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Duane S. Ellifritt

Robert Burnette

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"PULL-OVER STRENGTH OF SCREWS IN SIMULATED BUILDING TESTS"

Duane S. Ellifritt[1] and Robert Burnette[2]

INTRODUCTION

Those of us who have visited disaster areas after hurricanes or tornadoes and observed metal roof panels peeled back at the building edges have wondered just how much wind force it took to do that. The fasteners always seem to stay in the purlins while the roof panel pulls over them. If the damaged building is an old one, has an accumulation of fluctuating load cycles weakened the connection or fatigued the metal?

There is a simple pull-over test that any one can quickly perform with a single fastener and a small strip of panel, but does it really model the behavior of a roof panel in a windstorm? In many pre-engineered steel buildings, a trapezoidally corrugated panel is typically attached to cold-formed steel purlins on about five foot centers by means of self-drilling screws. Under wind uplift, the panel acts like a continuous beam. The flat portion of the panel, containing the screw, is subjected to bending tension in two directions at the same time that the screw is being put in tension. This is a completely different state of stress in the panel than that of the pull-over test performed on a small sample of the panel material.

The objective of this research was to simulate a real building roof (or wall; the same argument applies to wall panels under suction loads) to see how much force perpendicular to the panel is required to pull the fastener through the panel. The so-called standard pull-over test was then performed on the same material and a correlation coefficient developed that will relate the simpler test to real field conditions.

A secondary objective was to subject the panels and fasteners to dynamic loading to determine the fatigue resistance of the panels. It was felt that this could be an important determinant in assessing the strength in older buildings subjected to extreme winds.

THE STANDARD PULL-OVER TEST

Subcommittee #6 of the American Iron and Steel Institute's Specification Committee has developed a test procedure which will be incorporated into Part VII of the 1992 Cold-Formed Steel Manual.(1) A picture of the test specimen and the test set-up is shown in Figure 1. A U-shaped specimen is formed from a flat panel and screwed to a supporting member typical of the actual construction. A testing jig is built to grab the two sides of the test specimen at the open end of the 'U'. This device is used to provide a direct pull on the fastener, the sides of the panel specimen being parallel to the fastener. As load is applied, the panel material wraps around the fastener and, at failure, pulls over it. Hence the name "pull-over" test.

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[1] Crom Professor of Structural Design, University of Florida
[2] Graduate Student, University of Florida

This is a simple, inexpensive test to run, but it in no way models the behavior of a real panel fastened to real purlins in a real building.

STATIC AND DYNAMIC SUCTION PULL-OVER TEST

The authors have developed a test which they feel is a much better predictor of pull-over strength of sheathing in an actual field condition. It makes use of real roof or wall panels attached to real purlin or girt specimens. It is adjustable to fit any purlin or girt spacing, can accommodate different fastener spacings and location of the fastener with respect to the panel ribs, can be used with or without insulation, and can be used with cyclic loading. All of the above means, of course, that it is a more expensive test to perform and may be out of the reach of many users. However, using AISI's standard pull-over test as a base line test, it is possible to determine a coefficient that will relate the simpler base line test to actual field conditions. To differentiate this test from the standard pull-over test, the authors are calling it the "Static Suction Pull-Over Test" for static loading and the "Dynamic Suction Pull-Over Test" for cyclic loading.

TEST FRAME AND LOADING MECHANISM

The details of the test frame and loading mechanism are shown in Figure 2. The base is made of four rolled W-shapes with their flanges welded tip-to-tip. (This was left over from another research project and would not have needed to be this large. The base only needs to be strong enough to resist the tensile load on the panel assembly. An added advantage of this kind of base is that it is portable and can be moved out of the way when not in use.) The base supports four uprights, hot-rolled angles which in turn support the platform on which the test panel is mounted. The platform consists of two 1/4 inch plates that are slotted so that the span length of the panel can be varied.

The panel rests on the platform and is screwed to the channel section shown in Figure 3. The bottom flange of the channel is attached to an actuator and load cell that is connected to an MTS drive unit, as shown in Figure 4. During testing, the channel section is pulled downward until the screws pull through the panel. Deflections at the screw locations are monitored to insure an equal loading on all the fasteners.

A panel span length was selected to model the shears and moments that would exist in a continuous beam over many supports. For a support spacing of 5 feet, the equivalent simple span would be 20.5 inches. The panel length was 36 inches so it extended over the supports by 7.75 inches on either side. In the first test, the panel ends came up and the panel collapsed in the middle before the screw pull-over occurred. To more accurately model a continuous panel, the ends of the panels were held down in all subsequent tests in such a manner as to let the panel move parallel to its ribs and at the same time restrain it transverse to the ribs.

In a real roof or wall, panels are lapped at the sides so that there are two ribs resisting bending. When testing a single panel, it was necessary to cut additional ribs from another panel and attach them to the test panel with panel metal screws to simulate side laps.

All self-drilling screws were #12 x 1 1/4 and were installed by the same person using an electric screw gun. The head dimension, across the flats, was .309 inches and the washer was 5/8 inches. The same person installed the screw in both the standard pull-over tests and the static suction pull-over tests, so installation method was not a variable in the tests.

All of the panels tested were of Grade E material (Nominal Fy = 80 ksi) with profile as shown in Figure 5.

TEST RESULTS

Standard Pull-Over

The results of 13 tests, performed according to the Draft AISI standard, are recorded in Table 1. The mean pull-over value for these tests was 1962 lb and the standard deviation 254 lb.

Static Suction

The results of 11 tests are shown in Table 2. AISI recommends that if three tests are performed and the results of any one test varies from the mean of the three by more than 10%, then three more tests must be run. It can be seen that a few of these tests did differ from the mean by more than 10%. However, with eleven identical tests, the mean capacity should be fairly representative.

The mean value of pull-over force was 782 lb, with the standard deviation being 70 lb.

All failures resulted in a characteristic diamond-shaped pattern shown in Figure 6.

A typical load-deflection curve is shown in Figure 7. It can be seen that stiffness increases at about 25% of ultimate load. This is due to the membrane tension developing in the panel. Then at about 80% of ultimate the curve softens again as yielding starts.

Dynamic Suction

Using the results of the static suction tests as a guide, 14 similar tests were performed, cycling the load from around 100 lb. tension per screw to various percentages of the static ultimate load until a fatigue crack developed. The results are shown in Table 3. This data is plotted in Figure 8 and shows upper and lower bound results for different percentages of static ultimate load. Failure was assumed to have occurred when a fatigue crack grew to 1/2 inch on either side of the fastener, perpendicular to the ribs. Subsequent loading caused the crack to propagate all the way across the panel between major ribs.

EVALUATION OF TEST RESULTS

For the static suction tests, a factor of around 0.4, when applied to the standard test, will give a good estimate of the pull-over strength of a fastener in a real building application, at least for the material and configuration tested. All the test panels were Grade E, which is a high strength, low ductility material. For other grades of steel, the multiplier could be different. It should also be noted that the tests were designed around a specific purlin or girt spacing of 5 feet. Other spacings could likewise change the outcome.

It is felt that the dynamic suction tests were two few to draw any conclusions from. The fact that all panels tested were Grade E low ductility material may have influenced the fatigue failures. More research is needed on other grades of steel before any definitive conclusions can be drawn. However, Figure 8 does show some consistency of results. With more research in the future, it will be possible to develop a better failure band. When coordinated with research into the actual number of cycles of various load levels to be expected in a year at a given location, it may be possible to predict the remaining life left in a roof or wall panel or calculate its capacity to resist suction based on a reduced pull-over strength.

REFERENCE

1. AISI Draft #4, "Proposed Test Procedures for Cold Formed Steel Design Manual, Part VII", September, 1988.

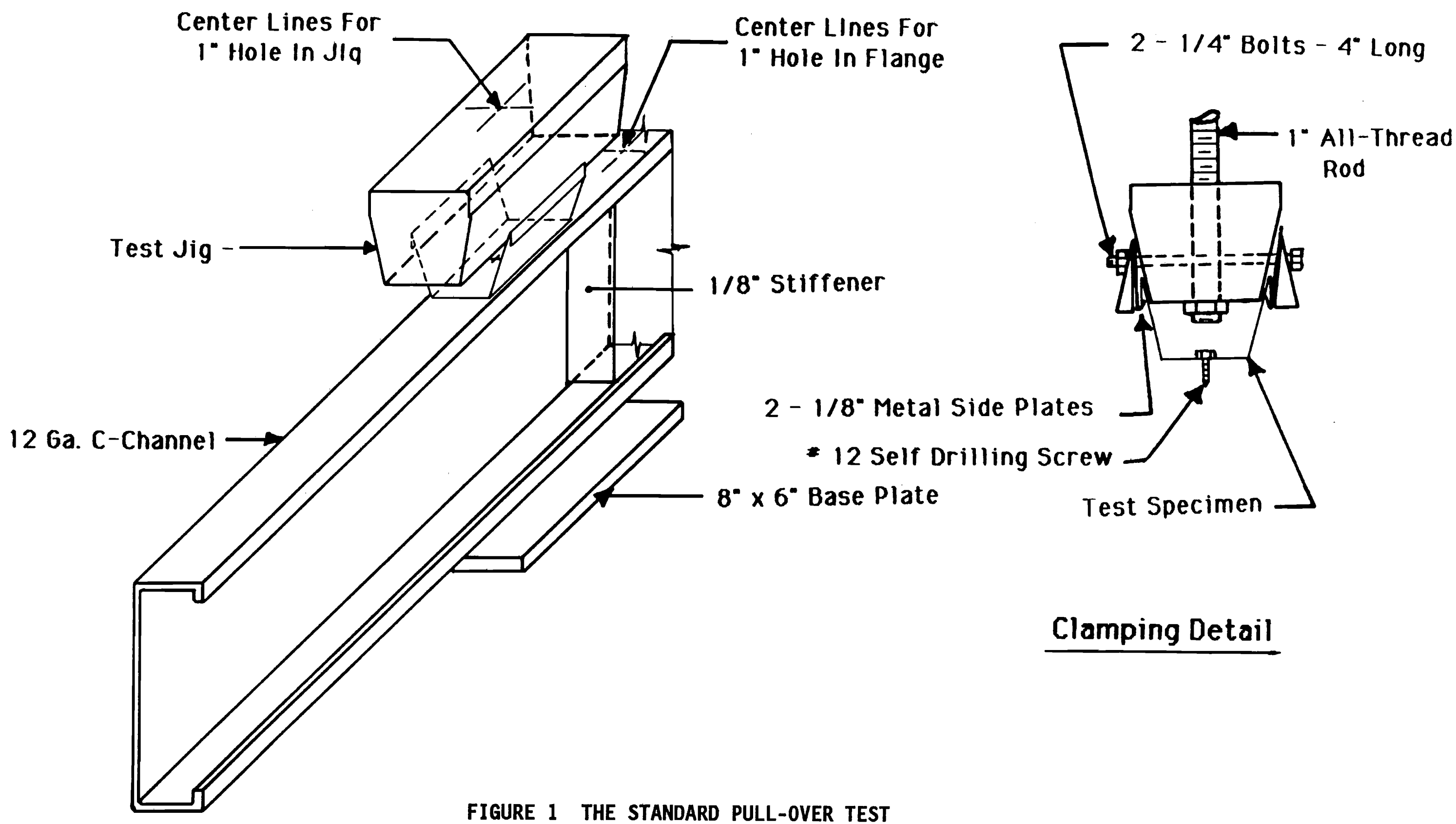

FIGURE 1 THE STANDARD PULL-OVER TEST

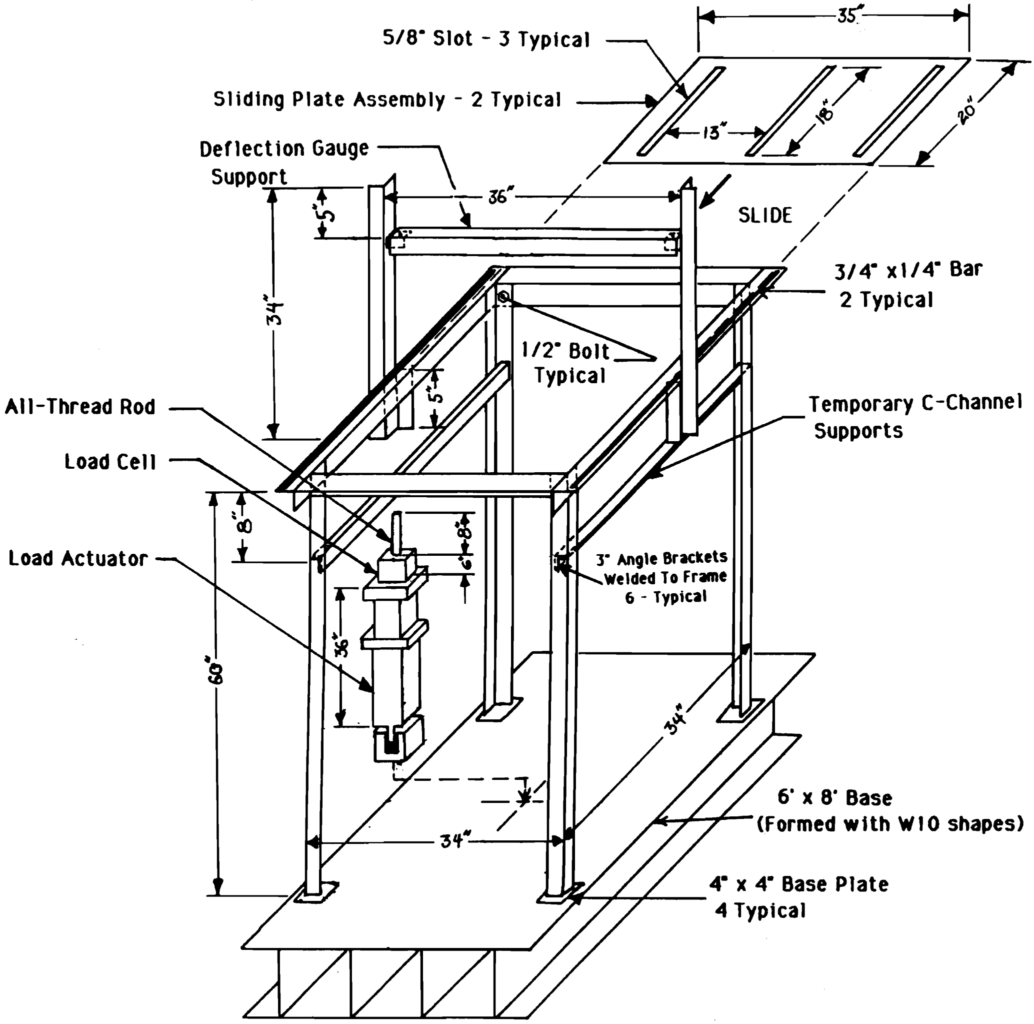

FIGURE 2 THE STATIC SUCTION PULL-OVER TEST FIXTURE

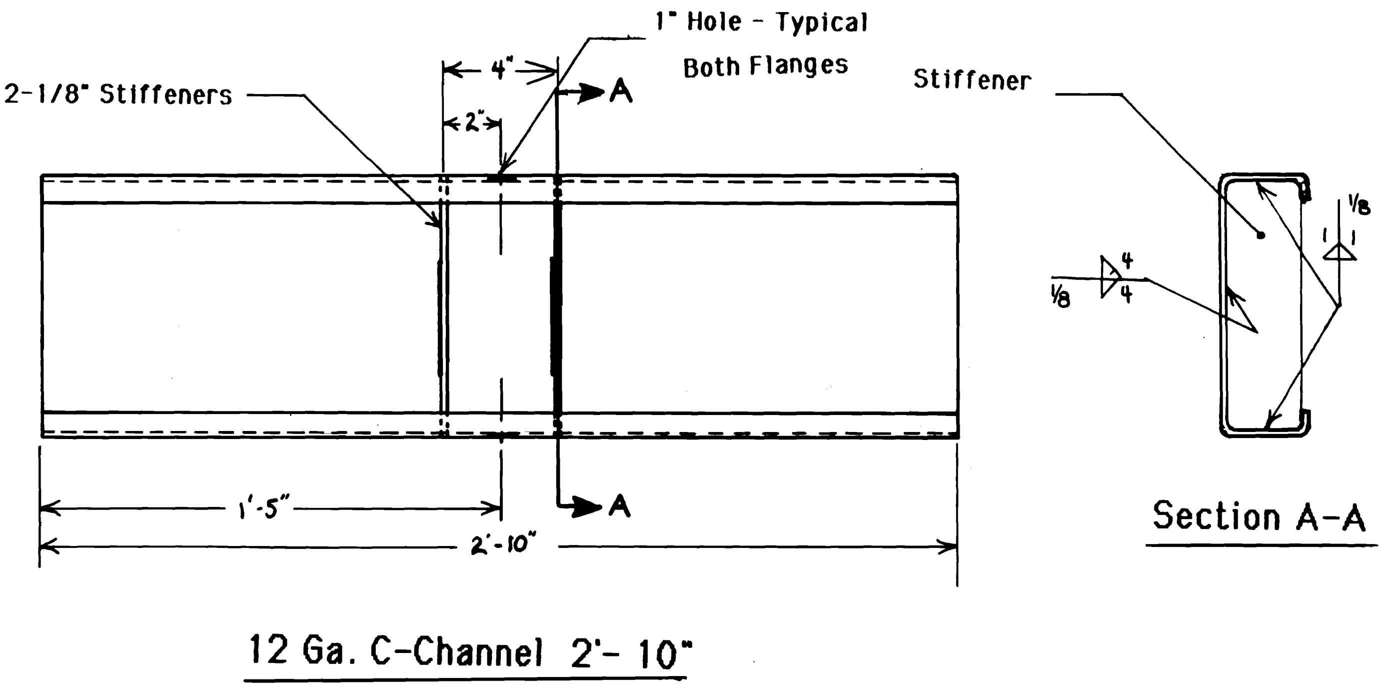

FIGURE 3 CHANNEL USED IN TESTS

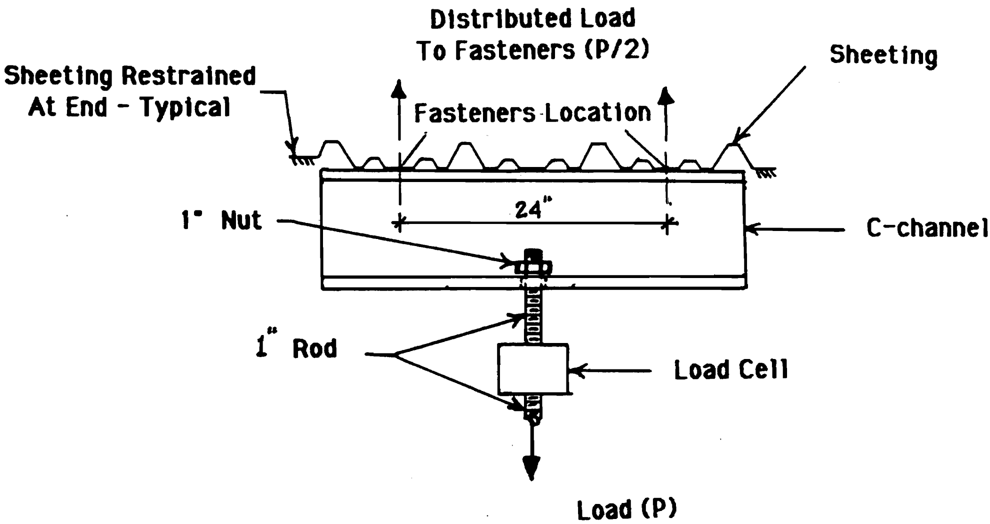

FIGURE 4 LOAD APPLICATION TO THE TEST SPECIMEN

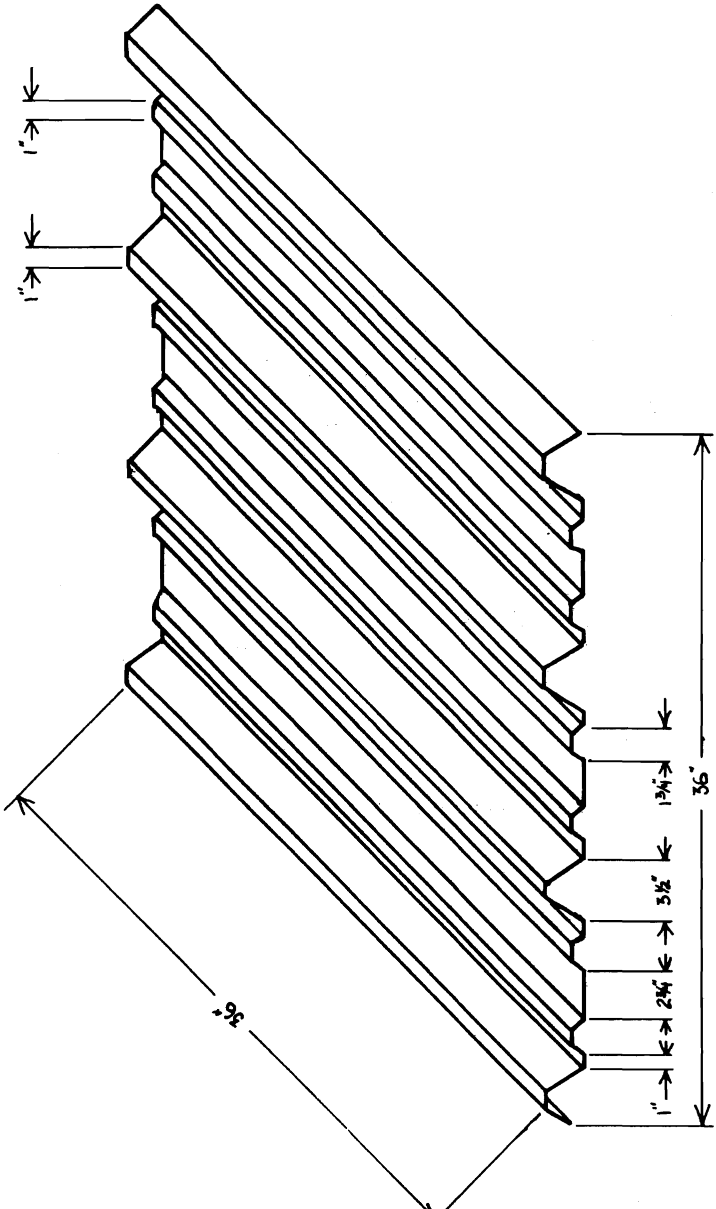

FIGURE 5 PANEL DIMENSIONS AND PROFILE

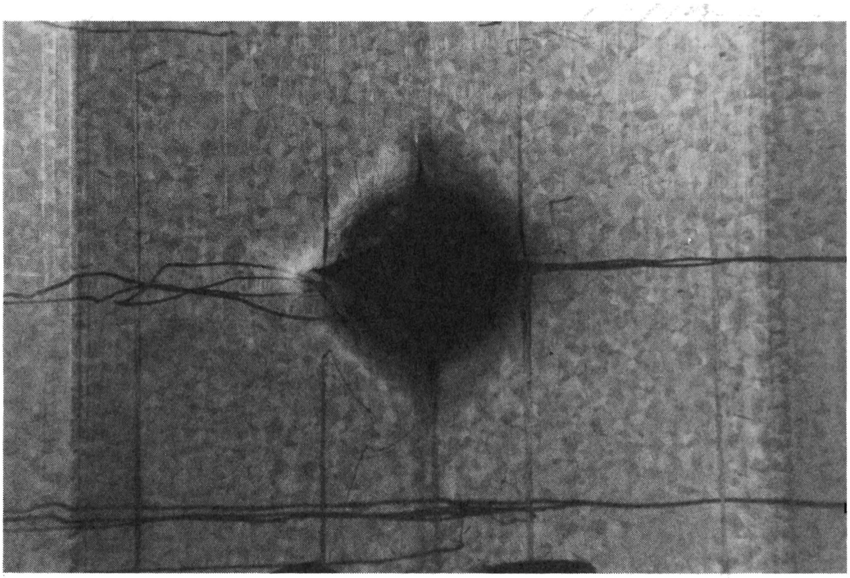

FIGURE 6 FAILURE PATTERN IN STATIC SUCTION TEST

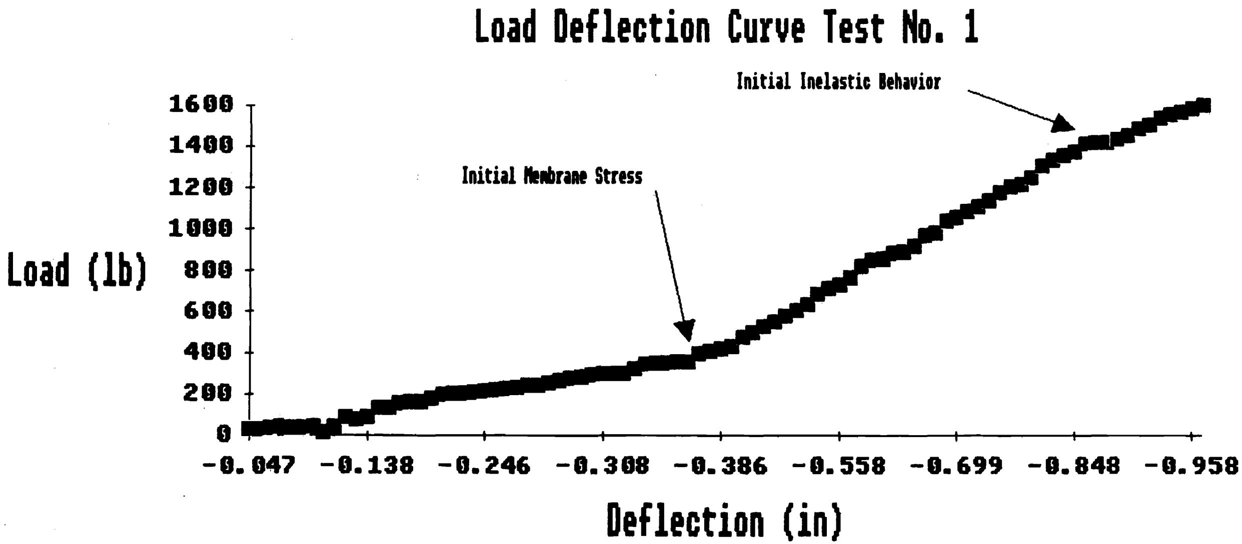

FIGURE 7 CHARACTERISTIC LOAD-DEFLECTION CURVE FOR STATIC SUCTION TEST

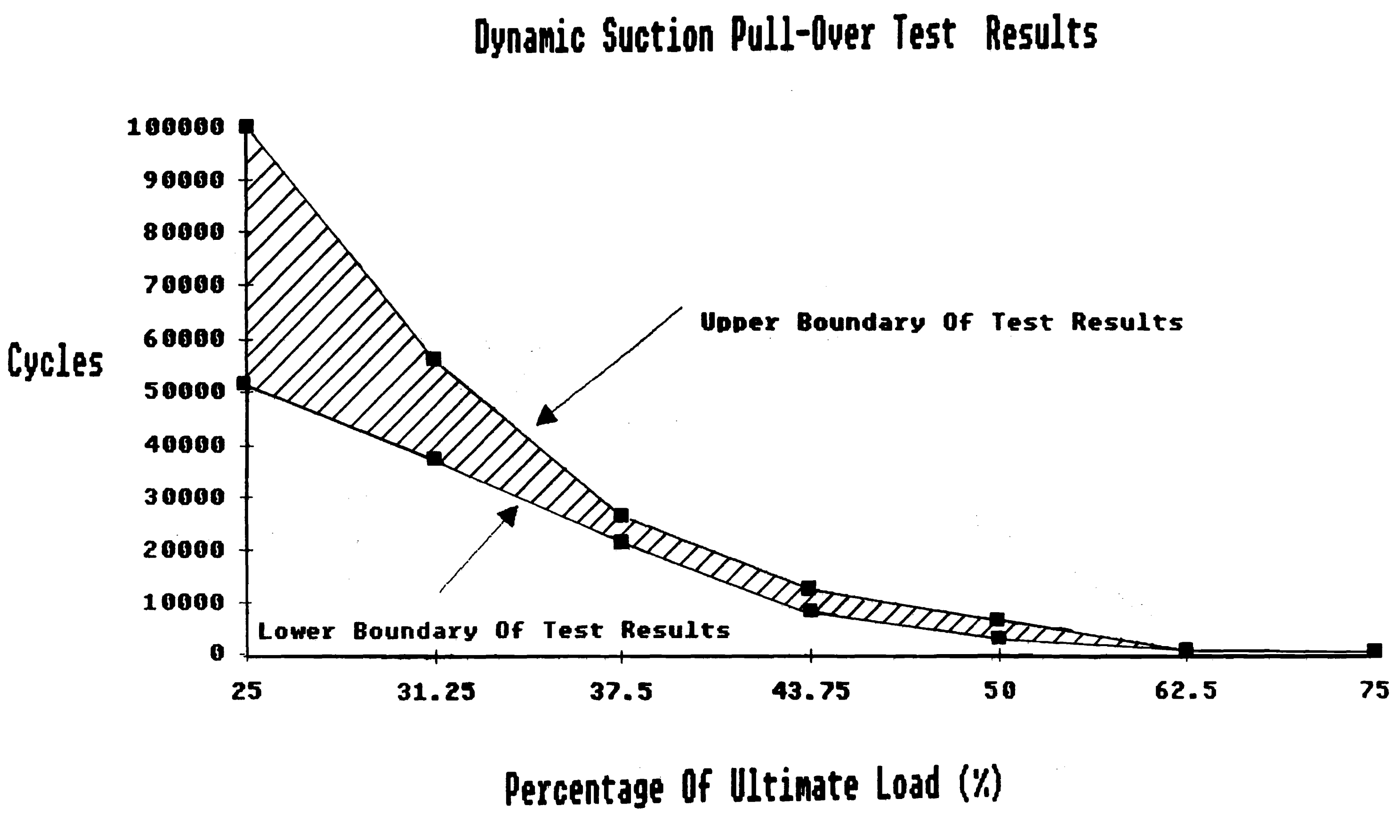

FIGURE 8 RESULTS OF DYNAMIC SUCTION PULL-OVER TESTS

TABLE 1 RESULTS OF STANDARD PULL-OVER TESTS

TEST NO.	LOAD (LB.)	% DEVIATION FROM MEAN
1	820	*
2	1740	11
3	950	*
4	1880	4
5	1640	16
6	2250	14
7	1680	14
8	1710	13
9	2170	10
10	1880	4
11	2180	11
12	2330	19
13	2120	8

AVERAGE = 1962
STDEV. = 254

NOTES: * indicates tests that have been omitted from the calculation of the average and standard deviation due to errors involved during testing.

TABLE 2 RESULTS OF STATIC SUCTION PULL-OVER TESTS

TEST NO.	TOTAL LOAD (LB)	LOAD PER FASTENER (LB)	% DEVIATION FROM MEAN	DEFLECTION OF LEFT FASTENER (IN)	DEFLECTION OF RIGHT FASTENER (IN)	LOAD RATE (LB/SEC)
A	1553	777	*	*	*	*
B	1400	700	*	*	*	*
C	1350	675	*	*	*	*
1	1599	800	2	.976	.976	17.8
2	1773	887	11	1.201	1.422	17.2
3	1686	843	7	.987	.970	24.8
4	1241	620	26	.774	.773	8.6
5	1637	819	4	.926	.931	12.6
6	1617	809	3	.965	.933	11.6
7	1652	826	5	.956	.876	14.9
8	1462	731	8	.887	.883	7.7
9	1501	751	5	.870	.887	8.8
10	1521	761	3	.937	.906	84.5
11	1515	757	3	.972	.918	7.3
AVERAGE =	1569	782				
STDEV. =	148	70				

NOTES:
1) * indicates tests that have been omitted from the calculation of the average and standard deviation due to errors involved during testing.
2) Deflections that are underlined represent the fastener that failed

TABLE 3 RESULTS OF DYNAMIC SUCTION PULL-OVER TESTS

TEST NO.	% ULTIMATE LOAD (%)	APPROX. LOAD RANGE (LB)	CYCLES To Failure
A	50	*	6000
1	75	50-1250	560
2	25	50-400	52,000
3	50	100-800	4520
4	50	100-800	6730
5	50	100-800	3040
6	37.5	100-600	26,520
7	25	100-400	89,440
8	25	100-400	100,000
9	31.25	100-500	56,280
10	31.25	100-500	37,800
11	37.5	100-600	21,820
12	62.5	100-1000	816
13	43.75	100-700	8720
14	43.75	100-700	12830

NOTES : * indicates test that is omitted from graphical representation due to inaccurate testing.