Compilation of k values

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O. Iuorio*, B.W. Schafer

*This report was prepared while O. Iuorio was a Visiting Scholar
with B.W. Schafer's Thin-walled Structures Group at JHU.

Summary:

The behavior of sheathed cold-formed steel walls involves a relatively complicated mechanism where screws, fastened through sheathing, are the primary method for stabilizing the thin studs under load. Understanding and modeling this behavior requires detailed consideration of this stud-fastener-sheathing interaction. As a first step towards this goal all available data on the spring stiffness 'k' and rotational stiffness 'kf' provided by the fasteners to the stud are summarized herein. This data is used to provide computational models of sheathed walls with realistic stud-fastener-sheathing stiffness values.

COMPILATION OF K VALUES

When the wall material is strong enough and it is adequately attached to the studs, then the sheathing can contribute to the structural economy by increasing the usable strength (resistance) of the stud.

In order to determine the necessary requirements for adequate lateral support of the wall studs, theoretical and experimental investigations were conducted since the 1940s by Green, Winter and Cykendall. Those studies included 102 tests on studs and 24 tests on different wall materials. Based on this investigation, specific AISI provisions (1962) were developed.

In 1970, the structural behavior of columns braced by steel boards was investigated at Cornell University. In this occasion, it was noticed that steel sheets behave as shear diaphragms rather then linear type. Simaaan (1973) and Simaan and Peköz (1976) provided procedures for computing the strength of C and Z section wall studs braced by sheathing materials. The bracing action was considered due to both the shear rigidity and the rotational restraint supplied by sheathing materials. AISI Specification 1980 were developed taking into account the results of these studies. In particular, those Specifications considered only the case of identical sheathing material on both sides of the studs and, for simplicity, only the restraint due to the shear rigidity of the sheathing material was considered.

In 1996, the design provisions were revised to permit all steel design and sheathing braced design of wall studs with either solid or perforated webs.

In 2004 the sheathing braced design provisions were removed from the Specification and it was required that sheathing braced design be based on appropriate theory. Moreover, tests specifications can be found in the AISI 2004.

The behavior of sheathed wall stud is strongly dependent on the stiffness of the stud-fastener-sheathing assembly. Since 1960, Winter tested sheathing-to-frame connections following the schema in AISI 1962 (Figure 1).

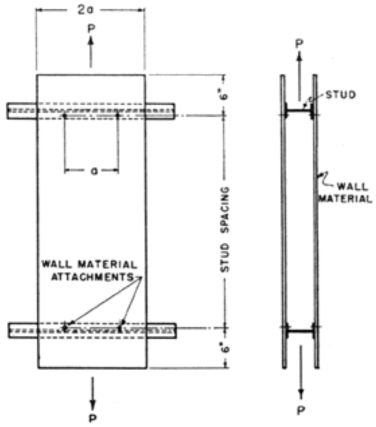

Figure 1: 1962 AISI: Wall material assembly [1]

The specimens were tested in tension, the loads were applied concentrically on each assembly and the k value was determined as:

$$k = \frac{P_1 - P_0}{4y_1}$$

Where
$P_1 = 0.75 P_{ultimate}$
P_0 is the initial load
y_1 is the elongation corresponding

It's worthy to be noticed that the test included both fastener and sheathing deformations, thus the stiffness is a combination of both properties [9]. Determined values are reported in Table 1.

thickness		*Sheathing material*	*Range of k values*			
inches	*mm*		*(lbf/in)*		*(kN/mm)*	
1/2	*12.7*	*Standard density Wood and Cane Fiber Insulating Boards*	*290*	*603*	*0.051*	*0.106*
1/2	*12.7*	*Paper Base Insulating Board*	*915*	1460	*0.160*	*0.256*
3/8	*9.5*	*Gypsum Board Sheathing*	*775*	1535	*0.136*	*0.269*
3/16	*4.8*	*Medium Density Compressed Wood Fiber Board*	*2010*	560	*0.352*	*0.799*
5/32	*4*	*High Density Compressed Wood Fiber Board*	*3960*	7560	*0.693*	*1.324*

Table1: 1962 AISI Section 4 [1].

Simaan and Peköz (1976) developed diaphragm test to determine the shear resistance of the fastener-sheathing combination. Compared with the tension test for determining k in the 1962 Specification, those diaphragm tests have the advantage of placing both local demands on the fasteners and global shear on the sheathing. Simaan developed 10 tests using four different stud sections. Schema of the tests is shown in Figure 2 and geometric and mechanical properties of the specimens are summarized in Table2.

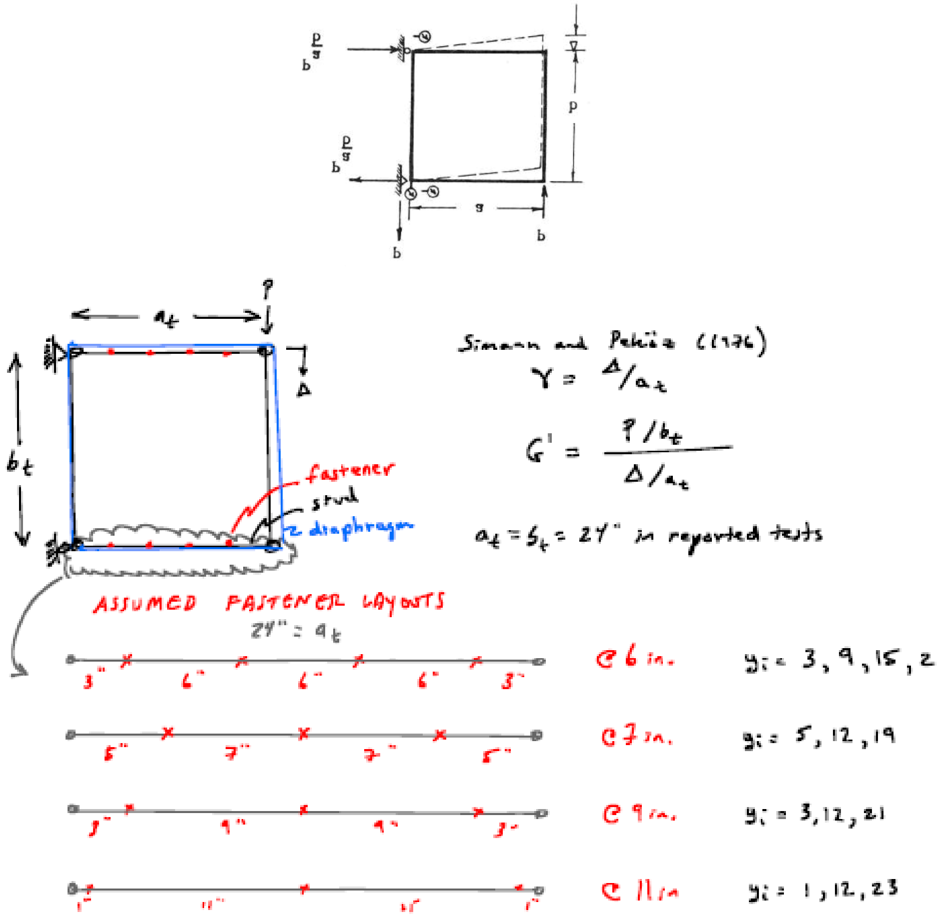

Figure2: Diaphragm testing reported in Simaan and Peköz [10, 11].

Thickness		*Sheathing material*	*Screw spacing*	*G'*	*γ*	*ø*
inches	*mm*		*inches*			
5/8	*15.9*	*Gypsum board*	6 9	2300 2700	0.0041 0.0132	
3/8	*9.5*	*Homosote*	9 11	2050 1600	0.014 0.013	0.15 0.15
1/2	*12.5*	*Celotex*	11	845	0.012	0.17
1/2	*12.5*	*Impregnated Celotex*	7 11	620 490	0.0083 0.0078	0.21 0.21
1/2	*12.5*	*Heavy impregnated celotex*	7 11	660 530	0.0096 0.0086	0.23 0.22
1/2	*12.5*	*Heavy impregnated celotex*	11	940	0.0106	

Table2: Property of sheathing-to-stud fastener specimens by Simaan [10,11]

where
G' is the diaphragm shear stiffness at $0.8P_{ult}$
γ_d is the shear strain at $0.8P_{ult}$
F' is the rotational restraint coefficient at $0.8P_{ult}$
$ø_d$ is the rotational capacity of the diaphragm at $0.8\ P_{ult}$
The tests results are summarized in Table 3.

Thickness	*Material*	*Screw*	*Screw spacing*	*a*	*G'*	*γd*	*K value from diaphragm tests*	
							Discrete spring model	*Foundation spring model*
inches		*No.*	*inches*		*lbf/in*		*lbf/in*	*lbf/in*
5/8	*Gypsum*	*6*	*9*	*6*	*2300*	*0.0041*	*876*	*863*
5/8	*Gypsum*	*6*	*11*	*9*	*2700*	*0.0132*	*1309*	*1519*
3/8	*Gypsum*	*6*	*11*	*9*	*2050*	*0.0140*	*994*	*1153*
3/8	*Gypsum*	*6*	*11*	*11*	*1600*	*0.0130*	*684*	*1100*
½	*Homosote*	*6*	*11*	*11*	*845*	*0.0120*	*361*	*581*

½	*Celotex*	*6*	*11*	*7*	*620*	*0.0083*	*337*	*271*
½	*Celotex*	*6*	*11*	*11*	*490*	*0.0078*	*209*	*337*
½	*Impregnated Celotex*	*6*	*11*	*7*	*660*	*0.0096*	*359*	*289*
½	*Impregnaed Celotex*	*6*	*11*	*11*	*530*	*0.0086*	*226*	*364*
½	*Heavy Impregnated Celotex*	*6*	*7*	*11*	*940*	*0.0106*	*402*	*646*

Table3: Test results by Simaan converted to k value [11/12]

The only direct comparison available is for 3/8” Gypsum Board: Winter’s tests range from 0.775-1.535 kip/in. and Simaan’s tests from 0.684-1.153 kip/in depending on methodology and test details. Although fastener spacing, fastener type, details of the stud, etc. can be different for the two tests the preliminary conclusion is that these two tests are generating reasonably similar stiffness values.

Miller (1994) tested 10 gypsum board-to-stud connections, using a setup similar to AISI 1962 Specification. They investigated the sheathing-to-stud fastener behaviour varying: sheathing thickness (1/2 and 5/8 inches) and edge distance to fastener (0.75,1 and 2.52 inches).

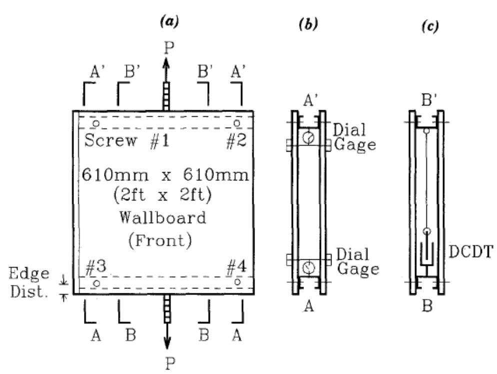

Figure3 : Wallboard fastener connection setup by Miller and Pekoz [5].

thickness	*Sheathing material*	*Screw*	*Edge distance*	*Range of k values@ 80% ult*	
inches		*No*	*inches*	*lbf/in*	
½	*Gypsum*	*8*	*0.75*	*2068*	*0.462*
½	*Gypsum*	*8*	*1*	*849*	*1321*
5/8	*Gypsum*	*8*	*0.75*	*2805*	*3181*
5/8	*Gypsum*	*8*	*1*	*2046*	

5/8	*Gypsum*	*8*	*2.52*	*972*	*1281*

Table3 : Test results by Miller and Pekoz [5]

Lee (1995) conducted a series of 36 wallboard fastener connection tests based on the method presented in the AISI 1962. The tests included three stud thickness (24, 20,14 gauge), two thickness of gypsum board (1/2 in and 5/8 in) and three edge distance (as schematized in Figure4).

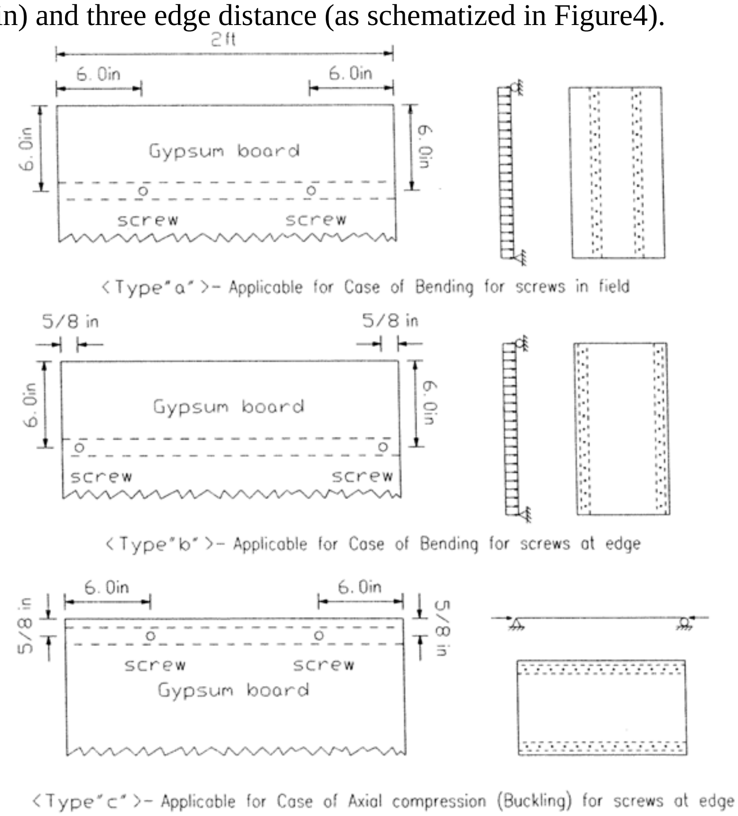

Figure4 : Wallboard fastener connection setup by Lee [4].

Sheathing thickness	*Sheathing material*	*Steel thick*	*Screw*	*Edge distance*	*Range of k values@ 80% ult*	
inches		*Gauge*	*No.*		*lbf/in*	
1/2	*Gypsum*	*25*	*6*	*a*	*363*	*3561*
1/2	*Gypsum*	*25*	*6*	*b*	*2386*	*1875*
1/2	*Gypsum*	*25*	*6*	*c*	*348*	*895*
1/2	*Gypsum*	*20*	*6*	*a*	*1492*	*3762*
1/2	*Gypsum*	*20*	*6*	*b*	*2167*	*3150*
1/2	*Gypsum*	*20*	*6*	*c*	*802*	*1202*
1/2	*Gypsum*	*14*	*6*	*a*	*8417*	*9285*
1/2	*Gypsum*	*14*	*6*	*b*	*9146*	*9662*

1/2	*Gypsum*	*14*	*6*	*c*	*1968*	*2831*
5/8	*Gypsum*	*25*	*6*	*a*	*229*	*1362*
5/8	*Gypsum*	*25*	*6*	*b*	*937*	*1011*
5/8	*Gypsum*	*25*	*6*	*c*	*960*	*1057*
5/8	*Gypsum*	*20*	*6*	*a*	*922*	*1160*
5/8	*Gypsum*	*20*	*6*	*b*	*1776*	*1880*
5/8	*Gypsum*	*20*	*6*	*c*	*1245*	*1275*
5/8	*Gypsum*	*14*	*6*	*a*	*1892*	*2026*
5/8	*Gypsum*	*14*	*6*	*b*	*1792*	*2732*
5/8	*Gypsum*	*14*	*6*	*c*	*1702*	*2252*

Table4 :Test results by Lee [4].

The author together with **Fiorino et al**. tested connection between studs and Gypsum board, or OSB. The program included 62 specimens, grouped in 29 series composed of 2, 3 or 4, nominally identical specimens.

The generic sheathing-to-profile connection specimen (Figure5) consisted of two single 200x600mm sheathings attached to the opposite flanges of 100x50x10x1.0mm C (lipped) cold-formed steel profiles. In particular, one single C-section was placed on the top side, whereas two back-to-back coupled C-sections were used for the bottom side. Sheathings were connected using three screws (spaced at 150mm on centre) for the top member (test connection) and two rows of eight screws for the bottom members (oversized connections). For specimens tested in tension, three different values of the loaded edge distance (a) were adopted (*a*=3/8in, *a*=5/8in, *a*=7/8in), while two values of *a* were adopted in the case of compression tests (*a*=3/8in, *a*=5/89in). The cyclic tests were carried out on specimens having *a*=5.9inches. Five displacement-controlled test procedures were adopted: monotonic tension, monotonic compression, and three types of cyclic loading history. In order to compare the results of the monotonic tests with the other available provided by the previous authors test results k value at 80% of P_{ult} have been reported in the Table5.

Figure5 : Specimen for connection tests by Fiorino et al. [2].

thickness		*Sheathing material*	*Steel thick*	*Screw*	*Edge distance*	*Range of k values@ 80% ult*	
inches	*mm*		*mm*	*No.*		*(lbf/in)*	
3/8	*9*	*OSB*	*1*	*8*	*10*	*2361*	*7250*
3/8	*9*	*OSB*	*1*	*8*	*15*	*2248*	*5339*
3/8	*9*	*OSB*	*1*	*8*	*20*	*2866*	*3485*
½	*12.5*	*GWB*	*1*	*8*	*10*	*2754*	*5733*
½	*12.5*	*GWB*	*1*	*8*	*15*	*1124*	*4440*
1/2	*12.5*	*GWB*	*1*	*8*	*20*	*3822*	

Table5: Test results of Unina.

The results of all the presented tests are summarized in the following Table (Table6).

Thickness		*Sheathing material*	*Author*	*Screw*	*Range of k values@ 80% ult.*	
inches	*mm*			*screw*	*(lbf/in)*	
3/8	*9*	*Gypsum*	*Winter*		*775*	*1535*
3/8	*9*	*Gypsum*	*Simaan & Pekoz*	*6*	*863*	*1519*
5/8	*16*	*Gypsum*	*Simaan & Pekoz*	*6*	*684*	*1153*
1/2	*12.5*	*Homosote*	*Simaan & Pekoz*	*6*	*361*	*581*
1/2	*12.5*	*Celotex*	*Simaan & Pekoz*	*6*	*209*	*337*
1/2	*12.5*	*Heavy Impregnate Celotex*	*Simaan & Pekoz*	*6*	*226*	*364*
1/2	*12.5*	*Impregnate Celotex*	*Simaan & Pekoz*	*6*	*402*	*646*
1/2	*12.5*	*Gypsum*	*Miller & Pekoz*	*8*	*849*	*2597*

5/8	*16*	*Gypsum*	*Miller & Pekoz*	*8*	*972*	*3181*
1/2	*12.5*	*Gypsum*	*Fiorino & al.*	*8*	*1124*	*5733*
3/8	*9*	*Oriented strand board*	*Fiorino & al.*	*8*	*2248*	*7250*
1/2	*12.7*	*Gypsum*	*Lee & al*	*6*	*741*	*3923*
5/8	*15.88*	*Gypsum Boards*	*Lee & al*	*6*	*811*	*2732*

Table6: Comparison of k value at 80% of P ultimate

As shown in Table6, a direct comparison can be set only in case of gypsum 0.5in thick boards (Table7).

thickness		*Sheathing material*	*Author*	*Screw*	*Range of k values@ 80% ult.*	
inches	*mm*			*screw*	*(kN/mm)*	
3/8	*9*	*Gypsum*	*Winter-Simaan&Pekoz*		*775*	*1535*
1/2	*12.5*	*Gypsum*	*Miller&Pekiz Lee &al. Fiorino & al.*	*8*	*741*	*5733*
0.36	*9*	*OSB*	*Fiorino & al.*	*8*	*2340*	*7250*
5/8	*16*	*Gypsum*	*Simaa&Pekoz Miller&Pekoz Lee & al*	*6*	*684*	*3181*

Table7: Comparison of k value at 80% of P ultimate

In the reported tests the sheathing-to-stud fastener stiffness values have been obtained following the 1962 Specification definition of secant stiffness at 80% of ultimate load. This measure of stiffness has a significant impact on the assumed stiffness in any bracing model. For this reason, the most modern studies have highlighted that the stiffness at 80% of the ultimate load does not reflect the real behaviour of the connections. In fact as shown in the load displacement curve (Figure6) and in Table8 secant *k* at 80% ultimate is about ½ of secant k at 40% ultimate.

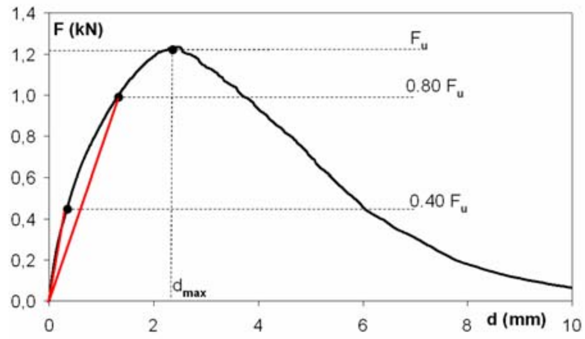

Figure6: Typical experimental responses (F) vs. displacement by Fiorino et al [2]

thickness		*Sheathing material*	*Steel thick*	*Screw*	*Edge distance*	*Range of k values@ 40% ult*	
inches	*mm*		*mm*	*No.*		*(lfp/in)*	
3/8	*9*	*OSB*	*1*	*8*	*10*	*4328*	*10229*
3/8	*9*	*OSB*	*1*	*8*	*15*	*5171*	*9723*
3/8	*9*	*OSB*	*1*	*8*	*20*	*6014*	*6182*
½	*12.5*	*Gypsum*	*1*	*8*	*10*	*9948*	*10735*
½	*12.5*	*Gypsum*	*1*	*8*	*15*	*3878*	*11522*
1/2	*12.5*	*Gypsum*	*1*	*8*	*20*	*8711*	

Table8: k value at 40% of P ultimate-Fiorino et al.

Sheathing material	orientation	Data	$(k@40\%P_{ult})/(k@80\%P_{ult})$
Gypsum	*blanck*	*Average of* (k@40%)/ (k@80%) *StdDev of* (k@40%)/ (k@80%)	*2.395* *0.714*
Oriented Strand Board	*parallel*	*Average of* (k@40%)/ (k@80%) *StdDev of* (k@40%)/ (k@80%)	*1.866* *0.275*
	ortogonal	*Average of* (k@40%)/ (k@80%) *StdDev of* (k@40%)/ (k@80%)	*1.775* *0.251*
Total Average of (k@40%)/ (k@80%)			*2.024*
Total StdDev of (k@40%)/ (k@80%)			*0.542*

Table9: Ratio of k value at 40% to secant k at 80% of P ultimate-Fiorino et al.

Therefore, the secant stiffness at 40% of the ultimate load is taken into account.

At McGill University two hundred and sixteen wood sheathing to light gauge steel stud connections were tested by **Okasha (2004)** under monotonic and cyclic loads. In total thirty groups were included, and each test group consisted of three monotonic and three reversed cyclic specimens. Twelve additional test groups composed of three monotonic specimens were also included in the test program. The variables investigated were:

- Sheathing typology (Douglas Fire Plywood, Canadian Softwood Plywood and OSB)
- Sheathing Orientation
- Sheathing thickness (3/8”,7/16”, 1/2”, 5/8”)
- Sheathing Edge distance (6mm, 3/8”, ½”, 5/8” and 1”).
- Steel grade (230MPa and 345MPa).
- Steel thickness (13, 16, 18 and 20 gauge).

The tests were conducted following the ASTM D171 Standard (1995) and results are reported in Table10.

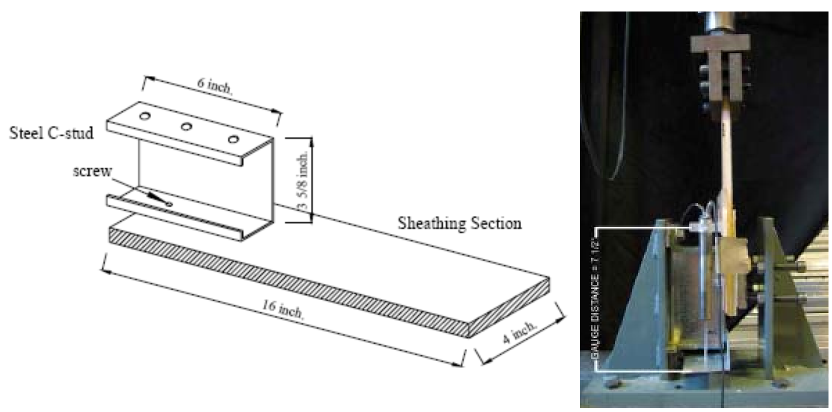

Figure7: Wall material assembly by Okasha [8].

thickness		*Sheathing material*	*Steel thick*	*Screw*	*Edge distance*	*Range of k values@ 40% ult*	
inches	*mm*		*mm*	*No.*	*inches*	*(lbf/in)*	
1/2	*12.5*	*CSP*	*0.84*	*8*	*1*	*3485*	*4103*
1/2	*12.5*	*CSP*	*1.11*	*8*	*1*	*7025*	*17985*
1/2	*12.5*	*CSP*	*1.37*	*10*	*1*	*16074*	*18210*
1/2	*12.5*	*CSP*	*1.73*	*10*	*1*	*20907*	*23212*
7/16	*11*	*OSB*	*0.84*	*8*	*1*	*4131*	*5047*
7/16	*11*	*OSB*	*1.11*	*8*	*1*	*6576*	*25235*
7/16	*11*	*OSB*	*1.37*	*10*	*1*	*23942*	*27033*

1/2	*12.5*	*DFP*	*0.84*	*8*	*1*	*2321*	*3428*
1/2	*12.5*	*DFP*	*1.11*	*8*	*1*	*7925*	*8487*
1/2	*12.5*	*DFP*	*1.37*	*10*	*1*	*21526*	*23661*
1/2	*12.5*	*DFP*	*1.73*	*10*	*1*	*35408*	*38330*
3/8	*9.5*	*OSB*	*1.11*	*8*	*1*	*22369*	
1/2	*12.5*	*OSB*	*1.11*	*8*	*1*	*10678*	*20739*
3/8	*9.5*	*CSP*	*1.11*	*8*	*1*	*6463*	
1/2	*15.5*	*CSP*	*1.11*	*8*	*1*	*6295*	
3/8	*9.5*	*DFP*	*1.11*	*8*	*1*	*13432*	
5/8	*15.5*	*DFP*	*1.11*	*8*	*1*	*3372*	

Table10: k value Okasha tests[8].

Rotational restraint

During the **MRI Project No. 7105-G** tests about rotational restraint of fasteners between sheet metal panel and purlins were executed. The rotational restraint in this case is function of the geometry of individual components. Therefore, the significant parameters are: purlin depth and thickness, roof sheet depth and thickness, insulation thickness, fastener type, fastener location. Hence, the program included tests on Z-sections having a thickness of 0.11in or 0.07in. The roof panels were either 0.2in or 0.21 steel sheets. Screw fasteners were self-drilling and self-tapping screw located at the centre of the joist flange.

All the results are summarized in Table11.

Panel		Purlin		Screw	Range of k values	
hp inches	*tp inches*	*hw inches*	*tw inches*	*No.*	(libin/in/rad)	
1.5	*0.02*	*8*	*0.118*	*14*	*140*	*270*
1	*0.021*	*8*	*0.11*	*14*	*140*	*280*
1	*0.02*	*8*	*0.11*	*14*	*150*	*240*
1.5	*0.02*	*9.5*	*0.07*	*14*	*110*	*200*
1	*0.021*	*9.5*	*0.07*	*14*	*110*	*160*
1.5	*0.02*	*8*	*0.069*	*114*	*110*	*190*
1	*0.021*	*8*	*0.069*	*14*	*130*	*190*

Table11: Rotational stiffness MRI Project [7].

Schafer et al. [8] 36 cantilever tests on joist-sheathing assemblies were conducted to determine the rotational restraint that sheathing provides to the compression flange of a CFS member in bending. This rotational restraint, which is characterized by the stiffness $k_ø$, can partially or fully retard distortional buckling. The tests were conducted to study the rotational restraint provided by the sheathing to a floor joist in bending, but the results can be extended to any CFS member in bending. Goal was to propose and validate a method for extending the cantilever tests such that the rotations associated with the connection may be decomposed. The basic test setup is shown in Figure8. The side of the joist not attached to the sheathing has a load (displacement) applied which generate a moment (rotation) on the sheathing-joist connection. As the sheathing bends and the connection rotates, vertical Δ_y and horizontal displacement Δ_h and load P are recorded.

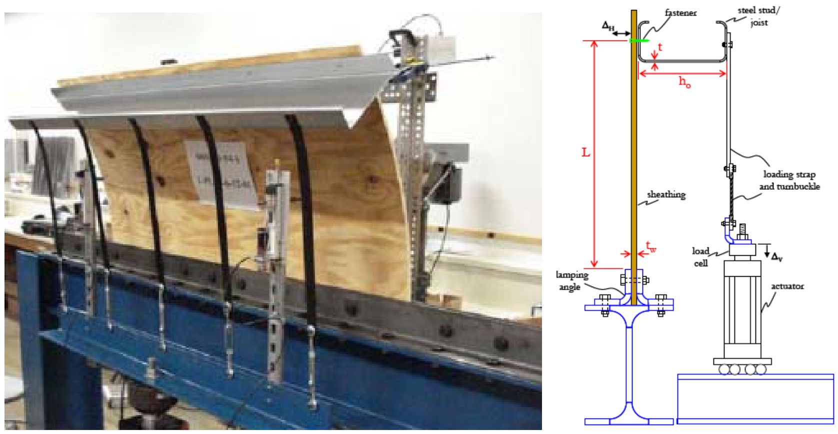

Figure8 : Test specimen by Schafer et al.

The investigated parameters were:

- Sheathing typology (plywood, OSB, gypsum)
- Joist length (12” and 24”)
- Joist depth (from 3 5/8 to 12in)
- Joist thickness (from 0.033 to 0.097)
- Fastener diameter (no.6 and no.10)
- Fastener spacing (6” and 12”)

All the results are reported in Table12.

$k_ø$ (lbfin/in/rad)			
Joist thickness	*mean*	*C.O.V.*	*n*
0.033	*91*	*0.15*	*2*
0.054	*105*	*0.27*	*19*
0.068	*119*	*0.20*	*2*
0.097	*174*	*0.19*	*10*

Table12: Rotational stiffnessof sheathing-to-joist fasteners independent of sheathing material [8].

4.4.2 REFERENCES

[1] AISI (1962), Light gage cold-formed steel design manual, American Iron and steel Institute, New York.

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