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EVALUATION FOR CORROSION STATE OF LOWER GUSSET PLATE CONNECTIONS ON STEEL TRUSS BRIDGE

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ABSTRACT

Many existing steel bridges in Japan were built in high economic growth period and the number of bridges over 50 years will increase drastically in the upcoming years. Due to the heavy traffic and severe natural environment, the deterioration and damage will increase rapidly. Improvement of technologies related to inspection, diagnosis, repair, reinforcement and appropriate maintenance is needed. Concerning the steel truss bridges, the serious corrosion damage has been reported recently, especially on the diagonal members and the gusset plate connections. The fracture of these members of steel truss bridge is likely to lead the collapse of the entire truss bridge.

In this study, the detailed corrosion shape of the two lower gusset plate connections that were cut from the steel truss bridge were measured by using the laser measurement equipment, and the actual corrosion state of the outside and the narrow inside surfaces of the lower chord members and the gusset plate connections were evaluated on the basis of the corrosion depth distribution of these surfaces. Based on the detailed results of corrosion measurement, the corrosion states and the corrosion characteristics of reinforced and non-reinforced gusset plate connections were clarified.

Key word: corrosion, lower chord member, gusset plate, steel truss bridge

1. INTRODUCTION

The majority of steel bridges in Japan were built during the 1950s - 1970s which coincides with the high economic growth period of Japan and the number of aged bridges is increasing rapidly. With the increase of the over 50 years bridges in Japan, serious damages due to corrosion have been reported such as Kiso river bridge on National Route No23 and Honjo bridge on National Route No7 in 2007. At the same time, the Minneapolis I-35W truss bridge (Kasano et al.2010) accidentally collapsed. The damages on steel truss bridges are usually occur at members or connections. Corrosion effects on truss bridges is large and it is the reason for significant section loss of truss member which may lead to damage of the bridge members. In order to evaluate efficiently and properly the corrosion impact, maintenance method must apply to ensure the safety of entire system of bridge.

In this study, the two lower connections were cut out from the steel truss bridge and the detailed shapes of corrosion at these connections were measured. More specifically, the outer surface of the lower chord members, diagonal members and gusset plates, as well as their inner surfaces were also measured by laser surface measurement equipment (Yamasawa et al. 2008, Nogami et al. 2012). The measurement results will clarify the actual conditions of corrosion on these two lower connections and the reinforced area.

2. CONNECTION STRUCTURE

The studied connections are P72d and P72u on the fifth span of five spans cantilever truss bridge which was demolished because over 50 years passed and the severe corrosion damage due to

influences of salt occurred as shown in Figure 1. The connection P72d and P72u consist of the lower chord members, the diagonal members, the gusset plates and the lower lateral bracings. In the connection P72d, gusset plates, lower chord and diagonal members were connected by rivets. In the connection P72u, gusset plates, and diagonal members were connected by rivets at the beginning but after that due to the severe corrosion the gusset plates were replaced then the bolt connection was used to connect between the gusset plates lower chord members and diagonal members, besides the diagonal member also was strengthened by bolt. The terms are defined in Figure 1 as an expression of the connection parts of P72d and P72u.

The lower lateral bracing was cut out from gusset connection, after that, the connections peeled off a coat and surface-burst had done.

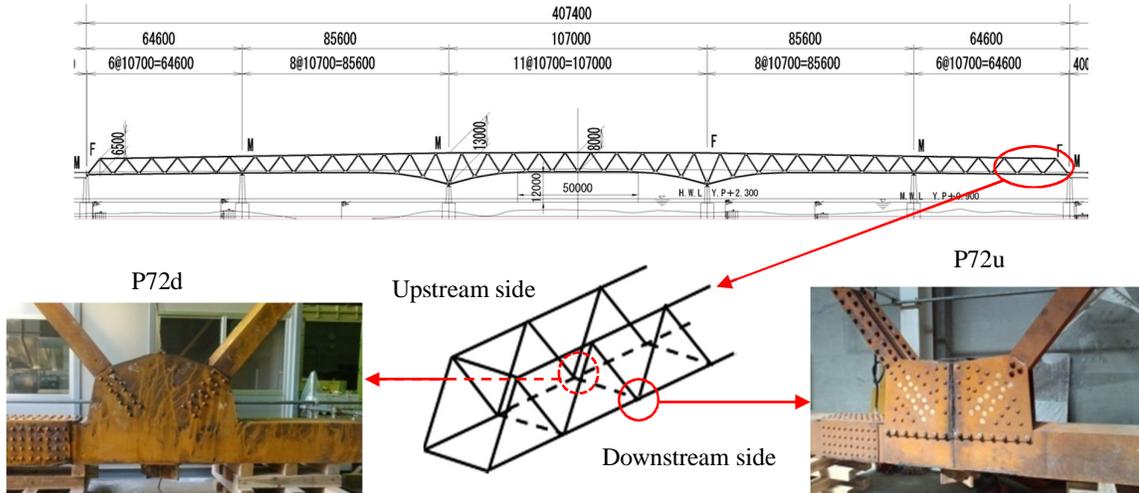


Figure 1: Connection P72d, P72u in the 5 spans truss bridge and definition terms

3. MEASUREMENT METHOD

3.1. Measurement equipment

In order to measure the corrosion shapes of the two lower connections, the laser measurement equipment was used. The laser measurement equipment is designed by Tokyo Metropolitan University researchers and manufactured by Optex company that composed of ① surface roughness measuring device, ② grab tool equipment, ③ A-D converter and ④ measurement and control equipment as shown in the Photo 1. The technical specifications of this laser measurement equipment is presented in the Table 2. The maximum and minimum measurement ranges in the direction x, y of this laser measurement equipment are 1m×1m and 1mm×1mm respectively, perpendicular direction depth is ± 35mm, the linear scale reading is 10μm.



Photo1: Corrosion shape measurement device

Table 1: Specifications of equipment

① surface roughness measuring device	
Measurement range (flat)	1000×1000 mm
Measurement range (Perpendicular direction depth)	100mm
Measurement speed(1mmTime interval measurement)	200data/min
Base of frame	Steel
② Grab tool equipment	
Maximum testing specimen dimensions	700×1000 mm
Horizontal rotation range	360°
Vertical rotation range	360°
Rotation range of microtremors	± 5degrees in 2 axis

3.2 Measurement procedure

In general, when a specimen is subjected to measure the shape of the surface corrosion, it is set on cross-ties as much vertical as possible. Procedure of setting laser measurement equipment as follow:

- ① The measured surface of the specimen and the laser measurement equipment must be parallel. The position of the laser measurement equipment is determined by the A-D converter to assure that the distances between the laser measurement equipment and the 4 targets are equal.
- ② Specify the origin of a measurement device (measurement device perform automatically)
- ③ Specify the measurement range (start point and end point) (perform manually).
- ④ To determine the based-surface, the attached targets are measured from both sides.
- ⑤ Start measurement

At the specific point, the corrosion depth t_i ($i = 1, 2, \dots, n$) is calculated by $t_i = H - h_i$ where (h_i) is the distance from the laser measurement equipment to corrosion point i , (H) is the distance from the laser measurement equipment to the based-surface. The remaining thickness t_R of the corrosion point i is calculated as $t_R = t_{il} + t_{ir} + t_i$ where t_{il} , t_{ir} are the corrosion depth of left and right surfaces respectively, t_i is the thickness of the target and t_0 is the initial thickness as shown in the Figure 2.

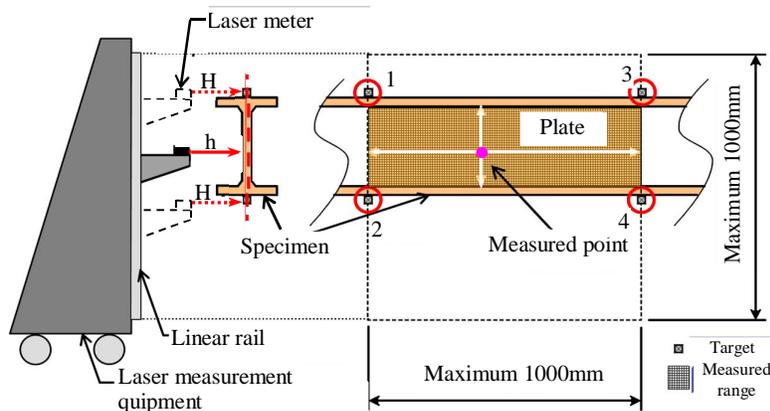


Figure 1: The specimen installation

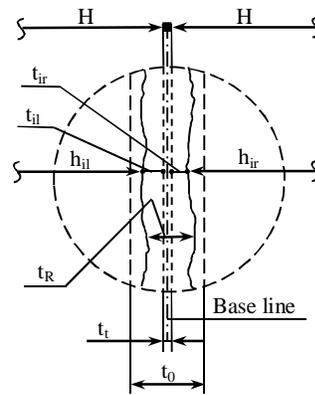


Figure 2: Thickness calculation method

3.3 Measurement method of the outer surface

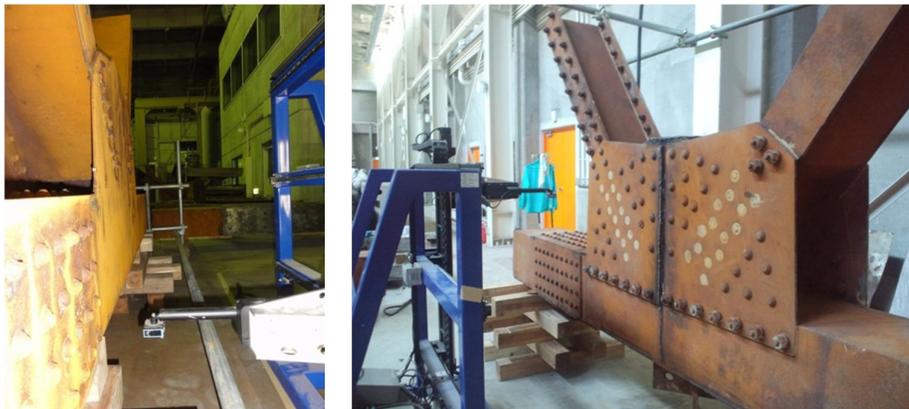


Photo 2: Laser measurement equipment set up for outer surface measurement of P72d (left) and P72u (right) connections

In order to measure corrosion shapes on the outer surfaces of the specimen, the concerned specimen must be set cross-tie as much vertical as possible as shown in the Photo 2. Due to the limited 1m×1m measurement range, the laser measurement device can not measure the outer surface of the specimen at the same time. Therefore, measurement range is divided into small parts depend on the dimension of the specimen. If the identification of the based-surface as shown in the Figure 1 of part 3.2 is too difficult so the base-surface must be determined that three ~ five target points by hands at the visually healthy place that corrosion has not occurred and then the measurement range will be selected and marked.

3.4 Measurement method of the inner surface

For the situation of the inner surface or narrow surface corrosion measurement, such as the inner surface of the gusset plate, where the measurement device could not measure directly so the method of molded plaster is adopted then the plaster specimen surface would be measured by laser measurement equipment as shown in the Photo 3. The plaster specimen is made by the process as shown in Photo 4. The based-plane in the case of inner surface measurement is set by using the 3-point measurement method on the plaster specimen surface. Procedure of setting laser measurement equipment is as same as the outer surface measurement process.

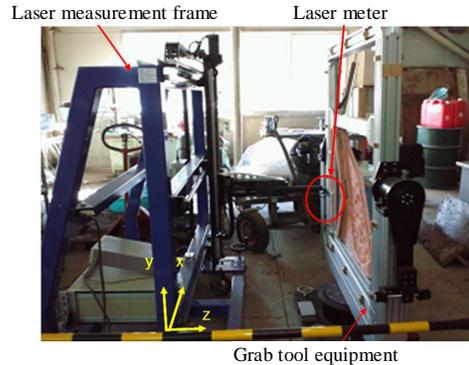


Photo 3: Plaster specimen measurement

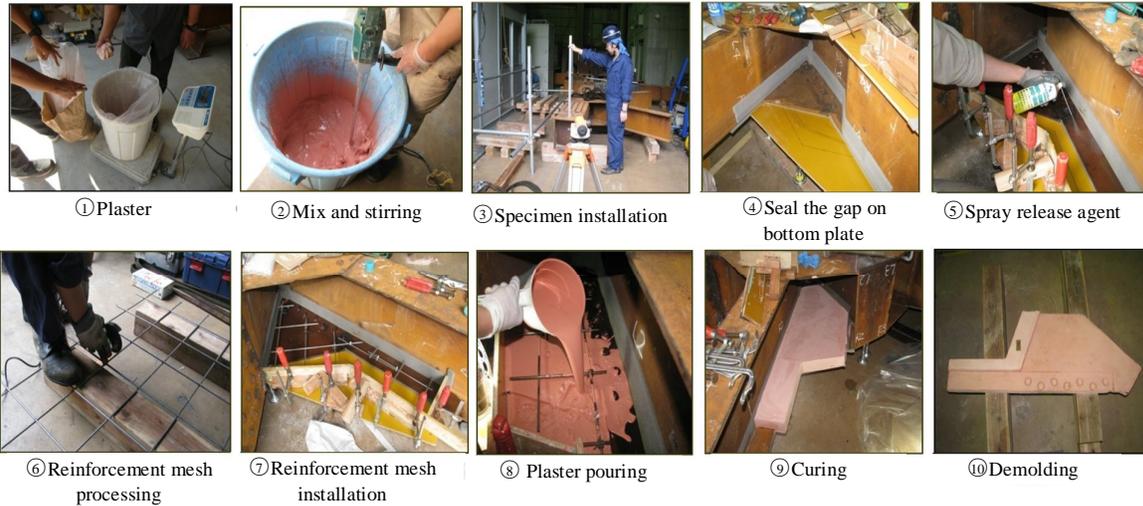


Photo 4: Procedure for making the plaster specimen

4. CORROSION STATE OF THE TWO LOWER CONNECTIONS

4.1 The P72d connection

4.1.1 Outer surface

In order to measure the outer surface of P72d connection, the measurement interval of the laser displacement equipment was selected as 1mm interval to understand its mechanical performance and it was set up as shown in the photo 2. The based-plane was set by hands equal zero. Due to the limited 1m×1m measurement range of the laser measurement equipment and the dimension of P72d connection, the measurement range is divided into 5 times in the vertical direction for both upstream and downstream side, as shown in the Figure 3. The corrosion occurred locally in some

parts the outer surface of the connection P72d so the corrosion measurement was conducted with the special concentration on these area. The measurement results of the upstream and downstream side were shown on the Figure 4, the average corrosion depth and the maximum corrosion depth of the outer surface on the downstream side are 1.52 mm and 9.99mm while in the upstream side they are 0.9mm and 7.97mm, respectively. For the corrosion of outer surface of gusset plates of the P72d connection, except for the area of the rivet, the average depth of surface corrosion and the maximum corrosion depth are 0.83 mm and 7.92mm on the upstream side. For the downstream side, they are 1.79mm and 7.99mm, respectively

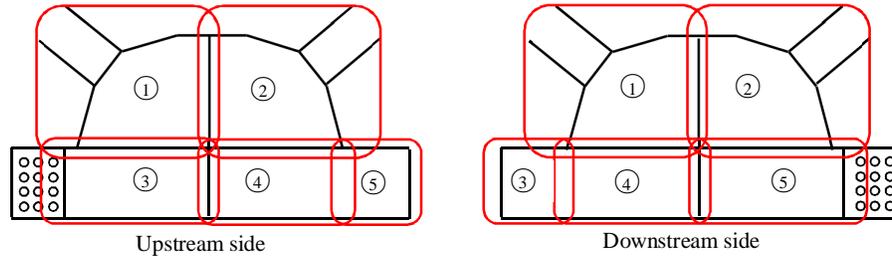


Figure 3: The measurement range of the outer surfaces of the P72d connection

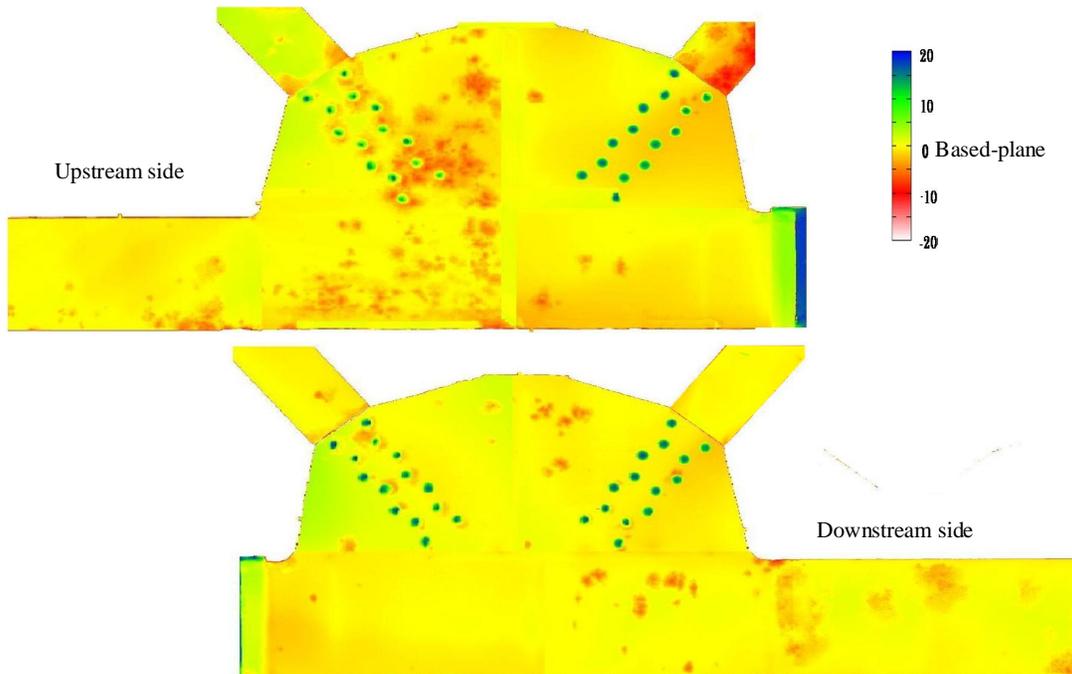


Figure 4: Corrosion depth distribution on the outer surface connection P72d

4.1.2 The inner surfaces

Photo 4 shows the situation of the inner surface corrosion of the gusset plate of P72d connection. This narrow section can not be measured directly by laser measurement equipment, so the method of molded plaster was adopted then the plaster specimen surface was measured by laser measurement equipment.

The moulage is carried out for the inner surface of gusset plate and the inner surface of diagonal member, total plaster specimen became 8 bodies as shown in the Photo 5 and the measurement results are presented in the Figure 5. Then the plaster specimen were fixed in the grab tool

equipment, then measured by laser measuring equipment as shown in photo 5. Performance of the grab tool equipment is listed in Table 2. The based-plane of the plaster specimen was set equal zero. As shown in the Figure 5, the corrosion of inner surfaces of the P72d connection occurred locally and concentrated mostly on the edges of gusset plate in the upstream side, on the flanges of diagonal members and on the transition area between diagonal member and the gusset plate in the downstream side. The average corrosion depth and the maximum corrosion depth of the inner surface on the downstream side are 1.16mm and 7.99mm respectively while in the upstream side they are 1.3mm and 8.98mm



Photo 4: Corrosion condition of the inner surface of narrow section



Photo 5: Plaster specimen at the inner surface of gusset plate



Photo 6: The plaster specimen measurement

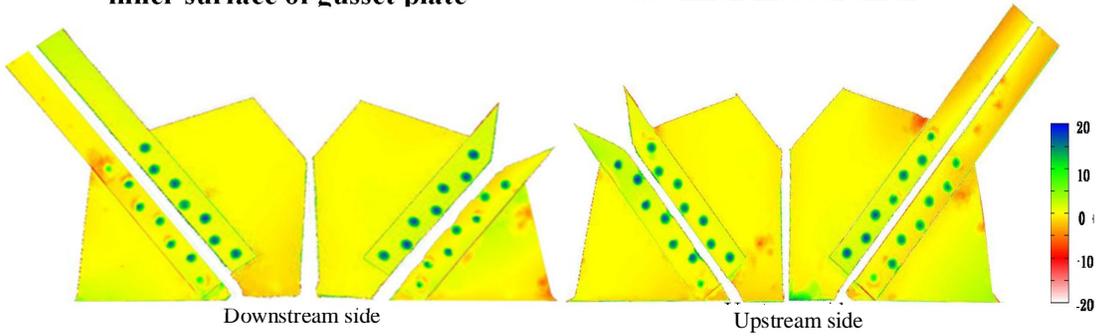


Figure 5: Corrosion depth distribution on the inner surface of the P72d connection

4.2 The P72u connection

On the outer surface of the P72u connection, because of the corrosion that has not seen clearly so the measurement interval of the laser displacement equipment was selected as 3mm interval and the based-plane was set equal zero. The measurement range is divided into several times (7 times for the upstream side and 6 times for the downstream side) as shown in the Figure 5. The measurement results of the upstream and downstream side were shown on the Figure 6. The corrosion mostly occurred on the flange of the reinforced diagonal member with the average corrosion depth in these flanges are 0.53mm and 0.45mm for the upstream side and downstream side, respectively.

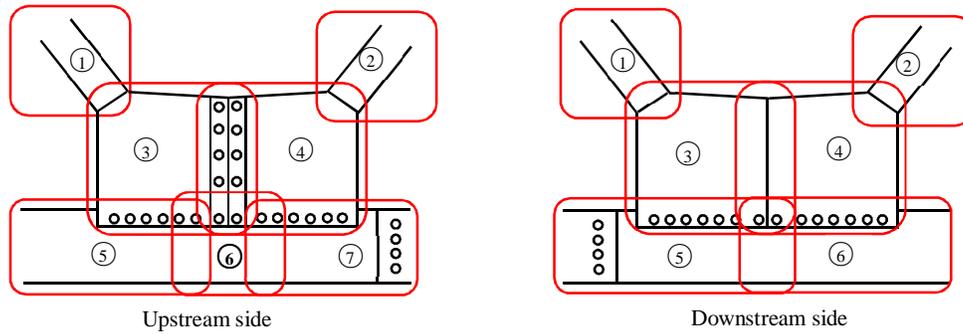


Figure 5: The measurement ranges of the outer surface of the P72u connection

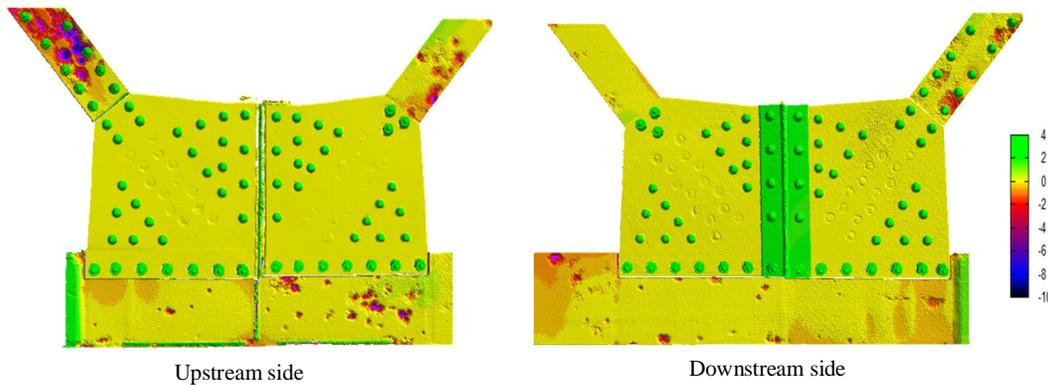


Figure 6: Corrosion depth distribution on the outer surfaces of the P72u connection

In the case of P72u connection, due to the severe corrosion in the past the gusset plate was replaced and the bolts were used to connect the new gusset plates and the flanges of the diagonal members. Because of the end of these bolts are too long, as seen on the Photo 7, the plaster specimen could not create. As the result, the inner surfaces of P72u connection could not be measured.



Photo 7: Inner surfaces of P72u connection

5. CONCLUSION

From the detailed corrosion measurement of the lower gusset plates connections (P72d and P72u). The summarizes are as follows:

1. For the P72d connection: Corrosion occurred locally on the surface of the gusset in the upstream and downstream side and on the flange of the diagonal members in both inner and outer surfaces. On the outer surface, the maximum corrosion depth reached to 9,99mm in the downstream side and 7.97mm in the upstream side while on the inner surfaces they are 7.99mm and 8.98mm for downstream and upstream side respectively. For the inner surface of gusset, the severe corrosion has also occurred locally at the edges of the gusset plate and on the transition region between gusset plate and the flange of diagonal members in both up and downstream side.
2. For the P72u connection: On the outer surfaces, the corrosion has not seen clearly on the whole of gusset plate, it only occurred on the flanges of the reinforced diagonal member in both upstream and downstream side with the average corrosion depth are 0.53mm and 0.45mm, respectively. In the case of P72u connection, because of the severe corrision in the past, the gusset were replaced and the bolt connection was used. Due to this bolt connection the plaster specimen could not created and the inner surfaces were not measured.

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