Accumulation of Bracing Strength and Stiffness Demand in Cold-Formed Steel Stud Walls

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Abstract

The problem of determining adequate bracing for multiple studs in a wall with similar imperfections is addressed. Pervious studies have determined the necessary brace strength and stiffness required to adequately brace a single axially loaded cold-formed steel stud. Using elastic non-linear software, the required bracing strength and stiffness demand for a single compression member that was derived by Winter and recommended by previous studies was replicated. The model was then expanded to include walls with up to thirty (30) studs, braced at both the mid-point and third-point. For these models the required brace stiffness and the resulting brace forces were recorded and compared to the requirements for a single stud. Analysis of the data indicates that the required brace strength accumulates directly as to the number of braced studs. The required brace stiffness for bracing multiple studs may be determined through the use of a simple second order equation.

Introduction

Cold-formed steel studs are used as axial load bearing members in walls. The *North American Specification for the Design of Cold-Formed Steel Structural Members* (AISI 2004) controls the design of these members. Currently, this document contains no guidelines for designing the bracing of these members.

Recent work by Green, Sputo, and Urala (2004) developed design criteria for the necessary bracing strength and stiffness for bracing a single stud against flexural bucking. However, an isolated stud is a rare occurrence. In most usages, multiple studs occur in a wall. This paper relates the required brace strength and

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stiffness of multiple stud walls to the required brace strength and stiffness for a single stud.

Using non-linear elastic software (in this case, MASTAN2), it is possible to replicate the required bracing strength and stiffness demand for a single compression member that was derived by Winter (1958) and recommended by the previous study. Since the required bracing strength and stiffness demand can be analytically determined for a single stud, it is possible to extend this to multiple studs.

The following parameters describe the walls that are modeled and analyzed in this study:

1. Columns (studs) were modeled with lengths of 8 feet and 12 feet. Each column (stud) was braced at 4-foot intervals.
2. Two column cross sections were considered. One set of columns possessed a moment of inertia of 0.15827 in^4. The second set of columns possessed a moment of inertia of 0.31654 in^4, twice that of the first set.
3. Each column possessed an ASTM C-955 maximum allowable straightness of L/384 in.
4. All studs were out-of-straight in the same direction. From ASTM C-955, the 8-foot columns were modeled out-of-straight by 0.25-inch at the midheight of the column. The 12-foot columns were modeled out-of-straight by 0.375-inch at the midheight of the column.
5. Walls consisting of 1, 2, 3, 4, 5, 6, 8, 10, 12, 15, 20, 25, and 30 studs were analyzed.
6. Stud spacing was 24 inches on center.
7. The bridging was modeled as a series of truss bars (without continuity).
8. The bracing was anchored at either
    a. One end of the wall.
    b. Both ends of the wall.

For each of the sections listed above, the minimum effective cross-sectional area of bracing was determined for each of the multiple stud walls using an elastic critical load analysis in MASTAN2. Once this value was found, the forces in each brace were recorded. Next, this minimum cross-sectional area was doubled, and new brace forces were recorded. Finally, the moment of inertia of the studs was doubled, new minimum effective brace stiffness was found, and the brace forces were recorded. Equations were then formulated that relate the brace force and effective stiffness in multiple stud walls to the brace force and effective stiffness of a single stud.

Results

Each wall model described was developed in MASTAN2 and analyzed using an Elastic Critical Load Analysis. The results of the 8 foot tall wall with the bracing restrained at one end are presented here as representative of all analyzed series.

Behavior at the Critical Brace Stiffness

Elastic second order analysis was performed on an 8-foot tall wall anchored at one end. The number of studs in each wall varied from one to thirty studs. An example of a wall with ten studs is illustrated in Figure 1. For each wall, the cross sectional area of the brace was incrementally reduced until the critical brace stiffness was determined. Table 1 reports the accumulated brace force in the wall in units of kips, while Table 2 reports the critical brace stiffness for each wall in units of kips per inch.

As reported in Table 3, the critical brace stiffness for each wall was normalized by dividing the critical brace stiffness by the critical brace stiffness for a wall

Deflected Shape: Elastic Critical Load,
Mode #1, Applied Load Ratio - 20.1497

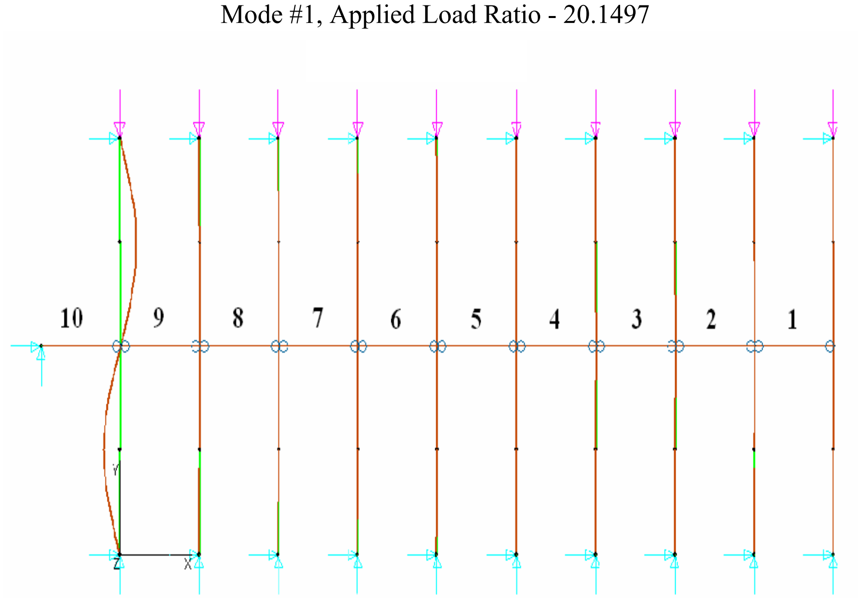

Figure 1. Model of 10-stud wall anchored on one end with 8-foot studs at 24 inches on center.

Table 1. Accumulation of brace force at critical brace stiffness, for 8-foot walls anchored on one end. (kips)

Num. Studs	**30**	**25**	**20**	**15**	**12**	**10**	**8**	**6**	**5**	**4**	**3**	**2**	**1**
Brace #	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**
1	0.150	0.150	0.150	0.150	0.150	0.151	0.151	0.151	0.151	0.152	0.152	0.154	0.161
2	0.301	0.301	0.301	0.301	0.302	0.302	0.303	0.304	0.306	0.309	0.314	0.326	
3	0.451	0.452	0.452	0.453	0.454	0.456	0.458	0.463	0.468	0.477	0.494		
4	0.603	0.603	0.604	0.606	0.609	0.612	0.618	0.630	0.642	0.662			
5	0.754	0.755	0.757	0.761	0.767	0.773	0.784	0.808	0.831				
6	0.906	0.908	0.911	0.919	0.928	0.939	0.959	1.000					
7	1.059	1.062	1.067	1.079	1.094	1.111	1.143						
8	1.213	1.217	1.225	1.243	1.264	1.291	1.339						
9	1.367	1.374	1.385	1.410	1.441	1.479							
10	1.523	1.532	1.548	1.582	1.625	1.678							
11	1.680	1.692	1.713	1.759	1.817								
12	1.838	1.853	1.881	1.941	2.017								
13	1.998	2.017	2.053	2.129									
14	2.160	2.184	2.228	2.324									
15	2.323	2.352	2.407	2.526									
16	2.488	2.524	2.591										
17	2.655	2.698	2.779										
18	2.824	2.876	2.972										
19	2.995	3.056	3.170										
20	3.169	3.241	3.374										
21	3.345	3.429											
22	3.524	3.620											
23	3.706	3.816											
24	3.891	4.017											
25	4.078	4.222											
26	4.270												
27	4.464												
28	4.662												
29	4.864												
30	5.070												

Table 2. Critical brace stiffness for 8-foot walls anchored on one end. (kip/inch)

Num. Studs	**30**	**25**	**20**	**15**	**12**	**10**	**8**	**6**	**5**	**4**	**3**	**2**	**1**
$\beta_{br,n}$	316.47	221.21	142.98	81.75	53.19	37.54	24.62	14.42	10.35	6.94	4.23	2.19	0.83

Table 3. Critical brace stiffness of 8-foot multiple stud walls anchored on one end divided by critical brace stiffness of a single 8-foot stud and the number of studs.

Num. Studs	**30**	**25**	**20**	**15**	**12**	**10**	**8**	**6**	**5**	**4**	**3**	**2**	**1**
$\beta_{br,n}$ / ($\beta_{br,1}$*n)	12.66	10.62	8.58	6.54	5.32	4.51	3.69	2.88	2.48	2.08	1.69	1.31	1.00

with a single stud. When this normalized brace stiffness is plotted against the number of studs in the wall, a linear relationship results as shown in Figure 2.

Likewise, the brace force for each wall was normalized by dividing the brace force by the brace force developed by a single braced stud. These results are listed in Table 4 and plotted against the number of studs in the wall in Figure 3. Much like for the brace stiffness, a linear relationship results.

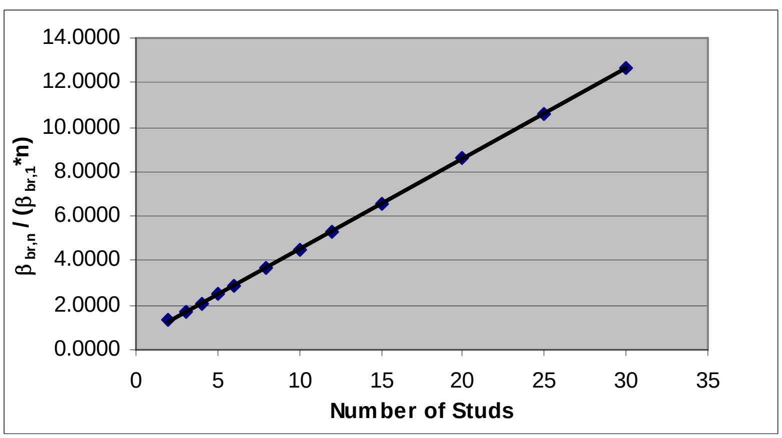

Figure 2. Critical brace stiffness of 8-foot multiple stud walls anchored on one end divided by the product of critical brace stiffness of a single stud and number of studs braced versus the number of studs braced.

Table 4. Brace force at critical brace stiffness of 8-foot multiple stud walls anchored on one end divided by brace force of a single 8-foot stud.

Num. Studs	**30**	**25**	**20**	**15**	**12**	**10**	**8**	**6**	**5**	**4**	**3**	**2**	**1**
$P_{br,n}$ / $P_{br,1}$	31.51	26.24	20.97	15.70	12.54	10.43	8.32	6.21	5.17	4.12	3.07	2.03	1.00

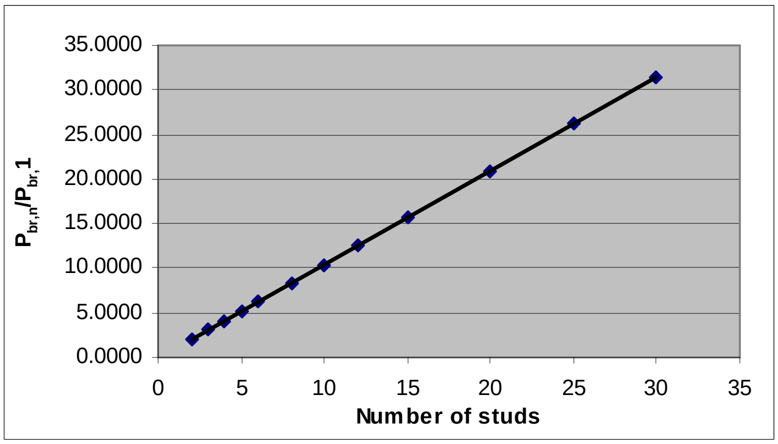

Figure 3. Brace force in the end brace of 8-foot multiple stud walls anchored on one end divided by the brace force of a single stud versus the number of studs braced, with braces with critical brace stiffness.

Behavior at Two Times the Critical Brace Stiffness

To control in-plane deformations, both Winter (1958) and Green, Sputo, and Urala (2004) recommend using two times the critical brace stiffness for design purposes. Table 5 reports the accumulated brace forces for walls braced at two times the critical brace stiffness (Table 6). When compared to the results contained in Table 1, it can be seen that the brace forces increase approximately 11 percent over the brace forces generated at the critical brace stiffness.

As reported in Table 7, the brace stiffness was normalized by dividing the stiffness for each wall by the brace stiffness for a single stud, and the results are plotted in Figure 4. Again, a linear relationship is seen.

Likewise, the brace force for each wall was normalized by dividing the brace force by the brace force developed by a single braced stud. These results are listed in Table 8. Much like for the brace stiffness, a linear relationship results.

Table 5. Accumulation of brace force at twice the critical brace stiffness, for 8-foot walls anchored on one end. (kips)

Num. Studs	**30**	**25**	**20**	**15**	**12**	**10**	**8**	**6**	**5**	**4**	**3**	**2**	**1**
Brace #	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**	**P_{br} (k)**
1	0.176	0.176	0.176	0.176	0.176	0.176	0.176	0.176	0.177	0.177	0.177	0.178	0.182
2	0.352	0.352	0.352	0.352	0.353	0.353	0.353	0.354	0.355	0.357	0.360	0.367	
3	0.528	0.529	0.529	0.529	0.530	0.531	0.532	0.535	0.538	0.543	0.553		
4	0.705	0.705	0.706	0.707	0.709	0.710	0.714	0.721	0.728	0.739			
5	0.882	0.882	0.883	0.886	0.889	0.893	0.899	0.913	0.926				
6	1.059	1.060	1.062	1.066	1.071	1.078	1.089	1.113					
7	1.236	1.238	1.241	1.248	1.256	1.266	1.285						
8	1.414	1.417	1.421	1.431	1.444	1.459	1.487						
9	1.593	1.596	1.603	1.617	1.636	1.657							
10	1.772	1.777	1.786	1.806	1.831	1.861							
11	1.952	1.959	1.971	1.997	2.031								
12	2.132	2.141	2.157	2.192	2.235								
13	2.314	2.325	2.346	2.389									
14	2.496	2.510	2.536	2.591									
15	2.680	2.697	2.729	2.796									
16	2.865	2.885	2.924										
17	3.050	3.075	3.121										
18	3.237	3.267	3.322										
19	3.425	3.461	3.525										
20	3.615	3.656	3.732										
21	3.806	3.854											
22	3.998	4.054											
23	4.193	4.256											
24	4.388	4.460											
25	4.586	4.667											
26	4.785												
27	4.987												
28	5.190												
29	5.395												
30	5.603												

Table 6. Twice the critical brace stiffness for 8-foot walls anchored on one end. (kip/inch)

Num. Studs	**30**	**25**	**20**	**15**	**12**	**10**	**8**	**6**	**5**	**4**	**3**	**2**	**1**
$\beta_{br,n}$	632.95	442.43	285.95	163.50	106.37	75.08	49.24	28.84	20.70	13.89	8.46	4.38	1.67

Table 7. Twice the critical brace stiffness of 8-foot multiple stud walls anchored on one end divided by twice critical brace stiffness of a single 8-foot stud and the number of studs.

Num. Studs	**30**	**25**	**20**	**15**	**12**	**10**	**8**	**6**	**5**	**4**	**3**	**2**	**1**
$\beta_{br,n}$ / ($\beta_{br,1*n}$)	12.66	10.62	8.58	6.54	5.32	4.51	3.69	2.88	2.48	2.08	1.69	1.31	1.00

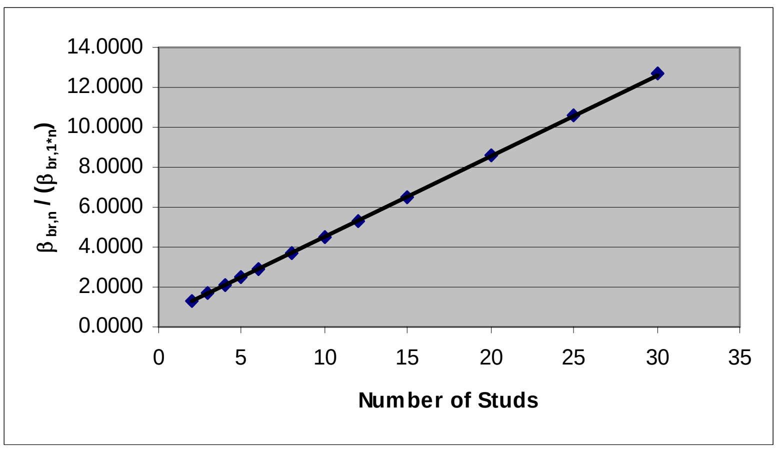

Figure 4. Twice the critical brace stiffness of 8-foot multiple stud walls anchored on one end divided by the product twice the critical brace stiffness for a single stud and number of studs braced versus the number of studs braced.

Results for Eight Foot Wall Anchored at One End

Excel was used to perform a regression analysis for the data contained in Tables 3 and 7 to relate the brace stiffness to the number of studs. Likewise, Excel was also used to perform a regression analysis for the data contained in Tables 4 and 8 to relate the brace force to the number of studs.

Table 8. Brace forces at twice the critical brace stiffness of 8-foot multiple stud walls anchored on one end divided by brace force of a single 8-foot stud. (kips)

Num. Studs	**30**	**25**	**20**	**15**	**12**	**10**	**8**	**6**	**5**	**4**	**3**	**2**	**1**
$P_{br,n}$ / $P_{br,1}$	30.77	25.63	20.49	15.35	12.27	10.22	8.17	6.11	5.09	4.06	3.04	2.01	1.00

Recommendations for Design

Based on the results of Green, Sputo, and Urala (2004) and this study, the following provisions are recommended for the design of flexural bridging for axially loaded studs:

Flexural Bracing of Axially Loaded Steel Studs

The design bracing stiffness and strength for in-plane flexural buckling of cold-formed steel studs shall be determined as follows:

The required brace strength for an individual stud shall be calculated as follows:

$$P_{br,1} = 0.01\, P_T \qquad \text{(Eq. 1)}$$

The required brace stiffness for an individual stud shall be calculated as follows:

$$\beta_{br,1} = \frac{2\left[4-2/n\right]\ P_n}{L_b} \qquad \text{(Eq. 2)}$$

The required brace strength for multiple studs in a wall shall be calculated as follows:

$$P_{br,n} = n_s * P_{br,1} \qquad \text{(Eq. 3)}$$

The required brace stiffness for multiple studs in a wall shall be calculated as follows:

$$\beta_{br,n} = \beta_{br,1} \quad \text{for } n_s = 1 \qquad \text{(Eq. 4)}$$

$$\beta_{br,n} = \beta_{br,1}[0.4n_s^2 + 0.5n_s] \quad \text{for } n_s > 1 \qquad \text{(Eq. 5)}$$

Design Example

Required:

Design bracing for an 8 foot tall wall consisting of (24) 362S162-68 studs spaced at 24 inches on center.

The wall is to be braced using one line of standard 150U50-54 bridging channel located at the mid-height of the wall. The bridging is to be anchored at each end of the run of bridging.

The bridging is to be anchored to the studs using clip angles screwed to both the stud web and the bridging channel.

Solution:

1. Calculate the allowable axial capacity of a single stud

   362S162-68
   L = 8 feet
   n = 1 (one line of bridging, unbraced length = 48 inches)

$$P_a = \frac{P_n}{\Omega} = 5447 \text{ lb} \quad \text{(per Figure 5)}$$

$$P_n = \Omega P_a = 1.80(5447) = 9805 \text{ lb}$$

2001 North American Specification ASD
DATE: 8/13/2005

SECTION DESIGNATION: 362S162-68 Single

INPUT PROPERTIES:

Web Height =	3.625 in	Steel Thickness =	0.0713 in
Top Flange =	1.625 in	Inside Corner Radius =	0.1069 in
Bottom Flange =	1.625 in	Yield Stress, Fy =	50.0 ksi
Stiffening Lip =	0.500 in	Fy With Cold-Work, Fya =	50.0 ksi
Punchout Width =	1.500 in	Punchout Length =	4.000 in

ALLOWABLE AXIAL LOADS

INPUT PARAMETERS
Overall Stud Length = 8 ft
Load has not been modified for load type or duration

TOTAL ALLOWABLE AXIAL LOADS (lb)

WEAK AXIS BRACING	MAXIMUM KL/r	CONCENTRIC LOADING	LOADED THROUGH WEB
NONE	161	2276	1490
MID Pt	81	5447	2939
24 in	67	7684	3702

Figure 5. Axial capacity of 362S162-68 stud

2. Calculate the necessary bridging stiffness and strength for a single stud

$P_{br,1} = 0.01P_T = 0.01\,5447) = 54.5\ \text{lb}$

$$\beta_{br,1} = \frac{2\left[4 - \frac{2}{n}\right]P_n}{L_b} = \frac{2\left[4 - \frac{2}{1}\right](9805)}{48} = 817\ \text{lb/in}$$

3. Calculate the necessary bridging stiffness and strength for the entire wall

Since the bridging is anchored on both ends:

$$n_S = \frac{24}{2} = 12$$

$$P_{br,n} = nP_{br,1} = 12(54.5) = 654\ \text{lb}$$

$$\beta_{br,n} = \beta_{br,1}[0.4n^2 + 0.5n] = 817[0.4(12)^2 + 0.5(12)]$$

$$= 51961\ \text{lb/in} = 51.96\ \text{kips/in}$$

4. Check connection of individual stud 150U50-54 bridging channel using screws:

Per Table 9, the initial stiffness of the connection of the 150U50-54 bridging channel to the web of a single 365S162-54 stud is:

β = 7018 lb/in

Since $\beta > \beta_{br.1}$ OK

5. Check the axial compression strength of the 150U50-54 at an unbraced length of 24 inches:

Allowable capacity if loaded concentrically → Pa = 653 lb (Per Figure 6)
Allowable capacity if loaded through web → Pa = 333 lb (Per Figure 6)

Since each stud loads the bridging through the bridging web:

$P_{br,1}$ = 54.5 pounds
$P_{allowable}$ = 333 pounds
Since $P_{allowable} > P_{br,1}$ OK

The total force in the bridging run is resolved concentrically into the bridging

654 lb ≈ 653 lb
$P_{br,n} \approx P_{allowable}$ OK

Table 9. Connection Initial Flexural Stiffness (Green, Sputo, Urala 2004)

SS Type Connection				
Connection Initial Flexural Stiffness in kip/in.				
D vs. T	**33**	**43**	**68**	**97**
362	1.89	3.94	7.18	
600	1.07	3.85		6.34
800		2.29		5.10

WW Type Connection				
Connection Initial Flexural Stiffness in kip/in.				
D vs. T	**33**	**43**	**68**	**97**
362			40.11	
600				16.72
800				15.84

DW Type Connection				
Connection Initial Flexural Stiffness in kip/in.				
D vs. T	**33**	**43**	**68**	**97**
362			56.41	
600				8.48
800				2.42

2001 North American Specification ASD
DATE: 8/13/2005

SECTION DESIGNATION: 150U50-54 Single

INPUT PROPERTIES:

Web Height =	1.500 in	Steel Thickness =	0.0566 in
Top Flange =	0.500 in	Inside Corner Radius =	0.1132 in
Bottom Flange =	0.500 in	Yield Stress, Fy =	33.0 ksi
Stiffening Lip =	0.500 in	Fy With Cold-Work, Fya =	39.7 ksi

ALLOWABLE AXIAL LOADS

INPUT PARAMETERS
Overall Stud Length = 2 ft
Load has not been modified for load type or duration

TOTAL ALLOWABLE AXIAL LOADS (lb)

WEAK AXIS BRACING	MAXIMUM KL/r	CONCENTRIC LOADING	LOADED THROUGH WEB
NONE	167	653	333

Figure 6. Axial capacity of 150U50-54 bridging channel

6. Check the bridging system stiffness

   (A) Stiffness of the bridging channel at 24 inches long

   $$K = \frac{AE}{L} = \frac{0.128(29500)}{24} = 157.33 \text{ kips/in} = 157333 \text{ lb/in}$$

   $K > \beta_{br,n}$
   157333 > 51960 OK

   (B) Total stiffness at the end anchorage using screwed clip angle to provide the anchorage:

   $$\frac{1}{K_{sys}} = \frac{1}{K_{brace}} + \frac{1}{K_{conn}} = \frac{1}{157.33} + \frac{1}{7.02}$$

   K_{system} = 6.72 kips/in = 6720 lb/in

   $K_{system} < \beta_{br,n}$

   6720 < 51960 NO GOOD

7. Check the bridging connection strength:

   (A) Individual stud to bridging strength

   $P_{br,1}$ = 54.5 lb
   $P_{allowable}$ = 305 lb (Table 10) OK

   (B) End Anchorage strength

   $P_{br,n}$ = 654 lb
   $P_{allowable}$ = 305 lb NO GOOD

Remarks:

The bridging is adequate for this application, however the end anchorage is deficient in both stiffness and strength.

Summary and Conclusions

Using computer models, this study considered the accumulation of bracing stiffness and strength demand in axially loaded steel stud bearing walls. Some conclusions from this study include:

1. Elastic critical load analysis indicates that brace forces in multiple stud walls accumulate directly as the ratio of the number of braced studs.

Table 10. Allowable Strength in Pounds (F.S.= 3.00) (Green, Sputo, Urala 2004)

SS Type Connection				
Connection Allowable Strength in pounds				
D vs. T	**33**	**43**	**68**	**97**
362	137	166	305	
600	121	205		448
800		133		520
WW Type Connection				
Connection Allowable Strength in pounds				
D vs. T	**33**	**43**	**68**	**97**
362			494	
600				471
800				390
DW Type Connection				
Connection Allowable Strength in pounds				
D vs. T	**33**	**43**	**68**	**97**
362			951	
600				1053
800				969

2. The critical and recommended brace stiffnesses in multiple stud walls are not a direct multiple of the ratio of the number of braced studs, however, it can be shown to be linearly related to the number of studs.
3. The stiffness of the anchorage at the end of the bridging line, as well as the splice joining sections of bridging together is critical, and can be a limiting factor in the effectiveness of the bridging system.

Appendix. – References

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Appendix. – Notation

L_b	=	distance between braces on one stud, in. (mm)		
$P_{br,1}$	=	required nominal brace strength for a single stud, kips (N)		
P_n	=	nominal axial compression strength of one stud, kips (N).		
n	=	number of equally spaced intermediate brace locations		
PT	=	required compressive strength, kips (N)		
	=	Φ Pn	(LRFD)	$\Phi = 0.85$
	=	Pn / Ω	(ASD)	$\Omega = 1.80$
$P_{br,n}$	=	maximum brace force for multiple studs, kips (N)		
$P_{br,1}$	=	required nominal brace strength of a single stud, kips (N)		
$\beta_{br,n}$	=	required brace stiffness for multiple studs, kips/in. (N/mm)		
$\beta_{br,1}$	=	required brace stiffness for a single stud, kips/in. (N/mm)		
n_s	=	number of studs, for walls anchored on one end		
	=	half the number of studs, for walls anchored on both ends		