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Cheng Yu

Ibraheem Sheerah

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Cold-Formed Steel Bolted Connections without Washers on Oversized Holes: Shear and Bearing Failures in Sheets

Cheng Yu[1], Ibraheem Sheerah[2]

Abstract

In cold-formed steel (CFS) construction, the bolted connections without washers on oversized holes may expedite the building process and lower the cost, at the same time provides satisfied strength. The current design specifications do not stipulate provisions for such connections, and washers are required to be installed on oversized holes. In order to investigate the behavior and determine the strength of CFS bolted connections without washers on oversized holes, a test program was developed and conducted at University of North Texas. This research was focused on the shear failure and the bearing failure of the connected sheets. No washer was used for the test specimens. The studied parameters included the steel sheet thickness: from 118 mil to 33 mil; the connection type: single shear and double shear; the number of bolts: one and two; the bolt type: ASTM A307, A325; the bolt diameter: 1/4 in. and 1/2 in.; and the ductility in the sheet steel: low and high. Based on the test results, new design method for bearing strength was proposed. The paper presents the test program, test specimens, and the proposed design for CFS bolted connections without washers on oversized holes.

[1] Assistant Professor, University of North Texas, Denton, TX (cyu@unt.edu)
[2] Graduate Student, University of North Texas, Denton, TX (isheerah@gmail.com)

Introduction

The cold-formed steel becomes an important alternative construction material for low-rise residential and commercial buildings. Light weight, high durability, high strength, and high material consistency are some of the reasons given for the increasing applications cold-formed steel structures in construction. The bolted connection is one important method of joining cold-formed steel members, and the subject has been studied by a number of researchers in the past [Gilchrist & Chong (1979), Yu (1982), Zadanfarrokh & Bryan (1992), LaBoube & Yu (1995), Wallace & Schuster (2002)]. However, the bolted connections using oversized holes and short slots without washers have not been fully studied yet. And the current North American Specification for the Design of Cold-Formed Steel Structures (NAS 2007) requires washers to be installed on oversized holes or short slots. The configurations of combining oversized holes or short slots and non-washers may significantly expediate the construction process and lower the cost. Therefore a research project funded by the American Iron and Steel Institute (AISI) was developed to investigate the bolted CFS connections with oversized holes and short slots without using washers. The research is still currently undergoing at the University of North Texas as of May 2008. This paper focuses on the completed tests on bolted connections with oversized holes. Bearing failure and shear failure in the sheets are of interest in this paper.

Background

The cold-formed steel bolted connections usually fail in three modes: shear of the sheet, bearing or piling up of material in front of the bolt, and tearing of the sheet in the net section, as shown in Figure 1.

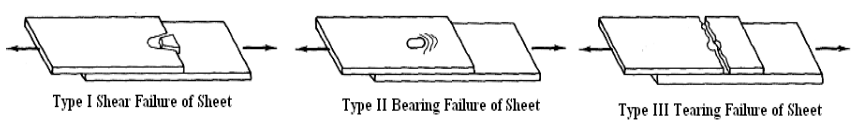

Figure 1 Typical failures of bolted connections

Experiments on bolted connections without washers for standard holes were conducted by a number of researchers [Yu 1982, Zadanfarrokh & Bryan 1992, LaBoube & Yu 1995, Wallace & Schuster 2002]. It was found that the shear strength of the sheet, type (I) failure, depends on the thinnest sheet thickness (t), the tensile strength of connected sheet (F_u), and the distance from the center of hole to the nearest edge of adjacent hole or to the end of the connected sheet parallel to the direction of applied force (e). The nominal shear strength per bolt (P_n) can be expressed as Equation 1 (Eq. E3.1-1 in NAS 2007).

$$P_n = t\ e\ F_u \tag{1}$$

It was also found that the Type (I) failure is likely to occur when the connections have small e/d ratios (e/d < 2.5), where (d) is the bolt diameter. NAS (2007) Eq E3.1-1 implies that the influence of the presence of washers to the strength of Type (I) failure can be ignored in design.

When the edge distance in the bolted connections is considerably large (e/d > 2.5), the bearing failure may occur. The previously conducted tests indicate that the bearing strength primarily depends on the tensile strength of sheet, the thickness of thinnest connected sheet, the ratio of bolt diameter to the sheet thickness (d/t) and the type of bearing connection (single or double shear, with or without washers, etc) [Yu 1982, Zadanfarrokh & Bryan 1992, LaBoube & Yu 1995, Wallace & Schuster 2002]. The presence of washers has significant impact on the bearing strength. The NAS (2007) takes into account the use of washers by using a modification factor (m_f) (Table E3.3.1-2 in NAS) in the equation. The nominal bearing strength, therefore, is expressed as Equation 2 (Eq. E3.3.1-1 in NAS 2007).

$$P_n = m_f C\ d\ t\ F_u \tag{2}$$

Where: C = bearing factor (refers to Table 1)
d = nominal bolt diameter
t = uncoated sheet thickness
F_u = tensile strength of sheet
m_f = modification factor (0.75 for single shear and 1.33 for double shear)

One should note that the bearing equation in NAS (2007) is only applicable to the connections with standard holes.

Table 1 Bearing factor, C, for bolted connections

Ratio of fastener diameter to member thickness, d/t	C
d/t<10	3
10≤d/t≤22	4-0.1(d/t)
d/t>22	1.8

The main objective of the research presented here were to experimentally investigate the bearing strength and shear strength of cold-formed steel bolted connections without washers on oversized holes; and to examine the validity of current NAS (2007) equations applied to those connection configurations.

Test Setup

The tensile tests were conducted in a 20 kip universal testing machine. The deformation of the bolted connection was measured by an extensometer with a gauge length of 0.9843 in. Figure 2 shows the test setup.

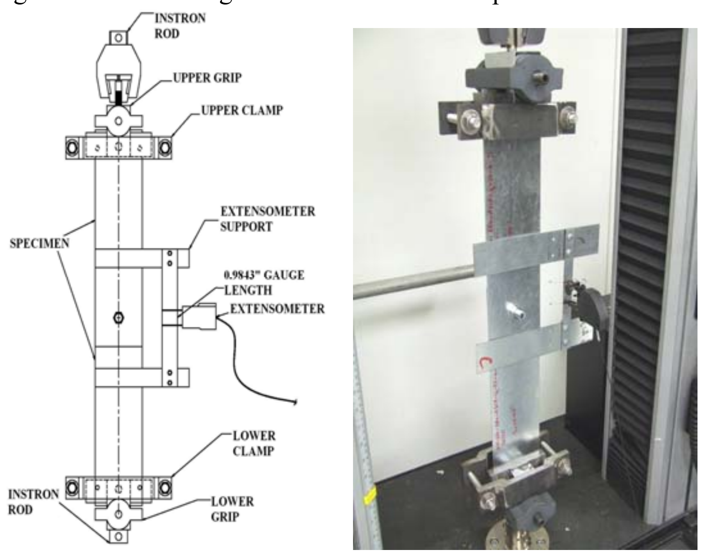

Figure 2 Setup for testing bolted connections

The tensile tests were performed in a displacement control mode. The bottom grip was fixed to the base of the machine. The top grip, connected to the crosshead of the machine, moved upwards at a constant speed of 0.1 in. per minute. The applied force, the displacement of the top grip, and the deformation of the connection were measured and recorded simultaneously. All bolts were installed and tightened manually. A torque wrench was used to assure the applied torque not to exceed 40 lb-in.

Test Specimen

Specimen Configurations

The studied the specimen configuration parameterss are as follows:

- Cold-formed steel sheet thicknesses ranged from 30 mil to 118 mil.
- Single shear and double shear connections with one bolt or two bolts.

- ASTM A307 Type A bolts (0.5 in. diameter, 1.25 in. long and 0.25 in. diameter, 1 in. long) and A325 bolts (0.5 in. diameter, 1.25 in. long) were used. Washer was not installed.
- The dimensions of oversize holes refer to the maximum sizes specified in Table E3a of NAS (2007), and listed in Table 2. All the holes in the CFS sheets were punched.

Table 2 Dimensions of oversized holes

Nominal bolt diameter, d (in.)	Oversized hole diameter, d_h (in.)
< 1/2	d + 1/16
≥ 1/2	d + 1/8

- Steel ductility in the sheets: high ductile and low ductile steel.
- For each specimen configuration, two identical tests were conducted. If the difference of the first two tests was greater than 10%, a third test was performed.

The specimens were labeled as the following.

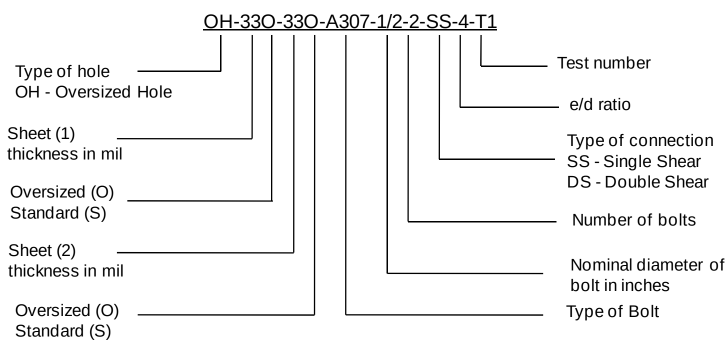

Figure 3 Specimen labeling

Sheet Dimensions

The dimensions of specimens and test matrices were designed to ensure the occurrence of the desired failure modes: Type I and II failures. The width of the connected sheets had to be sufficiently large to prevent net section fracture failure (Type III failure) from occurring. Zadanfarrokh and Bryan (1992) recommended the width of the connected sheet w = 6.25 d for bearing tests with the nominal bolt diameter d ≥ 0.4 in. Therefore the width of the sheets in all the tests was set to 4 in.

It was found that a small ratio of e/d would lead to shear failure in the sheet. On the other hand, a sufficiently large e/d ratio would trigger bearing failure in the sheet. Research done by Chong and Matlock (1975), Gilchrist and Chong (1979), and Yu (1982) indicated that an e/d = 2.5 is approximately the transition point to distinguish between the Type I and II failures. Furthermore, the NAS (2007) requires a minimum e/d = 1.5 for cold-formed steel bolted connections. Therefore in this research, the specimens for shear strength tests had e/d = 1.5, the specimens for bearing strength test had e/d > 3. The majority of bearing failure tests had e/d = 4. The overall length of all specimens was 15 in., the setup was based on the recommended by Zadanfarrokh and Bryan (1992).

The sheet dimensions for the tests are shown in Figure 4 for one-bolt connections and in Figure 5 for two bolt connections. for the two-bolt connections, the distance between centers of the bolt holes equals to three times of the nominal bolt diameter, d, which conforms to the spacing requirement in Section E3.1 of the NAS (2007).

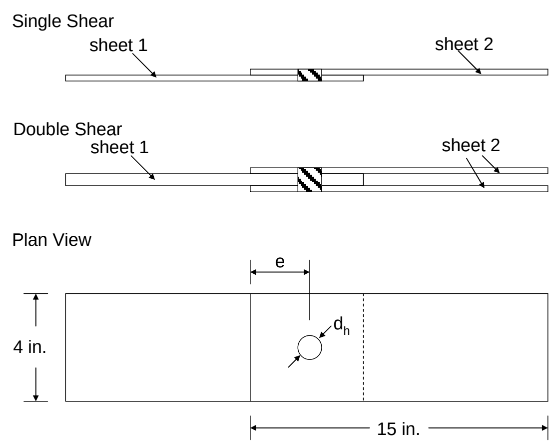

Figure 4 Dimensions of specimens with one bolt

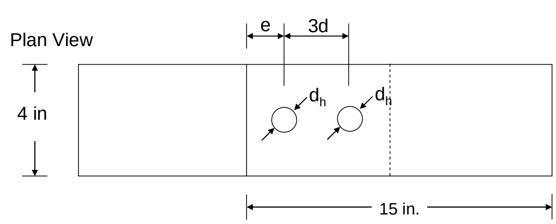

Figure 5 Dimensions of specimens with two bolts

Material Properties

Coupon tests were carried out to obtain the material properties of the connected sheets following ASTM A370 Specification (ASTM 2007). The coat on the cold-formed steel sheets was removed prior to the coupon tests. For each material thickness from the same coil, three coupons were cut and tested, and the average values were used in the analysis, and reported in Table 3.

Table 3 Materials properties

Sheet Materials	Measured Thickness (in.)	Experimental F_y (nominal) (ksi)	Experimental F_u (ksi)	F_u/F_y	Elongation 2-in. gage length	Ductility
33 mil	0.0361	44.6 (33 ksi)	54.1	1.21	30%	High
43 mil	0.0439	51.6 (50 ksi)	70.3	1.36	20%	High
68 mil	0.0691	50.0 (50 ksi)	69.7	1.39	25%	High
118 mil	0.1305	45.3 (33 ksi)	52.2	1.15	25%	High
39 mil (1.00 mm)	0.0390	90.0	90.7	1.01	4%	Low
30 mil (0.75 mm)	0.0293	86.0	87.2	1.01	7.5%	Low

The high ductile steels used in this research (33 mil, 43 mil, 68 mil, 188 mil) met the minimum requirements for material ductility specified by NAS (2007). The current NAS requires that the ratio of tensile strength to yield stress shall not be less than 1.08, and the total elongation shall not be less than 10% measured over a two-inch gage length. The low ductile steels used in this research (30 mil, 39 mil) did not meet those minimum requirements.

Test Results and Discussions

Shear Strength of Connected Sheet

Figure 6 and 7 respectively show the typical failure mode observed in shear strength tests on single shear and double shear bolted connections. In those shear strength tests, the holes were punched close to the edge of the connected sheets (e/d = 1.5). It was founded that the bolt was titled significantly in the single shear tests due to the eccentric loading and the oversized hole dimension. As a result, the sheet warped and piled up at the hole edge. A combined failure mode of shear and bearing were achieved in the single shear tests with e/d = 1.5. For the double shear tests, typical shear failure was observed on the inside sheet, as shown in Figure 7. The bolt was not tilted and it remained perpendicular to the sheets in the tests.

The results of the shear strength tests are summarized in Table 4 where P_{test} is the peak load, P_{NAS} is nominal strength calculated by Equation 1, and "Δ" is the connection deformation (measured by extensometer) at the peak load. Figure 8 illustrates a comparison of the tested shear strengths with the NAS (2007) predictions (Eq. 1). The plot indicates that the current NAS provisions for bolted connections without washer on standard holes have a good agreement with the test results on bolted connections without washer on oversized holes. The average ratio of P_{test} to P_{NAS} for all tests is 1.03 with a standard deviation of 0.19. Therefore the current design method can be extended to the bolted connections without washers on oversized holes as specified in Table 2.

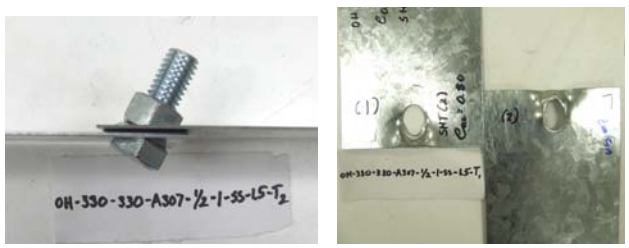

Figure 6 Failure mode of single shear connection OH-33O-33O-A307-1/2-1-SS-1.5-T2

Figure 7 Failure mode of double shear connection OH-33O-33O-A307-1/2-1-DS-1.5-T1

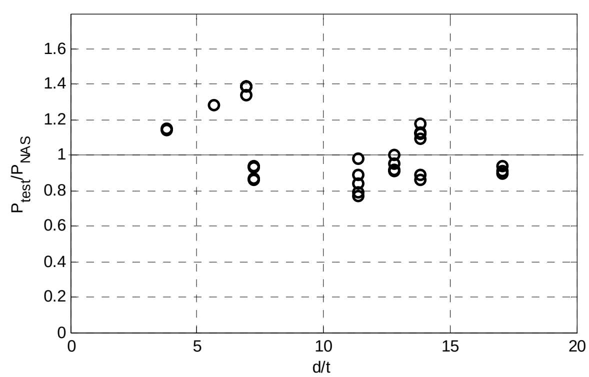

Figure 8 P_{test}/P_{NAS} vs d/t plot for shear strength tests

Table 4 Results for shear strength tests

No	Specimen Label	P_{test} (lbf)	Δ (in.)	d/t	P_{test}/ P_{NAS}
1	OH-118O-118O-A307-1/2-1-SS-1.5-T1	5804	0.521	3.83	1.14
2	OH-118O-118O-A307-1/2-1-SS-1.5-T2	5885	0.588	3.83	1.15
3	OH-68O-68O-A325-1/2-1-SS-1.5-T1	3404	0.692	7.24	0.94
4	OH-68O-68O-A325-1/2-1-SS-1.5-T2	3363	0.680	7.24	0.93
5	OH-68O-68O-A307-1/2-1-SS-1.5-T1	3134	0.445	7.24	0.87
6	OH-68O-68O-A307-1/2-1-SS-1.5-T2	3112	0.410	7.24	0.86
7	OH-43O-43O-A307-1/2-1-SS-1.5-T1	2056	0.342	11.39	0.89
8	OH-43O-43O-A307-1/2-1-SS-1.5-T2	1951	0.171	11.39	0.84
9	OH-43O-43O-A307-1/4-1-SS-1.5-T1	1483	0.347	5.69	1.28
10	OH-43O-43O-A307-1/4-1-SS-1.5-T2	1482	0.319	5.69	1.28
11	OH-33O-33O-A307-1/2-1-SS-1.5-T1	1259	0.440	13.85	0.86
12	OH-33O-33O-A307-1/2-1-SS-1.5-T2	1303	0.400	13.85	0.89
13	OH-33O-33O-A307-1/4-1-SS-1.5-T1	985	0.253	6.93	1.34
14	OH-33O-33O-A307-1/4-1-SS-1.5-T2	1017	0.279	6.93	1.39
15	OH-33O-33S-A307-1/2-1-SS-1.5-T1	1723	0.483	13.85	1.18
16	OH-33O-33S-A307-1/2-1-SS-1.5-T2	1603	0.529	13.85	1.09
17	OH-30O-30O-A307-1/2-1-SS-1.5-T1	1727	0.197	17.06	0.90
18	OH-30O-30O-A307-1/2-1-SS-1.5-T2	1720	0.231	17.06	0.90
19	OH-39O-39O-A307-1/2-1-SS-1.5-T2	2645	0.435	12.82	1.00
20	OH-39O-39O-A307-1/2-1-SS-1.5-T3	2429	0.445	12.82	0.92
21	OH-43O-43O-A307-1/2-1-DS-1.5-T1	2266	0.218	11.39	0.98
22	OH-43O-43O-A307-1/2-1-DS-1.5-T2	1832	0.248	11.39	0.79
23	OH-43O-43O-A307-1/2-1-DS-1.5-T3	1789	0.239	11.39	0.77
24	OH-33O-33O-A307-1/2-1-DS-1.5-T1	1659	0.388	13.85	1.13
25	OH-33O-33O-A307-1/2-1-DS-1.5-T2	1637	0.447	13.85	1.12
26	OH-33O-33O-A307-1/4-1-DS-1.5-T1	1022	0.386	6.93	1.39
27	OH-33O-33O-A307-1/4-1-DS-1.5-T2	1017	0.341	6.93	1.39
28	OH-30O-30O-A307-1/2-1-DS-1.5-T1	1735	0.265	17.06	0.91
29	OH-30O-30O-A307-1/2-1-DS-1.5-T2	1810	0.325	17.06	0.94
30	OH-39O-39O-A307-1/2-1-DS-1.5-T1	2518	0.324	12.82	0.95
31	OH-39O-39O-A307-1/2-1-DS-1.5-T3	2421	0.410	12.82	0.91
				Average	1.03
				St. dev.	0.19

Bearing Strength

Figures 9 and 10 respectively show the observed failure mode in the bearing strength tests on single shear connections and double shear connections with one bolt. Similar to the findings in the shear strength tests, the bolt in the single shear connections was tilted to a large degree. The connected sheets curled outwards as shown in Figure 9. For quite a few cases, the oversized hole was enlarged large enough during the tests to allow the tilted bolt head to go through the sheet. For the double shear connections, the bolt remained perpendicular to the loading direction during the test, and less curling deformation in the sheets was observed compared to the single shear connections.

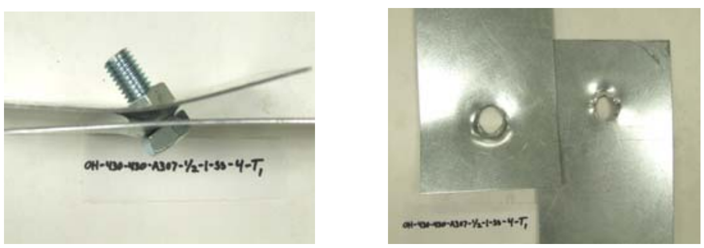

Figure 9 Failure mode of single shear connection OH-43O-43O-A307-1/2-1-SS-4-T1

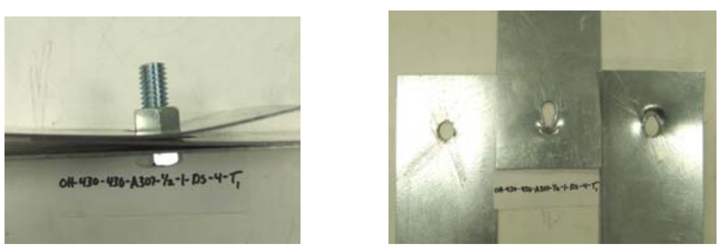

Figure 10 Failure mode of double shear connection OH-43O-43O-A307-1/2-1-DS-4-T1

Figures 11 and 12 show the failure mode for bearing strength tests on connections with two bolts. The same failure mode as that of single bolt connections was observed in the two-bolt connections. The bolts titled in the single shear connections and remained straight in double shear connections.

The test results for the bearing strength are summarized in Tables 5 for the single shear connections and Table 6 for the double shear connections. In Tables 5 and 6, P_{test} is the tested peak load per bolt and "Δ" is the connection deformation at the peak load. P_{NAS} is the NAS (2007) predicted nominal strength of bolted connections with standard holes without washers. The test results indicate that for both the single shear and double shear connections, the NAS (2007) equations for standard hole connections yield unconservative predictions for the tests on oversized hole connections. The average test-to-predicted ratio for single shear connections is 0.87, and 0.76 for double shear connections.

Based on the test results for the bearing strength, new bearing factor C and modification factor, m_f, were proposed for the oversized hole connections. The bearing strength equation (Eq. 2) will be kept unchanged. Table 7 and Table 8 respectively summarize the newly proposed factors. Figures 13 and 14 show the comparison between the test results and the two design methods for the single shear and double shear connections respectively. In the figures, the y axis is the $P/(F_u\ d\ t)$ where P represents the nominal bearing strength for the design methods and it also stands for the peak load per bolt for the tests. Figures 13 and 14 show that the proposed design method has a good agreement with the test results for both single shear and double shear bearing connections. The average test-to-predicted ratio for the proposed method is 1.02 for single shear connections and 1.01 for double shear connections. A standard deviation of 0.13 is achieved for both types of connections.

Figure 11 Failure mode of single shear connection OH-43O-43O-A307-1/2-2-SS-4-T1

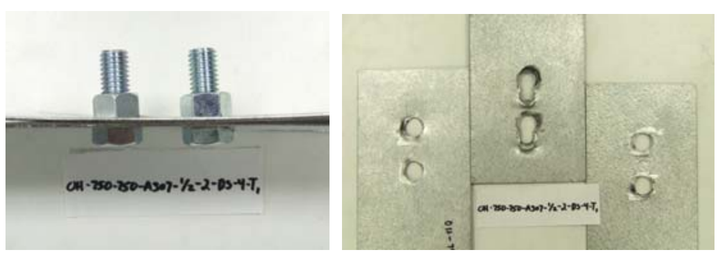

Figure 12 Failure mode of double shear connection OH-30O-30O-A307-1/2-1-DS-4-T1

Table 5 Results of bearing strength tests on single shear connections

No	Specimen Label	d/t	P_{test} (lbf)	Δ (in.)	P_{test} / P_{NAS}	P_{test} / P_{NEW}
1	OH-118O-118O-A307-1/2-1-SS-4-	3.83	8499	0.360	1.11	1.15
2	OH-118O-118O-A307-1/2-1-SS-4-	3.83	8408	0.420	1.10	1.14
3	OH-68O-68O-A325-1/2-1-SS-4-T1	7.24	4685	0.682	0.86	0.92
4	OH-68O-68O-A325-1/2-1-SS-4-T2	7.24	4945	0.691	0.91	0.97
5	OH-68O-68O-A307-1/2-1-SS-4-T1	7.24	3970	0.452	0.73	0.78
6	OH-68O-68O-A307-1/2-1-SS-4-T2	7.24	3925	0.547	0.72	0.77
7	OH-43O-43O-A307-1/2-1-SS-4-T1	11.39	1904	0.206	0.58	0.77
8	OH-43O-43O-A307-1/2-1-SS-4-T2	11.39	1929	0.237	0.58	0.78
9	OH-43O-43O-A307-1/2-1-SS-4-T3	11.39	1885	0.200	0.57	0.76
10	OH-43O-43O-A307-1/4-1-SS-4-T1	5.69	1835	0.244	1.06	1.10
11	OH-43O-43O-A307-1/4-1-SS-4-T2	5.69	1894	0.275	1.09	1.14
12	OH-43O-43O-A307-1/4-1-SS-8-T1	5.69	1825	0.244	1.05	1.10
13	OH-43O-43O-A307-1/4-1-SS-8-T2	5.69	1725	0.276	0.99	1.04
14	OH-43O-43O-A307-1/4-1-SS-3-T1	5.69	1790	0.347	1.03	1.07
15	OH-43O-43O-A307-1/4-1-SS-3-T2	5.69	1823	0.319	1.05	1.09
16	OH-33O-33O-A307-1/2-1-SS-4-T1	13.85	1451	0.352	0.76	1.03
17	OH-33O-33O-A307-1/2-1-SS-4-T2	13.85	1444	0.566	0.75	1.02
18	OH-33O-33O-A307-1/4-1-SS-4-T1	6.93	1165	0.285	1.06	1.10
19	OH-33O-33O-A307-1/4-1-SS-4-T2	6.93	1213	0.281	1.10	1.15
20	OH-33O-33O-A307-1/4-1-SS-8-T1	6.93	1145	0.355	1.04	1.09
21	OH-33O-33O-A307-1/4-1-SS-8-T2	6.93	1232	0.397	1.12	1.17
22	OH-33O-33O-A307-1/4-1-SS-3-T1	6.93	1129	0.382	1.03	1.07
23	OH-33O-33O-A307-1/4-1-SS-3-T2	6.93	1136	0.321	1.03	1.08
24	OH-43O-33O-A307-1/2-1-SS-4-T1	13.85	1672	0.421	0.87	1.18
25	OH-43O-33O-A307-1/2-1-SS-4-T2	13.85	1635	0.424	0.85	1.16
26	OH-33O-33S-A307-1/2-1-SS-4-T1	13.85	1540	0.374	0.80	1.09
27	OH-33O-33S-A307-1/2-1-SS-4-T3	13.85	1548	0.304	0.81	1.09
28	OH-30O-30O-A307-1/2-1-SS-4-T1	17.06	1620	0.319	0.74	0.97
29	OH-30O-30O-A307-1/2-1-SS-4-T2	17.06	1584	0.184	0.72	0.95
30	OH-39O-39O-A307-1/2-1-SS-4-T1	12.82	2423	0.373	0.67	0.91
31	OH-39O-39O-A307-1/2-1-SS-4-T2	12.82	2591	0.357	0.72	0.97
32	OH-43O-43O-A307-1/2-2-SS-4-T1	11.38	2100.5	0.333	0.63	0.85
33	OH-43O-43O-A307-1/2-2-SS-4-T2	11.38	2153	0.380	0.65	0.87
34	OH-33O-33O-A307-1/2-2-SS-4-T1	13.85	1306	0.400	0.68	0.92
35	OH-33O-33O-A307-1/2-2-SS-4-T2	13.85	1309	0.408	0.68	0.93
36	OH-33O-33O-A307-1/4-2-SS-4-T2	6.93	1105.5	0.263	1.01	1.05
37	OH-33O-33O-A307-1/4-2-SS-4-T3	6.93	1093	0.275	0.99	1.04
38	OH-33O-33O-A307-1/4-2-SS-8-T1	6.93	1149	0.329	1.05	1.09
39	OH-33O-33O-A307-1/4-2-SS-8-T2	6.93	1130.5	0.271	1.03	1.07
40	OH-33O-33O-A307-1/4-2-SS-3-T1	6.93	1169.5	0.381	1.06	1.11
41	OH-33O-33O-A307-1/4-2-SS-3-T2	6.93	1155	0.362	1.05	1.09
42	OH-43O-33O-A307-1/2-2-SS-4-T1	13.85	1752	0.311	0.91	1.24
43	OH-43O-33O-A307-1/2-2-SS-4-T2	13.85	1691.5	0.267	0.88	1.20
44	OH-30O-30O-A307-1/2-2-SS-4-T1	17.06	1701	0.303	0.77	1.02
45	OH-30O-30O-A307-1/2-2-SS-4-T2	17.06	1632.5	0.442	0.74	0.98
46	OH-39O-39O-A307-1/2-2-SS-4-T1	12.82	2232	0.255	0.62	0.84
47	OH-39O-39O-A307-1/2-2-SS-4-T2	12.82	2249.5	0.409	0.62	0.84
				Average	0.87	1.02
				St. dev.	0.18	0.13

Table 6 Results of bearing strength tests on double shear connections

No	Specimen Label	d/t	P_{test} (lbf)	Δ (in.)	P_{test} / P_{NAS}	P_{test} / P_{NEW}
1	OH-68O-68O-A325-1/2-1-DS-4-T1	7.24	6824	0.664	0.71	0.86
2	OH-68O-68O-A325-1/2-1-DS-4-T2	7.24	6779	0.681	0.71	0.86
3	OH-43O-43O-A307-1/2-1-DS-4-T2	11.39	3933	0.471	0.67	1.02
4	OH-43O-43O-A307-1/2-1-DS-4-T3	11.39	3677	0.595	0.63	0.95
5	OH-33O-33O-A307-1/2-1-DS-4-T3	13.85	2637	0.606	0.78	1.20
6	OH-33O-33O-A307-1/2-1-DS-4-T4	13.85	2798	0.549	0.82	1.27
7	OH-33O-33O-A307-1/4-1-DS-4-T1	6.93	1888	0.345	0.97	1.15
8	OH-33O-33O-A307-1/4-1-DS-4-T2	6.93	1997	0.428	1.02	1.22
9	OH-33O-33O-A307-1/4-1-DS-8-T1	6.93	1912	0.396	0.98	1.16
10	OH-33O-33O-A307-1/4-1-DS-8-T2	6.93	1906	0.427	0.98	1.16
11	OH-33O-33O-A307-1/4-1-DS-3-T1	6.93	1768	0.409	0.91	1.08
12	OH-33O-33O-A307-1/4-1-DS-3-T2	6.93	1618	0.346	0.83	0.99
13	OH-30O-30O-A307-1/2-1-DS-4-T2	17.06	2720	0.380	0.70	1.04
14	OH-30O-30O-A307-1/2-1-DS-4-T3	17.06	2548	0.466	0.65	0.98
15	OH-39O-39O-A307-1/2-1-DS-4-T1	12.82	3270	0.559	0.51	0.79
16	OH-39O-39O-A307-1/2-1-DS-4-T2	12.82	3335	0.675	0.52	0.81
17	OH-43O-43O-A307-1/2-2-DS-4-T1	11.38	3697	0.380	0.63	0.96
18	OH-43O-43O-A307-1/2-2-DS-4-T3	11.38	3595	0.351	0.61	0.93
19	OH-33O-33O-A307-1/2-2-DS-4-T1	13.85	2216	0.480	0.65	1.01
20	OH-33O-33O-A307-1/2-2-DS-4-T2	13.85	2004	0.464	0.59	0.91
21	OH-33O-33O-A307-1/4-2-DS-4-T1	6.93	1807	0.219	0.93	1.10
22	OH-33O-33O-A307-1/4-2-DS-4-T2	6.93	1994	0.343	1.02	1.21
23	OH-33O-33O-A307-1/4-2-DS-4-T3	6.93	1729	0.200	0.89	1.05
24	OH-33O-33O-A307-1/4-2-DS-4-T4	6.93	1675	0.366	0.86	1.02
25	OH-33O-33O-A307-1/4-2-DS-4-T5	6.93	1704	0.351	0.87	1.04
26	OH-33O-33O-A307-1/4-2-DS-8-T1	6.93	1740	0.587	0.89	1.06
27	OH-33O-33O-A307-1/4-2-DS-8-T2	6.93	1624	0.456	0.83	0.99
28	OH-33O-33O-A307-1/4-2-DS-3-T1	6.93	1594	0.474	0.82	0.97
29	OH-33O-33O-A307-1/4-2-DS-3-T3	6.93	1536	0.197	0.79	0.94
30	OH-33O-33O-A307-1/4-2-DS-3-T2	6.93	1770	0.480	0.91	1.08
31	OH-30O-30O-A307-1/2-2-DS-4-T1	17.06	2552	0.450	0.66	0.98
32	OH-30O-30O-A307-1/2-2-DS-4-T2	17.06	2681	0.287	0.69	1.03
33	OH-39O-39O-A307-1/2-2-DS-4-T1	12.82	3541	0.620	0.55	0.85
34	OH-39O-39O-A307-1/2-2-DS-4-T4	12.82	3422	0.515	0.54	0.83
35	OH-39O-39O-A307-1/2-2-DS-4-T2	12.82	4014	0.600	0.63	0.97
36	OH-39O-39O-A307-1/2-2-DS-4-T3	12.82	3116	0.483	0.49	0.75
				Average	0.76	1.01
				St. dev.	0.16	0.13

Table 7 Proposed bearing factor, C, for bolted connections with oversized holes

Ratio of fastener diameter to member thickness, d/t	C
d/t < 7	3
7 ≤ d/t ≤ 18	1+14/(d/t)
d/t > 18	1.8

Table 8 Proposed modification factor, m_f, for bolted connections with oversized holes

Type of bearing connection	m_f
Single shear connection without washers under both bolt head and nut on oversized hole	0.72
Inside sheet of double shear connection without washers on oversized hole	1.12

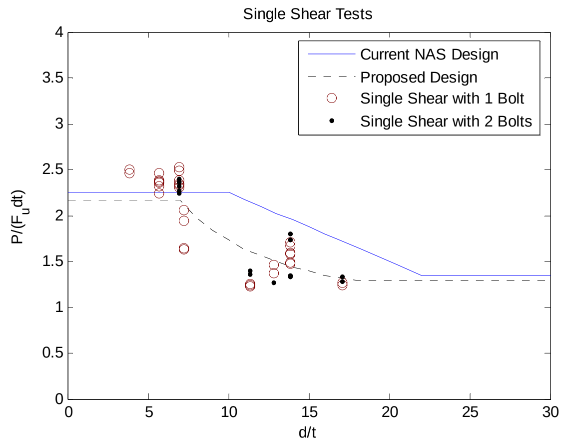

Figure 13 Test results vs. design methods for single shear bearing connections

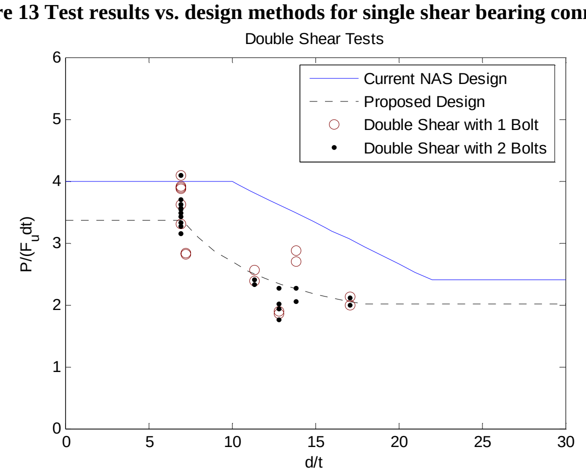

Figure 14 Test results vs. design methods for double shear bearing connections

Conclusions and Continuing Research

The tensile tests on cold-formed steel connections without washers on oversized holes were conducted to investigate both the shear strength and bearing strength. The results showed that current NAS (2007) design provisions for shear strength in connected sheets work well for the oversized hole connections. However for the bearing strength, the current design method yielded unconservative predictions. New bearing factor and modification factor were proposed herein to account for the loss in bearing strength by the oversized holes. The research is still underway to study the influence of the different bolt types and material ductility on the strength of the bolted connections without washers on oversized holes. Furthermore, the research will also investigate the behavior of bolted connections in short slots without washers.

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