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LATERAL LOAD STRENGTH OF SCREW CONNECTIONS IN 29ga METAL

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SUMMARY

The results of 300 tests on screwed connections in shear are presented. The load capacity of screws in a row is shown to be additive and screws placed in narrow ribs of 29ga steel have the same strength as screws placed in flat sheets. The AISI equation for tilting strength of screw connections under predicts the strength of the screw connections tested. A regression equation is developed for tilting and compared to the AISI tilting equation and a third party test data. The regression equation is more accurate but less precise than the AISI equation.

INTRODUCTION

Post-frame buildings depend upon light-gage metal over dimension lumber frames to resist lateral load (11). The structural properties of light-gage metal diaphragms are dependent upon the mechanical fasteners used to attach the sheathing to the frame, and to connect adjacent sheets together, seam fastener (1,2, and 6). Adjacent 28-29ga sheets generally overlap at the rib requiring fasteners to be placed in the often narrow, flat area on top of the rib, see Figure 1. The fasteners placed in the overlapping rib may penetrate both sheets and extend into the purlin at the purlin or only penetrate the two overlapping sheets at the purlin or between the purlins. Fasteners extending into the purlin generally do not tilt while fasteners that do not extend into the purlin do tend to tilt, see Figures 2 and 3.

The seam fasteners used to join two adjacent sheets may be 24" o-c (at purlins only) to 3" or 4" o-c. Fasteners spaced 24" o-c most likely behave as independent fasteners. Fasteners spaced 3" o-c may influence each other's behavior. Riskowski and Uken (9) found that two screws not in the same row only increased the joint strength by 37%. Luttrell(6) found that two screws in a row provided close to twice the strength as one screw. AISI (3) does not address specifically the strength of multiple fasteners in a row. Heavily fastened 29ga diaphragms may have 4-5 fasteners in a row between purlins. If it is assumed that the frame, purlins, tends to displace the sheets of the diaphragm relative to each other, then the fasteners along the rib between purlins may be thought of as a group of fasteners resisting the sheet displacement.

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The thread nearest the sheet not in contact with the head of the screw would behave as a small diameter washer if the thread angle were 0° or 45°, square or buttress thread, or if the pitch were close to zero. The thread angle is generally not given but the pitch, inverse of threads per inch, is generally provided by the screw manufacturer. Screws with a large pitch, few threads per inch, will tilt farther before engaging the thread and the sheet not next to the screw head. Also, as the pitch and there by the tilt is increased, it is more likely that the sharp edge of the sharp V thread will come in contact with sheet. Less thread bearing area will be provided against the sheet which will concentrate the load on the sheet surface.

The shear capacity of screws used in light-gage metal connections has long been recognized (10). Equations for predicting the shear strength of screwed connections were proposed by Stark and Toma (10). However, the proposed equations were not universally accepted leading Yu to recommend that screw connection strength be determined by appropriate tests (12). Screw testing continued by organization and private companies. Some companies developed shear strength design values and guides (4 and 5) but others did not. Pekoz (8) evaluated the test results from five sources which included 2286 shear tests. Pekoz recommended that the European Recommendation for shear strength of screw connections be adopted with a modification of the equations constants, multiplied by 1.3, and basing the strength on the sheet ultimate strength rather than the yield strength. It was also recommended that the safety factor be 3.0 for the allowable stress design procedure. AISI (3) adopted Pekoz's recommendations in 1993.

Screw fastener tests generally have involved a relatively wide flat sheet with one or two fasteners when the failure mode is tilting of the screws or bearing failure. Screws used to fasten 29ga seams in post-frame construction are often placed in ribs nominally are 3/8" wide with support from the metal comprising the side of the rib, see Figure 1. The steel used in the tests is generally 26ga and thicker rather than 29ga and screws in the rib (nominally ¾" to 1" high) at the purlins are generally long enough to penetrate the purlin.

OBJECTIVES

The objectives of the screw fastener test program are to evaluate the basic strength of common sizes of screws used with 29ga sheeting in the rib and the effect of blocking: where the screw penetrates the purlin. Also the test program will evaluate the effect of placing fasteners in a row along the rib and the effect of thread pitch on strength. A comparison will be made to determine if tests with flat sheets can be used to estimate the strength of fasteners placed in a narrow rib.

PROCEDURE

The 300 test specimens were tested on a Syntech 2/D universal test machine with grips that were modified to accommodate gripping the test specimens along the nominally 3/8" wide rib. The load head travel was 0.1 inches/minute. Load and displacement data were collected at the rate of 250 pairs of data per minute. The sheet material used for the test was 29ga [1]CENTURY DRAIN sheeting provided by Wheeling Corrugating Company. The sheets were 18" long and the outside (overlapping) ribs, total width 6", were cut off each sheet to make one test specimen for the screws in rib tests. The ribs for each test specimen overlapped 14 ½" leaving 1 ¾" for each grip. Screws were placed centered in the 14 ½" overlap, single screw, or symmetrically located around the overlap centerline with screws 2.5" o-c, multiple screws. The 2.5" o-c arrangement exceeds the AISI requirement (3). The screw placement excluded edge failure (8) and was deemed to be the closest practical spacing of the screws in a diaphragm. The tests were run until a total displacement of 0.4" was reached or the screw pulled out of the sheeting. The screws did not tend to pullout of the sheeting but had reached a peak load; i.e. load was constant or decreasing with displacement. The basic test setup is shown in Figure 4.

Sheet metal properties were determined from 5 specimens removed from 5-sheet sections selected arbitrarily. The sheet sections are the portion of the sheet remaining after the outside ribs were removed. The sheet ultimate strength was found to be 101,000 psi (COV = 3.03%) with an uncoated thickness of 0.0141" (COV = 1.07%).

The screws used in the test are identified by their size and length. For example, 9-11/2 would be a 9ga screw which is 1 ½" long. Table 1 provides the screw dimensions for each of the 4 sizes of screws utilized in the test program. The data found in Table 1 was determined from a sample of 10 screws randomly chosen from all the screws in each screw size. Table 2 shows the mean thread diameters of the screws as well as the thread diameters given by AISI and the NDS (3 and 7). The 9-11/2 screws are [1]East Coast fasteners while the 12-3/4, 14-3/4, and 14 7/8 are [1]Construction Fastener screws.

The screw test program is comprised of 300 tests with 30 replications of each of the 10 test variables. Sixty specimens were made with the 11/2" wide, flat section of the sheet and 240 specimens were made with the rib.

The 9-11/2 screws were utilized in the first 7 test variables. The first 4 test variables consisted of 1, 2, 3 and 4 #9 screws 1 ½" long being placed in overlapping ribs as discussed in the beginning of this section. The tests evaluate the basic strength of the screws and what affect placing the fasteners in a row may have on strength. The fifth test variable placed a single #9 screw 1 ½" long through the overlapping ribs into a block of wood which prevents the screw from tilting during the test. The sixth and seventh test variables involve #9 screws 1 ½" long placed in flat sections of the sheet which were

1) No endorsement of product intended.

removed from between the ribs. The sixth test variable had 1 screw while the seventh test variable had two screws spaced as discussed in the beginning of this section. The test variables evaluate the effect that the rib may have on screw strength.

The eighth, ninth, and tenth test variables used screws of different sizes placed individually in the overlapping ribs. The eighth test variable is a #12 screw ¾" long while the ninth and tenth test variables used a #14 screw ¾" long and 7/8" long respectively. Table 2 shows that the #14 screws had 15 threads per inch (3/4") and 20 threads per inch (7/8"). Also, the 14-7/8 screw has a self-tapping tip while the 14-3/4 has a fully threaded point common for screws that penetrate both steel and wood. The three test variables will estimate the effect the screw diameter has on seam fastening and see whether threads per inch influence screw performance.

RESULTS AND DISCUSSION

The results of the test program are given in Table 3 and Figures 5, 6, and 7. All data provided were obtained by averaging the 30 replication of each test variable. The data found in Table 3 is the average peak load, or first peak load, without regard to the displacement while the data used to develop Figures 5, 6, and 7 are the averages of the load for a given displacement. Comparing Figures 5, 6, and 7 to Table 3 shows that the peak load is not the same and the peak loads in Table 3 are generally higher than those in Figures 5, 6, and 7. The maximum load (strength) that the tested fastener can carry is given in Table 3. The data in Table 3 is then the best point estimate of the maximum strength of the fastener. The curves shown in Figures 5, 6, and 7 show the average load required to cause a given deflection; i.e. stiffness. These data are then the best estimate of load-deflection behavior of the screw in the 29ga metal for each fastener used. Design engineers are more interested in the strength while individuals modeling fastener behavior would be more interested in the load-deflection characteristics of the fasteners. It should be noted that if one is modeling the fasteners with the curves in Figures 5, 6, and 7, the fasteners will not obtain the ultimate strengths found in Table 3. A polynomial regression was performed on the curves found in Figures 5, 6, and 7. A sixth degree polynomial yielded a correlation coefficient of 0.85 or greater.

Table 3 gives maximum load the fasteners carried, peak load, and the first peak load. As the test specimens were loaded, they often exhibited periods of decreasing load with increasing displacement or relatively constant load for increasing displacement before the load began to increase again, see Figure 8. Stark and Toma (10) reported that screw connections that failed in hole bearing or tension failure of the net section reached a peak, then increased load until failure. The first peak may have been due to tilting of the screw, which is the initial dominant deflection term. At a certain load, the steel sheet in the connection begins to yield, bearing or tension, which becomes the dominant deflection term until failure. Stark and Toma (10) observed that screws that failed by tilting exhibited several peaks but of decreasing magnitude unlike those observed in this test program, see Figure 8. The peaks may be due to the movement of the screw in the sheets joined. As the screw first begins to tilt, the metal washer presses down on the neoprene washer compressing it on the top sheet at the same time the fluke of the thread pushes up into the bottom sheet. The neoprene washer becomes fully compressed and the fluke of the thread pushes into the sheet, causing it to yield, making the first peak. Other peaks are produced as the neoprene washer slips relative to the metal washer, a thread pulls through the bottom sheet, and the sheet fails in bearing. The #9 screws tilted significantly more than the #12 and #14 screws which caused a crack or split in the top sheet parallel to the direction of movement in the sheet under the washer. Another peak occurs when the screw begins to pull out of the sheet, primarily #9 screws. Table 3 shows that in all cases except for the #9 screws with block that the AISI equation for tilting is conservative and only the strength of the #9 screw with block, tilting prevented, is predicted by the AISI bearing equation. AISI equations are:

1) Tilting:
   $P= 4.2t^{3/2} F_u \sqrt{d}$

2) Bearing:
   $P=2.7tdF_u$

   P=connection strength, lb.
   t =base metal thickness, 0.0141"
   F_u=base metal teasel strength, 101,000psi
   d=screw thread diameter

Figure 4 shows that as the screw diameter increases, the peak load from testing increases relative to the AISI strength prediction equation for tilting making it unlikely that adjusting the constant in the tilting equation would account for the difference. Figure 9 shows the peak load, first peak load and AISI load predicted for the 9-11/2, 12-3/4, 14-3/4, and 14-7/8 single screw tests. The screw thread diameter is "x" in the equation shown in Figure 9. The constant in the AISI load equation ("calculated" in Figure 9) is found by substituting the base metal tensile strength and the base metal thickness into the tilting equation. The test data for the peak load yields the following equation from regression analysis.

$$P=5994\, d^{1.54}$$
$$r^2=0.9615$$

It is seen by comparing the AISI load prediction equation and the above equation that the exponent for the diameter (d) is 0.5 for the AISI equation and 1.54 for the regression equation. Also, the exponent for the thickness is 1.00 for the regression equation rather than 1.5 in the AISI predictive equation. The regression equation developed from this test program and the AISI predictive load equation were compared to test results for Buildex screws (5) with two equal thickness sheets, sheet thickness of 26-14ga and screw sizes of 10ga, 12ga, 14ga, and ¼", see Table 4. The thread diameter for the Buildex screws is reported as a range (5), average values of thread diameter were used in both the AISI predictive equation and the regression equation. Table 4 shows that regression equation on average is within 5% of the Buildex test data while the AISI equation is within 12% of the test data. The regression equation predicts strengths greater that test data on average and the AISI equation predicts strengths less than found by testing on average. However, the standard deviation of the test data to the predicted strength ratio for the regression equations is 3 times that of the AISI equation. The regression equation substantial overestimates (ratio <0.7) the strength of 14ga screws (diameter =0.251 and 0.243) in the 26ga and 24ga (thickness=0.018" and 0.024") metal while it under estimates the strength (ratio> 1.3) of the smaller 10ga screw (diameter=0.164") in the 22ga, 20ga, and 18ga (thickness=0.030", 0.036", and 0.048") sheet metal. The AISI equation tends to underestimate the strength of the single point 10ga and 12ga screws (diameter=0.186" and 0.212") in the 26ga, 24ga, and 22ga (thickness=0.018", 0.024", and 0.030") metal.

The test report on the Buildex fastener testing (5) states that the most common mode of failure was tilting of the screws with material build-up behind the screws leading to the screw pulling out of the bottom sheet (sheet away from screw head). The tilting failure with the screw slotting the bottom sheet was the mode of failure observed in the current test program with the additional observations that the top rib also developed a small split parallel to the direction of load and in the direction of the screw tilt when the screw being tested was a #9. The connections made with 2, 3, and 4 #9 screws also exhibited slotting of the top rib under the washer. Figure 9 shows that the AISI strength equation for screw tilting under predicts the strength of the screw connections tested. All of the screws used in the test program had a metal washer under the head of the screw. The metal washer may resist tilting of the screw increasing the tilting load capacity of the screw. Screw head or washer diameter may need to be considered in determining tilting strength of screws. Another factor that may need to be considered is the threads per inch as discussed in the "Introduction". Table 3 shows that the mean strength of the 14-7/8 screws is 10% greater than the 14-3/4 screws eventhough 14-3/4 screws have a somewhat greater thread and root diameter, see Table 1. The 14-7/8 screws do have a slightly greater washer diameter, but it would not appear to be significantly different. Also, the 1/8" longer length of the 14-7/8 screw did not affect the tilting strength because the extra length was not threaded and by the time the point of the screw is withdrawn from the sheet, the load has already dropped substantially. Further, Figure 9 shows that predicted load from the AISI equation deviates more from the test data. Table 1 shows that the washer diameter is relatively constant for the #12 and #14 screws but 25% greater than the #9 screw washer diameter. The thread diameter may interact with the washer diameter to influence strength.

It is unlikely that the screw placement in the rib affected the screw strength. Table 3 shows that the single and double 9-11/2 screws placed in flat sheets and in the rib differed by a maximum average peak load of 3%. The data supports the argument that tests conducted in flat specimens are applicable to fasteners used in the rib with a nominally 3/8" wide flat area.

Figure 10 shows that the number of fasteners in a row is linear and when a regression analysis is performed with the fitted line through zero, the individual screw strength is within 11/2% for the peak load (415.0lb vs 420.5lb) and the first peak load (328.8lb vs 333.5lb). The correlation coefficient is greater than 0.99 for both cases. The data plotted in Figure 10 includes the 9-1 1/2 tests in the rib and in the flat sheets. The linearly additive effect is exhibited by both the flat sheet and ribbed specimen.

Table 5 lists the minimum and maximum actual safety factors that would exist for the test data based on an intended safety factor of 3 if the ultimate strength of the fasteners were developed through testing, AISI equation, and the regression equation from Figure 9. The minimum actual safety factor from testing for any specimen is 2.03 while the maximum actual safety factor is 4.40. For tilting, the AISI safety factor was 3.21 minimum actual and 7.21 maximum actual which is the most conservative. The AISI equation for bearing provides a safety factor range from 2.26 to 3.12, which is comparable to the range established for testing. The regression equation from Figure 9 had a safety factor range of 1.88 minimum to 4.17 maximum which is a similar in magnitude but some what lower then the range for the testing. The regression equation was the least conservative method for determining design loads.

CONCLUSIONS/SUMMARY

The following conclusions can be made based on the test data contained herein:

1. The AISI equation can predict bearing strength (within 6%) of the screw connections as evidenced by the 9-1 1/2 block test.

2. The AISI equation under predicts the tilting strength of the tested connections by a factor of 1.39 to 2.09. The metal washer used under the screw head and the threads per inch may account for the differences.

3. The rib did not affect the performance of the fasteners. Test data derived from flat sheets may be used to estimate the strength of fasteners placed in the nominally 3/8" wide rib.

4. A regression equation was developed from the test data for screw tilting failure. The regression equation with the same terms as the AISI equation (thickness of sheet, thread diameter, and ultimate sheet strength) had an exponent of 1 for the thickness and 1.54 for the thread diameter compared to an exponent of 1.5 for the thickness and 0.5 for the thread diameter of the AISI equation. The regression equation increases the connection strength faster with changes in thread diameter than AISI equation but does not increase the connection strength as fast with increasing changes in sheet metal thickness as the AISI equation does.

5. The regression equation more accurately predicted Buildex screw test data than the AISI equation but was only about 1/3 as precise.

6. The regression equation is less conservative than the AISI equation.

7. The ultimate strength (peak load) of fasteners placed in a row on the rib of a sheet is the sum of the strength of the individual fasteners.

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NOTATION

P = connection strength, lb
t = base metal thickness, in
d = screw thread diameter
F_u = base metal tensile strength, lb/in
r = correlation coefficient
Δ = connection deflection, in

Table 1 . Mean screw dimensions and coefficient of variation (COV).

Nominal Size	Head Diameter in	Head Thickness in	Metal Washer Diameter in	Metal Washer Thickness in	Neoprene Washer Diameter in	Neoprene Washer Thickness in	Thread Diameter in	Root Diameter in	Thread per inch
9-1½"	0.249 (0.45%)	0.167 (0.63%)	0.463 (0.31%)	0.030 (2.73%)	0.413 (0.21%)	0.073 (2.03%)	0.176 (0.57%)	0.141 (0.50%)	17
12-¾"	0.311 (0.38%)	0.173 (0.59%)	0.589 (0.30%)	0.091 (0.44%)	0.403 (0.46%)	0.156 (0.70%)	0.209 (0.42%)	0.162 (0.46%)	20
14-¾"	0.367 (0.22%)	0.175 (0.63%)	0.589 (0.26%)	0.096 (1.02%)	0.401 (0.26%)	0.154 (0.73%)	0.249 (0.38%)	0.181 (0.35%)	15
14-⅞"	0.305 (0.15%)	0.206 (0.53%)	0.592 (0.07%)	0.093 (0.68%)	0.412 (0.24%)	0.150 (0.81%)	0.242 (0.36%)	0.180 (0.45%)	20

Table 2 . Screw thread diameters.

Gage	Mean Measured Diameter in	AISI Diameter in	NDS Diameter in
8	---	0.164	0.164
9	0.176	---	0.177
10	---	0.190	0.190
12	0.209	0.216	0.216
14	0.249 (3/4") 0.242 (7/8")	---	0.242
16	---	---	0.268

Table 3 . Mean screw loads and deflections with coefficient of variation (COV).

Screw	First Peak Load, lb	Deflections at First Peak Load, in	Peak Load, lb	Deflection at Peak Load, in	AISI Calculated Load, lb Tilting	AISI Calculated Load, lb Bearing
#9-1½" in rib						
single	309.5 (26.89%)	0.13 (56.54%)	416.5 (14.08%)	0.32 (21.48%)	298.2	675.8
double	668.6 (17.01%)	0.14 (38.98%)	799.4 (11.39%)	0.30 (28.86%)	---	---
triple	1011.3 (20.59%)	0.14 (54.39%)	1285.5 (11.2%)	0.36 (13.51%)	---	---
quadruple	1330.7 (14.15%)	0.15 (29.48%)	1686.0 (6.57%)	0.36 (14.74%)	---	---
block	594.9 (10.60%)	0.10 (28.31%)	636.6 (7.05%)	0.20 (47.95%)	677.2	675.8
flat						
single	348.0 (17.97%)	0.11 (47.64%)	413.5 (14.38%)	0.24 (43.17%)	298.2	675.8
double	699.4 (19.46%)	0.14 (35.21%)	821.5 (11.32%)	0.28 (34.29%)	---	---
#12-¾" in rib						
single	337.1 (50.05%)	0.06 (61.88%)	542.5 (11.49%)	0.29 (40.29%)	325.0	802.5
#14-¾" in rib						
single	576.6 (23.01%)	0.08 (45.84%)	661.7 (14.00%)	0.24 (48.14%)	354.7	956.1
14-⅞" in rib						
single	657.6 (17.39%)	0.11 (47.67%)	731.7 (9.46%)	0.23 (49.57%)	349.7	929.2

Table 4. Comparison of Buildex test data (5), AISI predicted Predicted strength, and regression equation predicted strength.

Dia (in)	Threads per in.	Point	Sheet Thickness (in)	Sheet Strength (psi)	Tested Strength (lb)	Regression Equation Strength (lb)	Ratio Test to Regression	AISI Strength (lb)	Ratio Test to AISI
0.186	16	1	0.018	68100	398	386	1.0311	298	1.3356
0.186	16	1	0.024	71900	584	544	1.0735	484	1.2066
0.186	16	1	0.030	53500	659	506	1.3024	504	1.3075
0.186	16	1	0.036	67400	884	764	1.1571	834	1.0600
0.186	16	1	0.048	63100	1374	954	1.4403	1202	1.1431
0.212	14	1	0.018	68100	432	472	0.9153	318	1.3585
0.212	14	1	0.024	71900	703	660	1.0652	517	1.3598
0.212	14	1	0.030	53500	753	618	1.2184	538	1.3996
0.212	14	1	0.036	67400	1018	935	1.0888	890	1.1438
0.212	14	1	0.048	63100	1452	1167	1.2442	1283	1.1317
0.251	10	1	0.018	68100	409	613	0.6672	346	1.1821
0.251	10	1	0.024	71900	663	862	0.6892	563	1.1533
0.251	10	1	0.030	53500	811	802	1.0112	585	1.3863
0.251	10	1	0.036	67400	1089	1213	0.8978	969	1.1238
0.251	10	1	0.048	63100	1614	1514	1.0661	1396	1.1562
0.164	16	2	0.018	68100	312	318	0.9811	280	1.1544
0.164	16	2	0.024	71900	478	448	1.0670	455	1.0513
0.164	16	2	0.030	53500	589	416	1.4154	473	1.2457
0.164	16	2	0.036	67400	830	630	1.3175	783	1.0600
0.164	16	2	0.048	63100	1206	786	1.5344	1129	1.0685
0.164	16	2	0.060	63200	1268	984	1.2886	1580	0.8026
0.212	14	2	0.018	68100	365	472	0.7733	318	1.1478
0.212	14	2	0.024	71900	600	665	0.9023	517	1.1605
0.212	14	2	0.030	53500	623	618	1.0081	538	1.1580
0.212	14	2	0.036	67400	898	935	0.9604	890	1.1112
0.212	14	2	0.048	63100	1370	1167	1.1748	1283	0.9096
0.212	14	2	0.060	63200	1758	1461	1.2033	1796	0.8135
0.212	14	2	0.075	67000	2138	1936	1.1043	2661	0.8034
0.243	14	3	0.018	68100	326	583	0.5592	340	0.9574
0.243	14	3	0.024	71900	540	820	0.6585	553	0.9757
0.243	14	3	0.030	53500	756	763	0.9908	576	1.3135
0.243	14	3	0.036	67400	930	1154	0.8059	953	0.9757
0.243	14	3	0.048	63100	1442	1440	1.0014	1374	1.0496
0.243	14	3	0.060	63200	2100	1803	1.1647	1923	1.0920
0.243	14	3	0.075	67000	2584	2389	1.0816	2849	0.9069
							x = 0.9501		1.1196
							s = 0.4100		0.1618
							cov = 43.15%		14.46%

Table 5. Range of safety factors for screws tested.

Screw	Peak Load, lb		[1]Design Load, lb	Safety Factor		AISI Load,lb divided by 3	Safety Factor		Regression Load, lb divided by 3	Safety Factor	
	Minimum	Maximum		Minimum	Maximum		Minimum	Maximum		Minimum	Maximum
9-1 1/2"											
Single in Rib	337.5	573.6	138.8	2.43	4.13	99.4	3.40	5.77	137.6	2.45	4.17
Single in Flat	318.6	531.8	137.8	2.31	3.86	99.4	3.21	5.35	137.6	2.32	3.86
12-3/4"											
Single in Rib	367.9	642.1	180.8	2.03	3.55	108.3	3.40	5.93	179.3	2.05	3.58
14-3/4"											
Single in Rib	442.4	814.9	220.6	2.03	3.69	118.2	3.74	6.89	234.8	1.88	3.47
17-7/8"											
Single in Rib	569.0	840.2	243.9	2.33	3.44	116.6	4.88	7.21	224.7	2.53	3.74
9-1 1/2"											
Single in Rib and Block	509.1	704.1	212.2	2.40	3.32	225.6	2.26	3.12	-	-	-
9-1 1/2"											
Double in Rib	464.8	971.2	220.9	2.10	4.40	-	-	-	-	-	-
Triple in Rib	1075.5	1611.9	428.5	2.51	3.76	-	-	-	-	-	-
Quadruple in Rib	1508.5	1914.2	562.0	2.68	3.41	-	-	-	-	-	-
9-1 1/2"											
Double in Flat	708.3	1102.0	273.8	2.59	4.02	-	-	-	-	-	-

Note: 1. Design load equals 1/3 of test mean peak load.

Table 6. [1]Regression Coefficients for Curves Shown in Figures 5, 6, and 7.

Screw	Polynomial Coefficients Δ^0	Δ^1	Δ^2	Δ^3	Δ^4	Δ^5	Δ^6	r^2
9-11/2 in rib								
single	--	9.02×10^3	1.39×10^5	1×10^6	-4×10^6	9×10^6	-7×10^6	0.985
double	--	1.60×10^4	1.78×10^5	1×10^6	-4×10^6	6×10^6	-4×10^6	0.996
triple	--	2.14×10^4	-2.50×10^5	2×10^6	-7×10^6	1×10^7	-1×10^7	0.998
quadruple	--	1.93×10^4	-8.09×10^4	1.57×10^5	2×10^6	-6×10^6	5×10^6	0.999
block	--	1.87×10^4	-2.26×10^5	1×10^6	-4×10^6	6×10^6	-4×10^6	0.956
9-11/2 in flat								
single	--	8.68×10^4	-1.1×10^5	8.28×10^5	-3×10^6	7×10^6	-5×10^6	0.853
double	--	1.43×10^4	-1.34×10^5	7.21×10^5	-2×10^6	4×10^6	-3×10^6	0.993
12-3/4 in rib								
single	--	1.31×10^4	-2.10×10^5	2×10^6	-7×10^6	1×10^7	-1×10^7	0.983
14-3/4 in rib								
single	--	1.94×10^4	-2.63×10^5	2×10^6	-6×10^6	1×10^7	-8×10^6	0.971
14-7/8 in rib								
single	--	2.12×10^4	-2.95×10^5	2×10^6	-7×10^6	1×10^7	-9×10^6	0.971

1) Regression Equation Form: $P = a\Delta^1 + b\Delta^2 + c\Delta^3 + d\Delta^4 + e\Delta^5 + f\Delta^6$

P – force required to cause the displacement, Δ, lb

Δ - displacement, in a, b, c, d, e, f – regression coefficient in table.

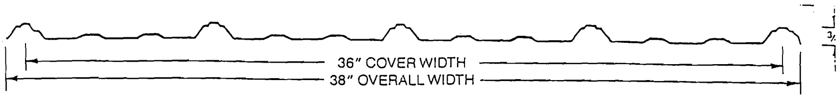

Figure 1. Profile of CENTURY DRAIN, Wheeling Corrugating Co., Wheeling, WV.

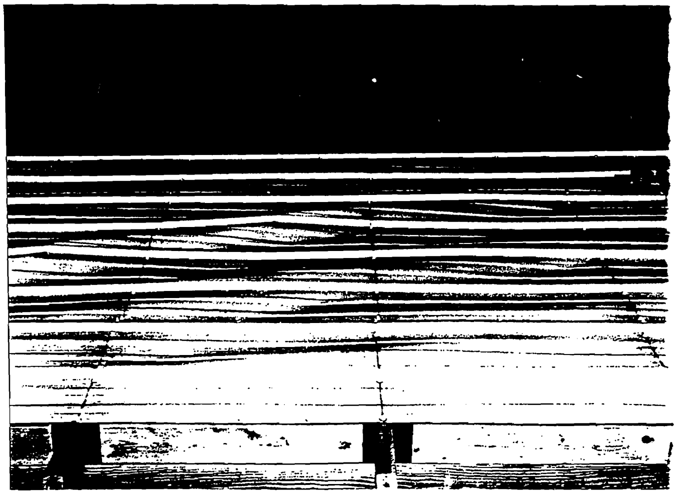

Figure 2. Pro Panel-II (Metal Sales Manufacturing Corp., Louisville, KY) Sheathed diaphragm showing screws in rib between purlins tilting while fasteners in rib and purlin do not tilt.

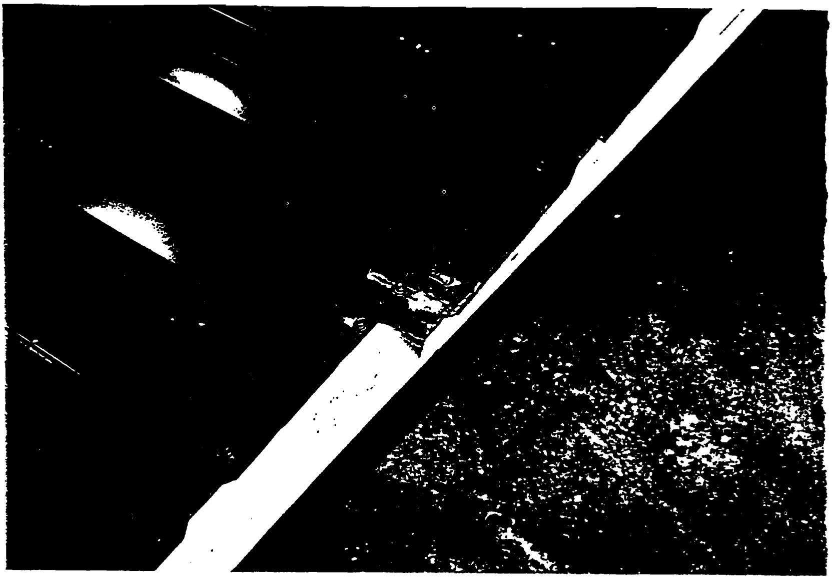

Figure 3. CHANNEL DRAIN 2000 (Wheeling Corrugation Co., Wheeling, WV) diaphragm showing screw through overlapping ribs tearing both sheets and not tilting.

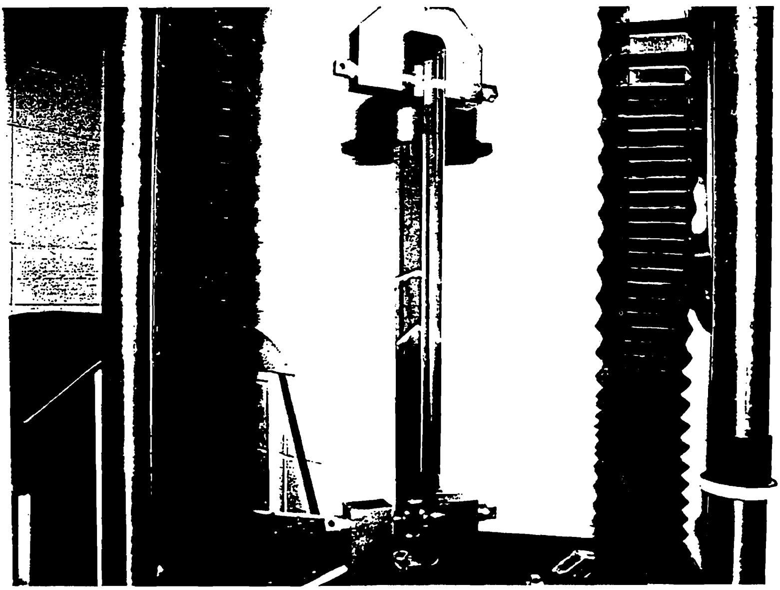

Figure 4. Test specimen with 2 9-11/2" long screws placed in Syntech 2/D universal testing machine.

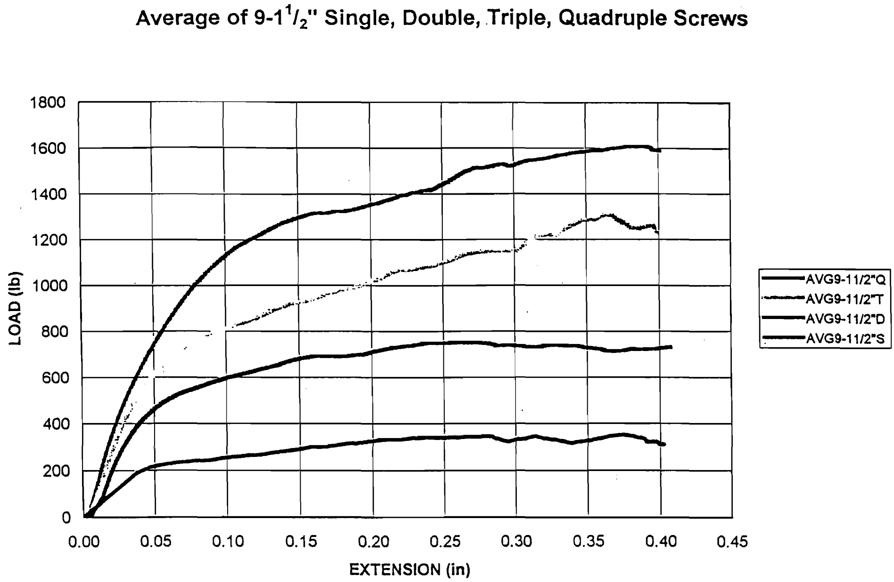

Figure 5. Average load-deflection curves for 9-11/2 screw in rib single, double, triple, and quadruple.

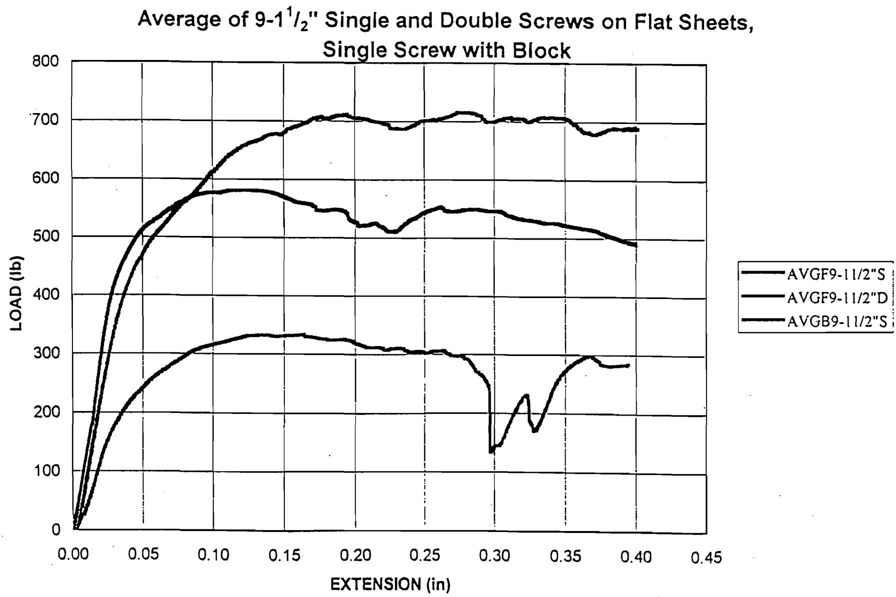

Figure 6. Average load-deflection curves for 9-11/2 single and double screws in flat and 9-11/2 single screw in rib and block.

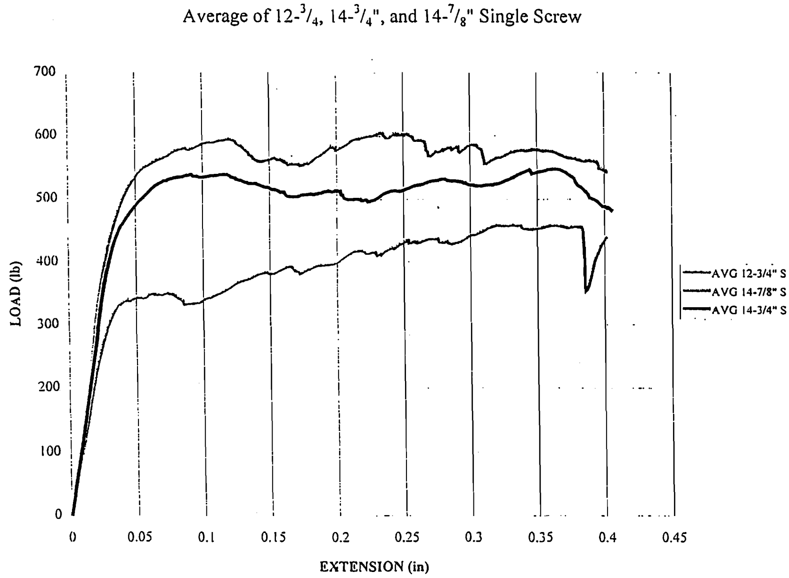

Figure 7. Average load-deflection curves for 12-3/4, 14-3/4, and 14-7/8 single tests in rib.

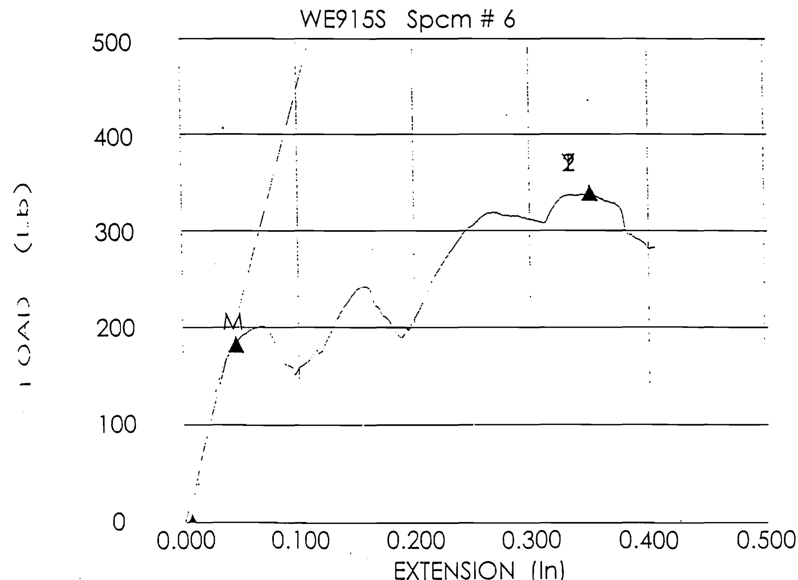

Figure 8. Load-deflection curve for the 6 specimens of 9-11/2 single screw.

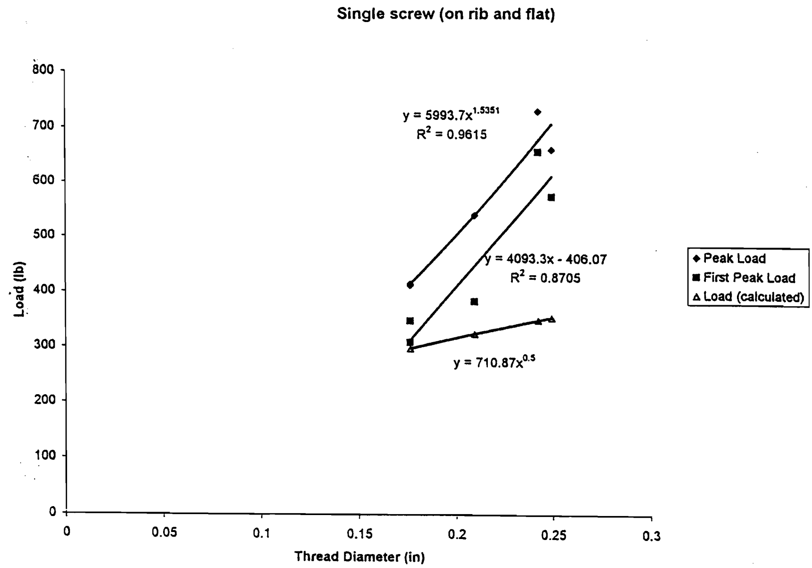

Figure 9. Test data and AISI (3) equation variation of screw strength (tilting) with diameter.

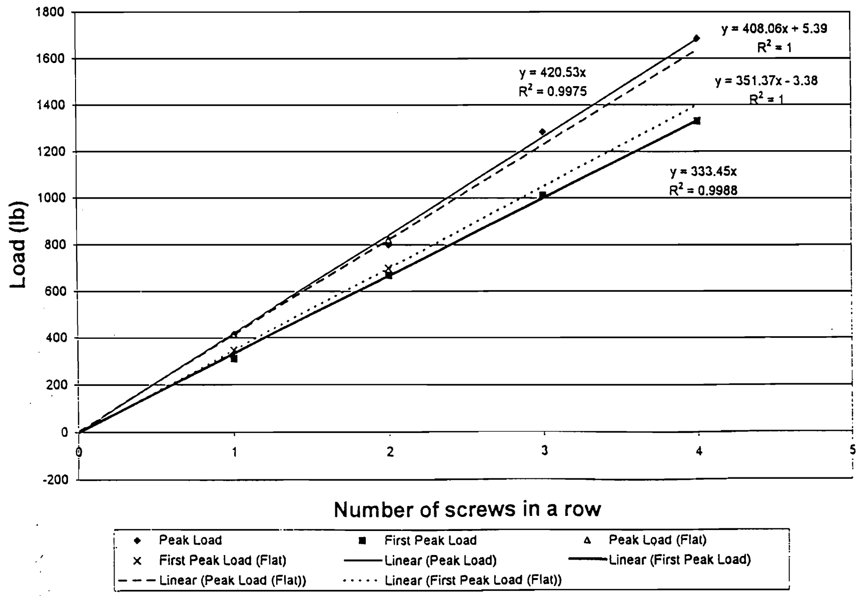

Figure 10. Strength of the number of fasteners in a row.