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ORIGINAL ARTICLE

INVESTIGATION OF BOLTED CONNECTION BETWEEN COLD/HOT-FORMED STEEL PLATES UNDER STATIC SHEAR LOADING

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ABSTRACT: Nowadays steel shear walls are popular as a resistive system for the lateral load affecting on the buildings. To design such a wall, especially for higher floors, bolted connections are suggested due to the facts that the thickness of the applied plates reduces, also welding thin plates faces some limitations. In applying steel shearing walls a plate made of hot-rolled steel which is in common called as Fish plate, is used which is applied as a medium between the shearing wall and the elements around beams and columns. In this article, the connections between cold-formed steel sheets and hot-rolled ones under the static shearing load are tested. Based on the provided results and studying load-displacement behavior of the specimens, the functions of the aforementioned connections are explained regarding the load tolerance and the style of failure.

KEYWORDS: Bolted Connection, Cold-Formed Steel Sheets, Hot-Rolled Steel Plate, Thin Steel Shear Walls.

INTRODUCTION

Applying steel shearing walls in the tall buildings has been increased in recent decades as a resistive system against the lateral loads of wind and earthquake. In designing these walls and especially in higher elevations and floors of the buildings and due to the thickness reduction of the applied plates, using cold-formed plates are popular. Due to the lower thickness of the plates and welding limitations of such plates, bolted connections are often applied to provide the needed support. Schumacher *et al.,* (1997) introduced a hot-rolled steel plate called Fish plates in bolted connections. This plate provides a connection between steel shearing wall and the elements around the columns and beams.

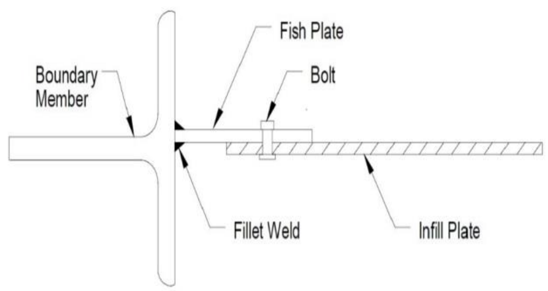

Figure 1: Sample of Fish Plate

Astaneh, (2001) has expressed that thin-walled steel shearing walls are greatly applied and popular because of high hardness, good ductility and energy loss power. Generally such walls are applicable because of the post-buckling strength of the thin plates, or in fact the resistance due to diagonal tensile field which it occurs after the primary buckling of the steel plate. Great amount of studies have not been done in the field of bolted connections between cold-formed and hot-rolled plates. Most of these studies are in the field of bolted connections between two cold-formed plates which are mostly applied in light steel frame (LSF) structures. These studies can be mentioned as the followings by Chung and Ip, (2000); Yu and Sheerah, (2008); Yu and Xu, (2010) and Teh and Gilbert, (2012).

Fan *et al.,* (1997) proposed a finite element model to study the final resistance and deformation in the components of bolted connections between two plates of cold-formed plates and stress distribution of these components. This model was composed of a bolted single-shearing connection under a static shearing load in plates with different thicknesses. This model was applied to measure and predict the resistance, deformation, bolt rotation, and ultimate stress distribution of the connections. The results revealed a good relation of the experiments with each other. Lu *et al.,* (2008) proposed the limited element model through ABAQUS software for cold-formed and hot rolled plates in 0.8 mm and 0.10 mm respectively, which they were connected with bolts. The specimens produced in different temperatures with rising ranges of 20 to 600°C were undergone the tension and their minimum and maximum elongations were evaluated. It was observed that increasing the temperature

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leads to the yield force reduction and correspond to point increases with elongation increases. Figure 2 shows the displacement-load curve of these parts.

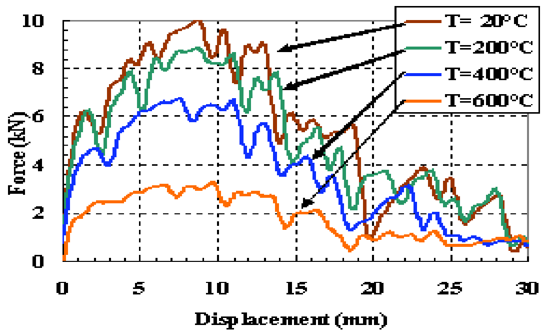


Figure 2: Load-displacement curve

BOLTED CONNECTIONS

Using bolt connection is an efficient method for connecting fish plate to shear walls. Failure of these bolts will be accrued in different modes. As shows in figure 3, different types of bolted connection fail under a shearing force. Shearing failures can be accrued because of:

- Shearing failure of the plate which is due to low distance of the hole to the edge of the plates.
- Bearing failure which is due to high distance of the hole to the edge of the plates with higher thicknesses.
- Net section failure due to the lower ratio of width-diameter (w/d) in connections.
- Bolt shear failure.

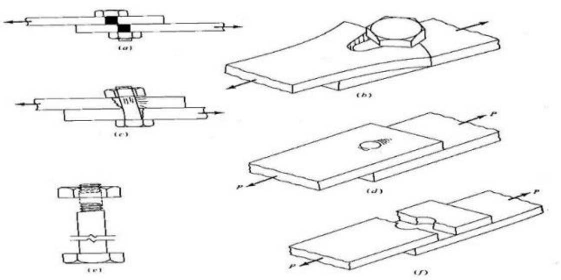
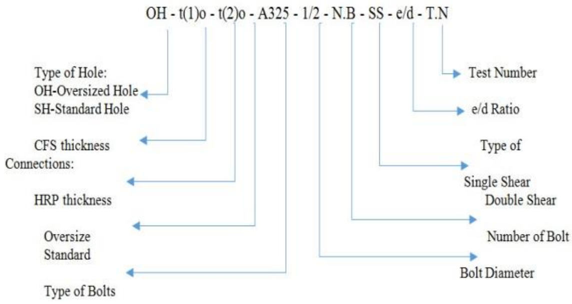


Figure 3: Types of Bolted Connections Failure

Yu and Sheerah, (2008) proposed the following nomination for the tested specimens based on some parameters like bolt diameter, plate thickness, e/d ratio, bolt quantity, connection functions based on single-shear, double-shear or other variables.



The specifications of the tested specimens based on the available parameters in figure 4 are as the followings:

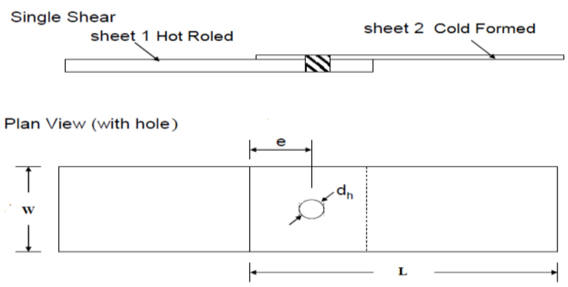


Figure 4: Specifications of specimen

Where:
e = Distance from center of hole to edge of sheet
d = Bolt Diameter
w = Width of specimen

INSTRON 4484 tension test machine is applied to run the tests, in which the effect of eccentricity of the load is compensated through making a clamp and in order to apply static load, the loading velocity of the machine is set as 5 mm/min (figure 5).

Figure 5: specimen in the test machine

The mechanical specifications of the tested plates are provided in Table 1. Specimens are made through wire cut machine and their dimensions are set as ASTM E8/E8M standards.

Table 1: Mechanical property of CFS

	Specimen Thickness (mm)	Average Yield Stress, Fy (MPa)	Average Ultimate Stress, Fu (MPa)	Percent Elongation (%)
CFS-1	0.57	84	98	13.5
CFS-2	0.8	139	148	10.7
CFS-3	1.0	65	149	10.4
CFS-4	2.0	65	184	12.1

Table 2: List of experiments

No	HRP Thickness (mm)	CFS Thickness (mm)	Type Of Bolt	Bolt Diameter (mm)	Number Of Bolt	Type of Connections	e/d
1	5	0.57	A325	6	1	ss	4
2	5	0.57	A325	8	1	ss	4
3	5	0.57	A325	10	1	ss	4
4	5	0.8	A325	6	1	ss	4
5	5	0.8	A325	8	1	ss	4
6	5	0.8	A325	10	1	ss	4
7	5	1.0	A325	6	1	ss	4
8	5	1.0	A325	8	1	ss	4
9	5	1.0	A325	10	1	ss	4
10	5	2.0	A325	6	1	ss	4
11	5	2.0	A325	8	1	ss	4
12	5	2.0	A325	10	1	ss	4
13	8	1.0	A325	10	1	ss	4

The total number of 13 specimens were tested and their specifications are provided in Table 2. The rows 1 to 12, and 13 are allocated to specimens with the width of 50 mm and 100 mm, respectively. In order to make sure that the experiments are correct, the specimens were tested two times.

RESULTS AND DISCUSSION

Force-displacement graph can be achieved by tensile test. According figure 6, these graphs can be divided to four regions. Description of these regions is as follow:

1- At the beginning of the loading, the Load-displacement curve can be considered linear with a proper approximation which is concurrent with bearing stress in cold-formed plates. When the load increases, deformation does too.

2- In point 2, the curling phenomenon happens which in its occurrence, the load maximizes and as we can see, load reduction is seen. In point 2, the load is 5.30 kN that is proportional to the displacement of 1.59 mm, which then it decreases to 5.13 KN in 1.9 mm displacement. Figure 7, figure 8 and figure 9 show the above relations.

3- After that, load changes are less. This is with shearing failure in the parts. In region 3 the parts under shearing load have a good ductility.

4- With some load increases due to the curling effect and the bolt penetration into the plate web, the curve reaches the point 4 which is shown in figure 6. At this point shearing failure finishes and a new one happens in the plate which accompanies with great reduction of load-carrying capacity. This failure starts from the edge of the bolt hole and spreads to the external edges. It continues until the complete failure happens.

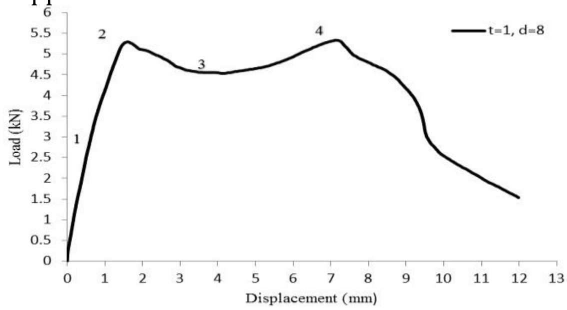


Figure 6: Load-Displacement Curve schematic

Figure 7: Before the start of Curling

Figure 8: Curling Begins

Figure 9: Final shape

Figure 11: Connection Failure

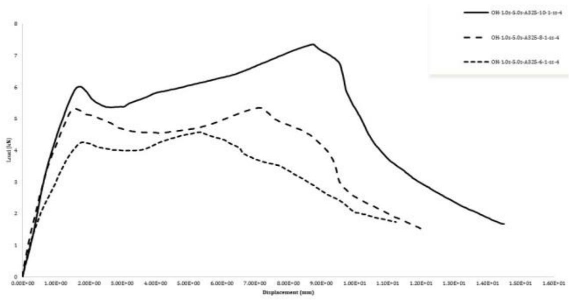


Figure 10: shows displacement-load curves of the cold-formed plate with the thickness of 1mm

Figure 12: Side view of connection failure

Table 3: Tensile load in different samples

No	Name	Thickness of Cold Formed Sheets	Bolt Diameter	Load (kN)
1	OH-0.57s-5.0s-A325-6-1-ss-4	0.57	6	1.66
2	OH-0.57s-5.0s-A325-8-1-ss-4	0.57	8	2.65
3	OH-0.57s-5.0s-A325-10-1-ss-4	0.57	10	3.37
4	OH-0.8s-5.0s-A325-6-1-ss-4	0.80	6	3.52
5	OH-0.8s-5.0s-A325-8-1-ss-4	0.80	8	4.36
6	OH-0.8s-5.0s-A325-10-1-ss-4	0.80	10	5.04
7	OH-1.0s-5.0s-A325-6-1-ss-4	1.00	6	4.24
8	OH-1.0s-5.0s-A325-8-1-ss-4	1.00	8	5.26
9	OH-1.0s-5.0s-A325-10-1-ss-4	1.00	10	6.00
10	OH-2.0s-5.0s-A325-6-1-ss-4	2.00	6	12.3*
11	OH-2.0s-5.0s-A325-8-1-ss-4	2.00	8	15.4
12	OH-2.0s-5.0s-A325-10-1-ss-4	2.00	10	16.3
13	OH-1.0s-5.0s-A325-10-1-ss-4**	1.00	10	6.90

* In this series of experiments, bolt failure in the connection is seen.
** In the rows of 1 to 12, and 13, the specimen widths are 50mm and 100mm, respectively.

Table 4: Percentage of stress increasing versus stress in lower bolt diameter

	Thickness (mm)	Fy (%)		
		$\frac{d_{10}-d_8}{d_8}$**	$\frac{d_8-d_6}{d_6}$	$\frac{d_{10}-d_6}{d_6}$
*CFP-1	0.57	27%	31.7%	103%
*CFP-2	0.80	16%	23.7%	44%
*CFP-3	1.00	14.5%	23.6%	42%
*CFP-4	2.00	12.3%	-	33%

* CFP: Cold Formed Plate
** d10: Bolt Diameter 10 mm

As shown in Table 3 and Table 4, increasing the diameter of the applied bolts leads to the increase of the load-carrying capacity of the connection. This is true for all the cold-formed plates with different thicknesses. For example, the bolt diameter increase from 8mm to 10mm led to the 27% increase of the load-carrying capacity in a plate with the thickness of 0.57mm.

In figure 11 and figure 12, the failure is seen from two sides.

CONCLUSION

The results of this research can be listed as follow:

1- Using bolts with higher diameters leads to an increase in the load-carrying capacity and more hardness in the connections, but it's worth mentioning that any extra diameter increase can change the failure type.

2- By increasing the bolt diameter from 6mm to 8mm, and from 8mm to 10mm, load-carrying capacity growth ranges between 24% to 31%, and 44% to 58%, respectively.

3- Any increase in the thickness of the plate from 50 mm to 100 mm leads to an increase of the load-carrying capacity and the connection function regarding curling style and form changes.

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