STUDY AND REINFORCEMENT ON CRACKS AT BEAM-TO-COLUMN CONNECTION WELDING

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Abstract

This study reveals that steel pier with particular assembly geometry of beam-to-column connection has more clacks compare to those with the other assembly geometries. The complexity of steel plate assembly geometry at the crossover points of horizontal and vertical weldings causes the welding difficulty, and the defects of welding can lead to fatigue cracks. Additionally, simple reinforcement with triangle bolted splice plates to reduce the stress due to live load is determined with finite element analyses. The reinforcement with appropriate size of splice plates can reduce the stress at the crossover points of the weldings by half.

Introduction

One of the most serious damage on steel structure is fatigue crack. The fatigue cracks occur especially at welding due to residual stress and defect of welding. Beam-to-column connections are assembled by welding, and then the crossover points of welding sometimes have defects because of its complex geometry of flange plate and web plate. This study focuses on the relation between assembly geometry and cracks, and as a result, it is revealed that particular geometry has more cracks than the other geometries. The assembly geometry is that both ends of flange plates for beam and column are on the surface of the structure. 30.5% of the piers with the particular assembly geometry have cracks while the other piers with the other assembly geometries have about 10%. Besides, a reinforcement to reduce live load stress for improvement of fatigue life is determined using finite element analyses. Splicing triangle plate, the projection length is 1/3 of the height of the beam, can reduce live load stress by half.

Hanshin Expressway and Steel Piers

The Hanshin Expressway is 242.0km urban expressway in Kansai area Japan. The first section was opened to traffic in the year 1964. Nowadays, the amount of vehicles driving on the expressway is about 900,000 a day. The expressway has 2 separated networks; 233.8km between Osaka and Kobe area, and 8.2km in Kyoto area. The 8.2km in Kyoto area is really new, that has been opened to traffic in 2008, and then attention should be focused on between Osaka and Kobe area network since the cracks seems to be related to fatigue of steel. There are 9559 spans of bridges and 8681 piers in the area. The amount of steel piers with beam-to-column connection is 1199.

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Total Inspection

Inspection for all corners at beam-to-column connections of steel piers in the expressway was conducted in 1996. There were 141 steel piers with cracks at the corner out of 1199 that means 12% of the piers were damaged.

According to the severity of the cracks, the 141 piers were classified into 4 ranks.

Rank A Cracks longer than 100mm and close to web
Rank B Cracks 30 – 100 mm and close to web
Rank C-1 Cracks shorter than 30mm and close to web
Rank C-2 Cracks in the middle of flange

The number of each rank is shown in Table 1.

Table 1. Result of Total Inspection

Total piers	No crack	With cracks			
		A	B	C-1	C-2
1199 (100%)	1058 (88%)	141(12%)			
		4	29	44	64

Structure of Steel Piers

Table 2. Shapes of Steel Piers

Total piers	Rectangular column				Other column
	"WW"	"WF"	"FW"	"FF"	
1199 (100%)	929(77%)				270 (23%)
	800	37	10	82	

Cross sectional shapes of steel columns in the expressway can be divided in three types as shown in Table 2, rectangular circular and other particular shape. 929 piers out of the 1199 piers, that is accounted for 77 %, have rectangular shape. Therefore, analysis of cracks and detail structure are conducted for steel piers with rectangular column.

In the steel piers with rectangular column, there are mainly 3 types of assembly geometry for flanges and webs of beams and columns in the expressway steel piers, "WW", "WF/FW" and "FF". "WW", shown in Figure 1, has assembly geometry that both ends of web plates for beam and column are on the surface of the structure. Ends of flange plates are touched to inner surface of web plates.

"WF", shown in Figure 2, has assembly geometry that ends of flange plates for beam and ends of web plates for column are on the surface of the structure. Ends of flange plates for column and ends of web plates for beam are touched to inner surface of the other plates.

"FF", shown in Figure 3, has assembly geometry that both ends of flange plates for beam and column are on the surface of the structure. Ends of web plates are touched to inner surface of flange plates. All 3 assembly types have crossover points of vertical and horizontal weldings and those might have defects due to the difficulty of welding at the time of construction.

Analyses of Cracks and Detail Structure

Damage rate of the beam-to-column connection welding in rectangular steel pier is dependent on the assembly geometry. As shown in Table 3 and Figure 4, the damage rate by the amount of pier is 10.8% for "WW", 14.9% for "WF/FW" and 30.5% for "FF". It is assumed that relatively complex detail shape of the plate for "FF" causes the higher damage rate than the other assembly geometries because of the welding difficulty. The crossover point of welding is also a concentrated point of stress due to live load. Therefore, welding defect at the crossover point possibly causes fatigue cracks.

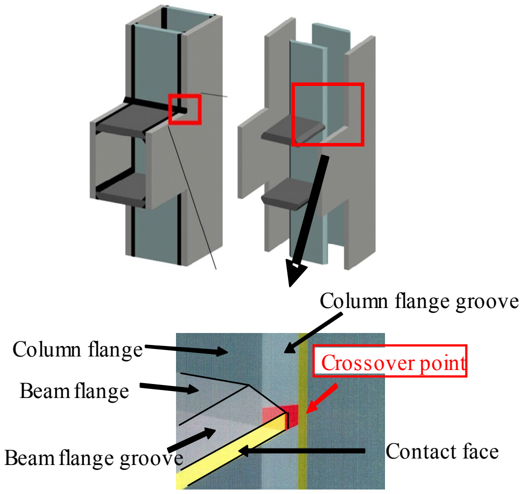

Figure 1. Assembly

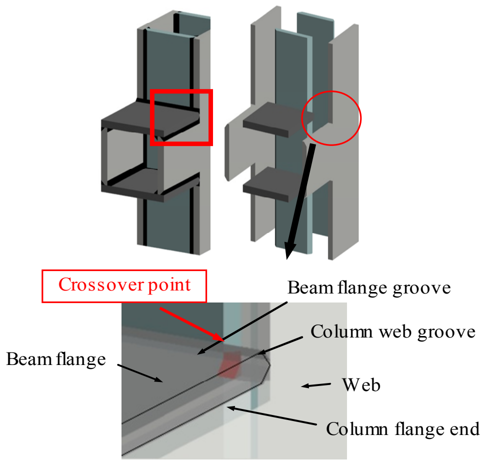

Figure 2. Assembly

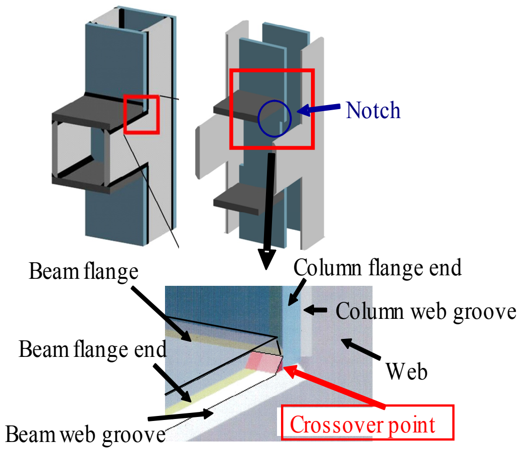

Figure 3. Assembly

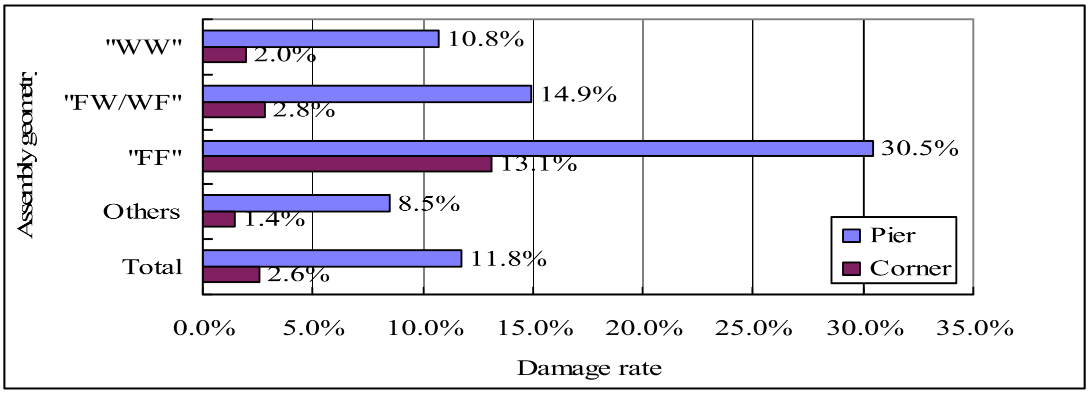

Figure 4. Damage Rate by Piers and Corners

Table 3. Damage rate by Piers and Corners

	Pier			Corner of the connection		
	Amount of pier	Damaged	%	Amount of corner	Damaged	%
"WW"	800	86	10.8%	7132	142	2.0%
"FW/WF"	47	7	14.9%	498	14	2.8%
"FF"	82	25	30.5%	755	99	13.1%
Others	270	23	8.5%	3142	45	1.4%
Total	1199	141	11.8%	11527	300	2.6%

Crack patterns of the 3 assembly geometries are different as shown in Figure 5 to Figure 7. The breakdown of the cracks on “WW” is; (5)crossover point(flange) 37%, (1)corner welding and (6)flange(toe) 13%, (3)crossover point(corner) 12% and the others. The breakdown of the cracks on “WF” is; (5)crossover point(flange) 62%, (4)crossover point(web) 25% and (7)flange(bead) 13%. The breakdown of the cracks on “FF” is; (5)crossover point(flange) 51%, (3)crossover point(corner) 22%, (4)crossover point(web) 21% and the others. Compare to “WW”, “WF” and “FF” have large percentage for the cracks related to crossover point of the weldings. Especially, almost all cracks on “FF” is

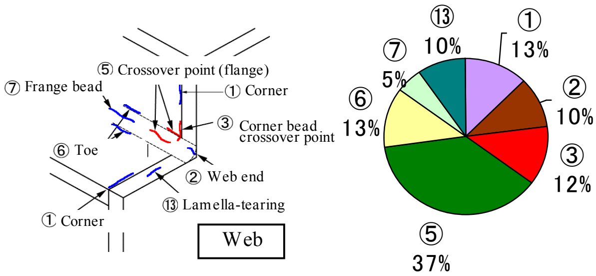

Figure 5. Cracks on “WW”

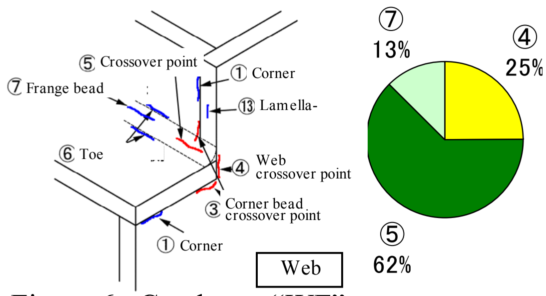

Figure 6. Cracks on “WF”

related to crossover point of the weldings. It is assumed that complex detail shape of the plates at the connection between beam and column causes defect of welding, then the defect and concentrated live load stress cause fatigue cracks.

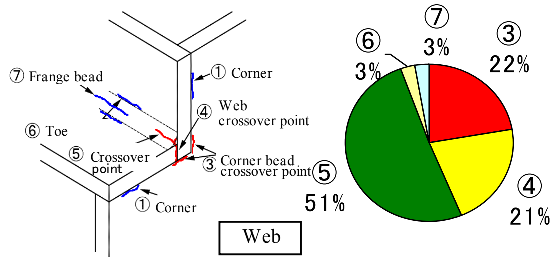

Figure 7. Cracks on “FF”

Reinforcement

The purpose of reinforcement is to prolong life against fatigue failure. There are two ways to prolong the life; reconstruction of the connection and reduction of the stress causing fatigue cracks. The later way was selected since it can be done in short duration and is economical.


Figure 8. Reinforcement

Practical way to reduce the stress is to splice an additional plate onto a web plate as shown in Figure 8. Bolted splice is used for the reinforcement instead of field welding splice since its fatigue resistivity. Bearing type bolt is chosen instead of friction type because the surface of the web plate is not completely flat. The reinforcement aims to reduce the stress by half, which can prolong the life more than 8 times according to fatigue curve (Japan Society of Steel Construction 1995).

Parametric Study of Reinforcement

The shape of the splice plate to bypass stress of the web should not be complex since it must not cause additional damage and it can be fabricate easily. Thus, the shape is set to triangle. Then, the size should be determined to accomplish the aim that reduction of the stress by half. The three size, “Da” “Ha” and “ta” as in Figure 9 , of the triangle splice plate, was determined using finite element analyses.

Da; Overlap width of pier and splice plate.

Ha; Projection length of the splice plate.

ta; Thickness of the splice plate.

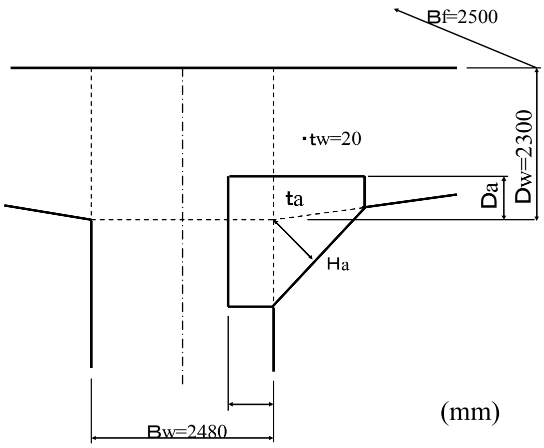

Figure 9. Shape of Reinforcement

Table 4. Stress Rate After to Before Reinforcement
(Effect of Plane Size) (%)

	Ha=312mm Ha/Dw=0.14	Ha=521mm Ha/Dw=0.23	Ha=769mm Ha/Dw=0.33	
Da=330mm	70.7	58.4	47.6	Lower flange
Da/Dw=0.14	73.0	60.5	50.2	Column flange
Da=420mm	70.6	58.6	47.8	Lower flange
Da/Dw=0.18	72.7	60.4	50.1	Column flange
Da=580mm	71.1	---	48.6	Lower flange
Da/Dw=0.25	73.1	---	50.6	Column flange

Table 5. Stress Rate after to Before Reinforcement
(Effect of Thickness) (%)

ta (mm) ta / tw	22 1.1	30 1.5	40 2.0
Lower flange	47.8	42.8	38.9
Column flan	50.1	45.1	41.3

The results of the parametric analyses are as follows. As in Table 4, the "Da" has slight effect to the reduction of the stress. Change of the "Da", that is from 330m to 580mm, causes slight different of the stress rates after to before reinforcement. On the other hand, the "Ha" has certain effect to the reduction of the stress. In the case of "Da" is 330mm, the stress rate after to before reinforcement is 70.7% or 73.0% if "Ha/Dw" is 0.14 and the stress rate is 47.6% or 50.2% if "Ha/Dw" is 0.33. The rate, "Ha/Dw"=0.33, can reduce the stress almost by half. As in Table 5, if "ta" is changed from 22mm to 40mm, the stress rate is changed from 47.8% to 38.9% or from 50.1% to 41.3%. However, the increase of the thickness causes stress concentration at bolt. Therefore, the "ta" should be 22mm in the case of the thickness of web plates is 20mm.

As a result of the parametric analyses, the three sizes were determined as follows.

The ratio of "Ha" to "Dw" should be more than 0.35.

The thickness of the splice plate "ta" is equal to the thickness of the web plate and should be greater than or equal to 22mm.

Conclusion

As a result of the total inspection and the analysis of crack patterns, the relation between assembly geometries of steel piers and cracks at the beam-to-column connection were found. "FF" cause more cracks than "WW" and "WF/FW". The most cracks of "FF" related to the crossover point of the weldings. Difficulty of welding due to complex detail shape of the "FF" causes the cracks.

As a result of the parametric study of reinforcement, the dimensions of triangular splice plate to reduce live load stress by half are determined. The ratio of "Ha" to "Dw" should be more than 0.35. "ta" is equal to the thickness of web and at least 22mm.

References

Japan Society of Steel Construction (1995), *Fatigue Design Recommendations for Steel Structures*, Japan