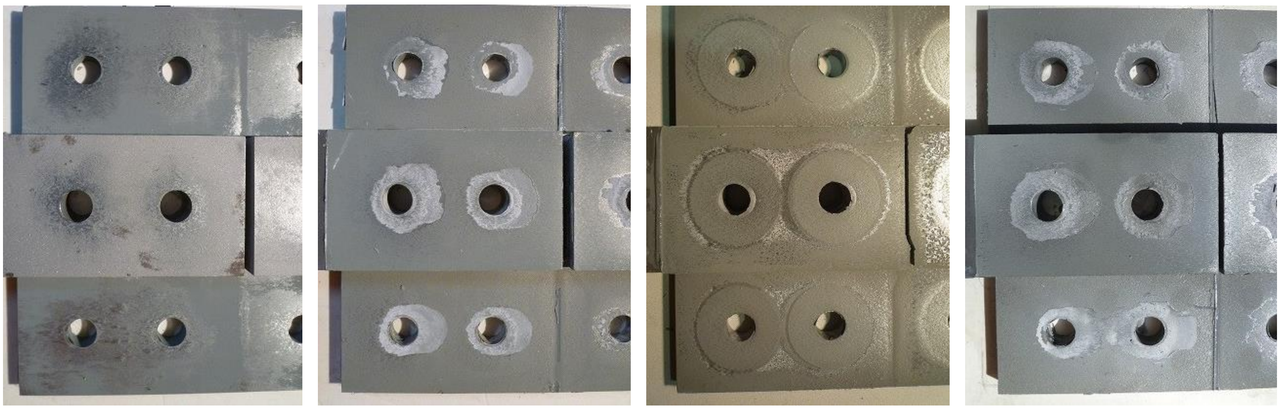


Figure 5: Slip resistance

3.4. Failure surface after experiment

The connected surfaces of the base plates and the splice plates are observed after the slippage test. Picture 2 shows the typical examples of connected surface after slippage. It is understood that adhesives near bolt holes were failed and inorganic zinc-rich paint apart from the bolt holes also failed. Both failures are categorized into the cohesive failure of the adhesive/the inorganic zinc-rich paint. It is considered that the shear strength of inorganic zinc-rich paint is higher than that of the adhesive because of influence of the bolts axial force. It is concluded that the slip resistance of the joint depends on the shear strength of inorganic zinc-rich paint.



(a)No.1-1 **(b)No.2-1** **(c)No.3-1** **(d)No.4-1**

Picture 2: Example of connected surface after experiment

4. CONCLUSIONS

In this paper, in order to clarify the influence on the slip resistance by the location, the depth and the number of concavities, the slippage test for frictional high strength bolted joints with epoxy resin on some concavities has been executed. The main conclusions obtained are as follows:

(1) It is found that the slip resistance of the joint with epoxy resin doesn't decrease compared with that of the joint without epoxy resin, and that the depth and the number of concavities have no influence on the slip resistance of the joint.

(2) In the case that there are concavities with adjacent the bolt holes, decreasing ratio of the bolt axial force isn't almost influenced by the depth, the diameter and the number of concavities. On the other hand, decreasing ratio of the bolt axial force is about 12% in the case that there is a concavity under the bolt.

(3) It is observed that failures of adhesives near bolt holes and inorganic zinc-rich paint apart from bolt holes were cohesive failure.

(4) Rational design strength of the bolted joints with adhesive would be proposed newly which could consider various applications on site. Accordingly, additional bending tests for the joints with bolts and adhesive should be carried out varying the structural parameters, such as the length of concavities and the thickness of splice plate and so on.

REFERENCES

J. Murakoshi, Y. Tanaka, T. Funaki (2008). Experimental study on static behavior of bolted connections with epoxy resin , JSCE collected papers of structural engineering, Vol.54A, pp.563-574. (in Japanese)

P. Albrecht, A. H. Sahli (1988). Static strength of bolted and adhesively bonded joints for steel structures, Adhesively Bonded Joints－Testing, Analysis and Design－, ASTM STP981, pp.229-251.

Japan Society of Steel Construction (1993). Application of glued connection for steel structure, technical report No.26. (in Japanese)

Hanshin Expressway Company Limited (2005). Repair Manual of Road Structure, part 1, Steel Structure. (in Japanese)

Japan Road Association (2012). Specifications for highway bridges, Part2 steel bridges. (in Japanese)

Japan Society of Civil Engineers (2006). Recommendations on design, construction and maintenance for friction type of high strength bolted connections. (in Japanese)