Light-Gage Metal Panel Deflections

Metal panels are a common component of curtainwall systems. These panels are sometimes used as exterior cladding material or interior covers for spandrel and shadowbox panels. The ability to achieve light weight, while maintaining the required deflections limits, is of a significant factor in the design of these panels. To attain this goal it is crucial to compute the in-service movements of these panel with a reasonable degree of accuracy. This study examines the appropriate methodology for the design of light-gage metal panels. The paper discusses the concept of large deflection analysis of thin plates, and presents numerical simulations to establish simplified relations for calculating panel peak deflections. Experimental tests have been conducted to complement the analytical work.

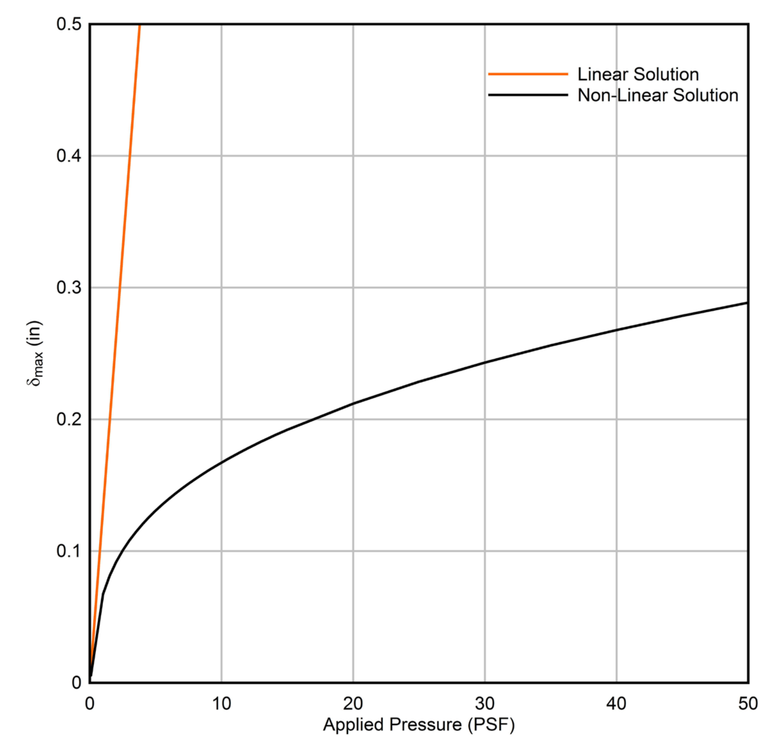

Figure 1. Peak displacement of a rectangular panel (3'-0" W x 5'-0"H), with a thickness of 3/32". The linear solution (show in orange) could significantly over estimate the peak displacement of the panel.

INTRODUCTION

Light-gage aluminum, stainless steel and galvanized steel metal panels can be used as the cladding component of some curtainwall units. They can be used as exterior spandrel barrier or a back-pan panel on the interior of units. They can be visually exposed or concealed within other structural elements.

The main parameter for the design of metal panels is the deflection limits. The required constraints are either controlled by visual considerations or interference requirements. These limits range from span / 60 in typical non-exposed conditions to span / 175 for highly visible plates.

In general linear plate deflection theory is inadequate to accurately predict the displacement of thin plates. Especially in cases where the plate deflection exceeds the plate thickness.

Figure 1 depicts the displacement response of a 3'-0" x 5'-0" aluminum plate with a thickness of 3/32". It can be seen that as the peak deflection exceeds the thickness of the plate (at about 2 pounds per square feet), the error increases by order of magnitude. At 10 PSF the computed deflection by linear theory is 8 times greater than the correct estimate.

COMPUTER SIMULATIONS

To be able to generate a simple analytical means to compute the non-linear plate deflection a series of parametric analysis are performed. In these studies the following parameters are set as variables:

1. Plate thickness
2. Plate aspect ratio
3. Applied pressure
4. Support condition

An empirical equation in the following form is considered as the proposed solution approximation:

$$d_{m1} = \left(a \; \square \; b e^{\square 3(\frac{b}{a})} \right) \sqrt[3]{\frac{a^4 p_c}{E_m t_m}}$$

Where:

a = Smaller of a and b dimension (inches)
b = Larger of a and b dimension(inches)
p_c = Applied pressure (psi)
E_m = Young's Modulus (psi)
t_m = Plate thickness (inches)
□,□ = Support condition coefficients

The objective of the parametric study is to determine the support condition coefficients, and evaluate the sensitivity of these coefficients to various loading conditions.

Figure 2 shows the peak displacement of a 3/32" aluminum plate for an applied load range of 0 to 80 pound per square feet, for a series of plates with aspect ratios ranging from 1.0 to 2.7. It is clear that as the plate becomes more rectangular (b/a > 1.5) the peak deflection becomes less sensitive to this parameter.

Figure 3 shows the same results both for simply supported case and fixed boundary conditions.

A parametric regression analysis indicates the following support condition coefficients:

	□	□
Simply Supported	**0.346**	**-1.25**
Fixed	**0.321**	**-1.21**

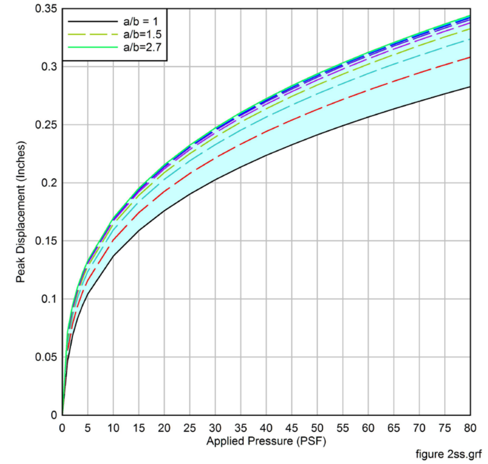

Figure 2. Effect of the plate aspect ratio on peak plate deflection.

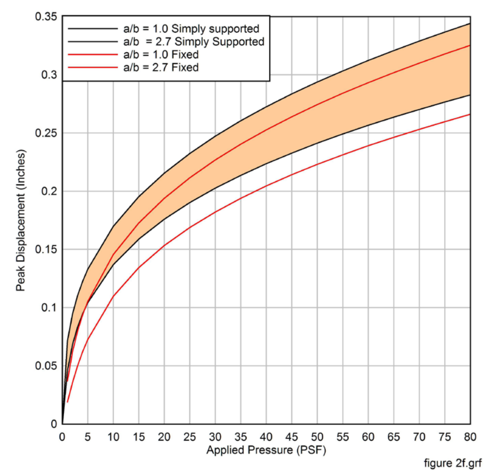

Figure 3. Effect of the plate support condition on the peak plate deflection.

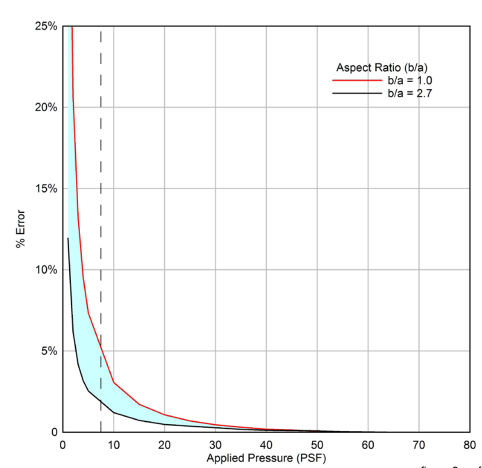

Figure 4. Error between the numerical simulation and the empirical equation for SS plate.

EXPERIMENTAL STUDY

To validate the above equation, an experimental analysis is proposed to measure the displacement of a set of metal panels as a function of the applied pressure. The test setup is presented in Figure 4.

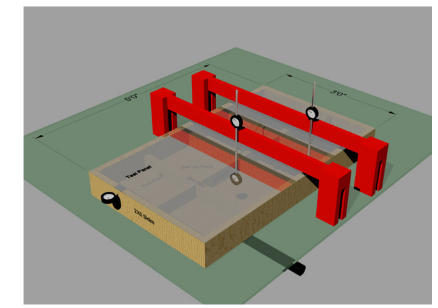
Figure 5. Schematic of test setup

The equipment consists of the following:

1. Chamber Box; this is a wooden box made of 2x6 side members with 2x4 internal ribs and ¾" plywood sheathing for the base (see figure 2). The test panels are mounted on the top of the box. The outside dimensions of the box are 5'-0" by 3'-0". The ribs attach to the base such that there is a 2-inch gap between the ribs and the bottom of the test panel. Silicone is applied at all the joints to achieve a hermetically sealed chamber.

2. Displacement Gages; at lease two displacement dial gages are attached to movable stands positioned at center and quarter-points of the test panel. It may be useful to add a third gage to measure the displacement at the longitudinal center line at a quarter-point as well. The resolution of the dial gages is ± 0.001" and the maximum travel is 1'-4".

3. Pump / Vacuum and Pressure Gage; a two directional pump is attached to the box to pump air into the camber (to mock negative pressure) or draw air from the chamber (to mock positive pressure). The pump should be able to generate up to 80 PSF of pressure inside the chamber.


Figure 6a. Flat Edge Condition; lay a 1-inch wide neoprene gasket (1/8" thick) along the four sides of the box. Secure the panel using 3/8" stainless steel self-taping screws on the corners and on 12" centers along the edges.

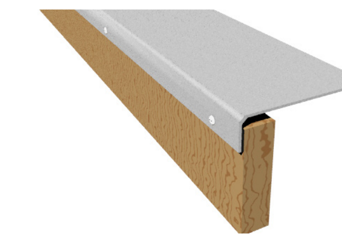
Figure 6b. Bent edge condition; use a bent edge of 1-½" on two or four sides of the panels (if using bent edge on only two sides, apply to the long sides). The bent radius is not to be less than two times the thickness of the material. Lay a 1-inch wide neoprene gasket (1/8" thick) along the four sides of the box. Secure the panel using 3/8" stainless steel self-taping screws on the corners and on 12" on center along the edges

TEST PROCEDURE

For each specimen above, follow this procedure:

1. Install the test panel.
2. Secure the edge condition.
3. Position the dial gage stands.
4. Place the dial gages.
5. Zero the dial gages.
6. Record the test information on a form as indicated in Figure 4 below.
7. Photo document the assembly.
8. Commence testing for positive panel pressure (vacuum mode in chamber).
9. Set the pressure to the value on the table and record the dial gage data (note; it is not possible to set the pressure at the value on the table; write the actual tested value next to the pressure column on the table).
10. Repeat step 5-9 for each of the positive panel pressure tests.
11. Repeat Step 5-9 for the negative panel pressure tests (positive pressure mode in chamber).

Table 1. Summary of test measurements

Material	Aluminum				Aluminum				Galvanized Metal		Galvanized Metal	
Connection Detail	Flat Structurally Glazed				Flat Fastened				4 Side - Folded Fastened		2 Side - Folded Fastened	
Gage	3/32	1/8	3/16	1/4	3/32	1/8	3/16	1/4	20 Gage	16 Gage	20 Gage	16 Gage
Thickness	0.0938	0.1250	0.1875	0.2500	0.0938	0.1250	0.1875	0.2500	0.0396	0.0635	0.0396	0.0635
Load	Deflection				Deflection				Deflection		Deflection	
-80	-1.430	-1.040	-0.690	-0.495	-0.980	-0.745	-0.405	-0.305	-0.880	-0.710	-0.680	-0.810
-75	-1.390	-1.005	-0.660	-0.472	-0.950	-0.720	-0.388	-0.290	-0.830	-0.685	-0.650	-0.780
-70	-1.340	-0.970	-0.640	-0.438	-0.920	-0.700	-0.370	-0.275	-0.800	-0.660	-0.620	-0.760
-65	-1.290	-0.930	-0.610	-0.415	-0.890	-0.670	-0.350	-0.255	-0.755	-0.625	-0.600	-0.740
-60	-1.247	-0.895	-0.580	-0.380	-0.860	-0.650	-0.330	-0.235	-0.720	-0.600	-0.570	-0.710
-55	-1.202	-0.860	-0.550	-0.354	-0.825	-0.615	-0.310	-0.220	-0.680	-0.560	-0.540	-0.690
-50	-1.157	-0.822	-0.520	-0.328	-0.795	-0.590	-0.285	-0.200	-0.630	-0.530	-0.510	-0.660
-45	-1.112	-0.780	-0.485	-0.300	-0.755	-0.555	-0.260	-0.180	-0.590	-0.500	-0.470	-0.630
-40	-1.055	-0.735	-0.450	-0.266	-0.710	-0.520	-0.235	-0.160	-0.540	-0.465	-0.435	-0.590
-35	-1.007	-0.690	-0.415	-0.246	-0.675	-0.490	-0.215	-0.140	-0.500	-0.420	-0.400	-0.560
-30	-0.950	-0.642	-0.375	-0.212	-0.630	-0.450	-0.195	-0.120	-0.460	-0.385	-0.365	-0.530
-25	-0.882	-0.585	-0.330	-0.180	-0.575	-0.410	-0.165	-0.100	-0.410	-0.345	-0.320	-0.490
-20	-0.812	-0.525	-0.280	-0.150	-0.525	-0.360	-0.135	-0.080	-0.355	-0.295	-0.280	-0.440
-15	-0.720	-0.452	-0.225	-0.112	-0.460	-0.300	-0.110	-0.060	-0.290	-0.240	-0.230	-0.380
-10	-0.600	-0.352	-0.155	-0.075	-0.390	-0.225	-0.070	-0.040	-0.220	-0.185	-0.130	-0.310
-5	-0.445	-0.215	-0.085	-0.040	-0.280	-0.120	-0.040	-0.020	-0.115	-0.110	-0.110	-0.200
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.185	0.160	0.082	0.040	0.170	0.085	0.045	0.020	0.110	0.120	0.520	0.140
10	0.300	0.260	0.151	0.082	0.270	0.145	0.085	0.040	0.180	0.190	0.860	0.220
15	0.390	0.335	0.215	0.115	0.340	0.195	0.130	0.060	0.235	0.250	0.990	0.280
20	0.417	0.412	0.269	0.153	0.400	0.240	0.170	0.080	0.280	0.305	1.060	0.330
25	0.530	0.460	0.318	0.189	0.450	0.280	0.215	0.100	0.320	0.345	1.120	0.370
30	0.590	0.502	0.357	0.220	0.490	0.315	0.250	0.120	0.355	0.380	1.160	0.410
35	0.640	0.549	0.390	0.248	0.530	0.345	0.285	0.140	0.390	0.405	1.200	0.440
40	0.680	0.580	0.419	0.270	0.560	0.375	0.315	0.160	0.420	0.435	1.240	0.470
45	0.732	0.619	0.457	0.300	0.600	0.405	0.360	0.180	0.455	0.470	1.270	0.510
50	0.775	0.655	0.487	0.328	0.630	0.440	0.390	0.200	0.500	0.495	1.310	0.540
55	0.815	0.687	0.515	0.350	0.655	0.460	0.420	0.220	0.530	0.520	1.340	0.570
60	0.855	0.720	0.542	0.375	0.680	0.490	0.450	0.240	0.565	0.545	1.370	0.590
65	0.885	0.750	0.569	0.400	0.705	0.515	0.475	0.260	0.590	0.565	1.390	0.620
70	0.925	0.780	0.594	0.420	0.730	0.540	0.500	0.280	0.625	0.580	1.420	0.640
75	0.913	0.810	0.619	0.440	0.750	0.560	0.525	0.300	0.655	0.605	1.440	0.670
80	1.002	0.840	0.644	0.460	0.775	0.580	0.550	0.315	0.680	0.625	1.470	0.690

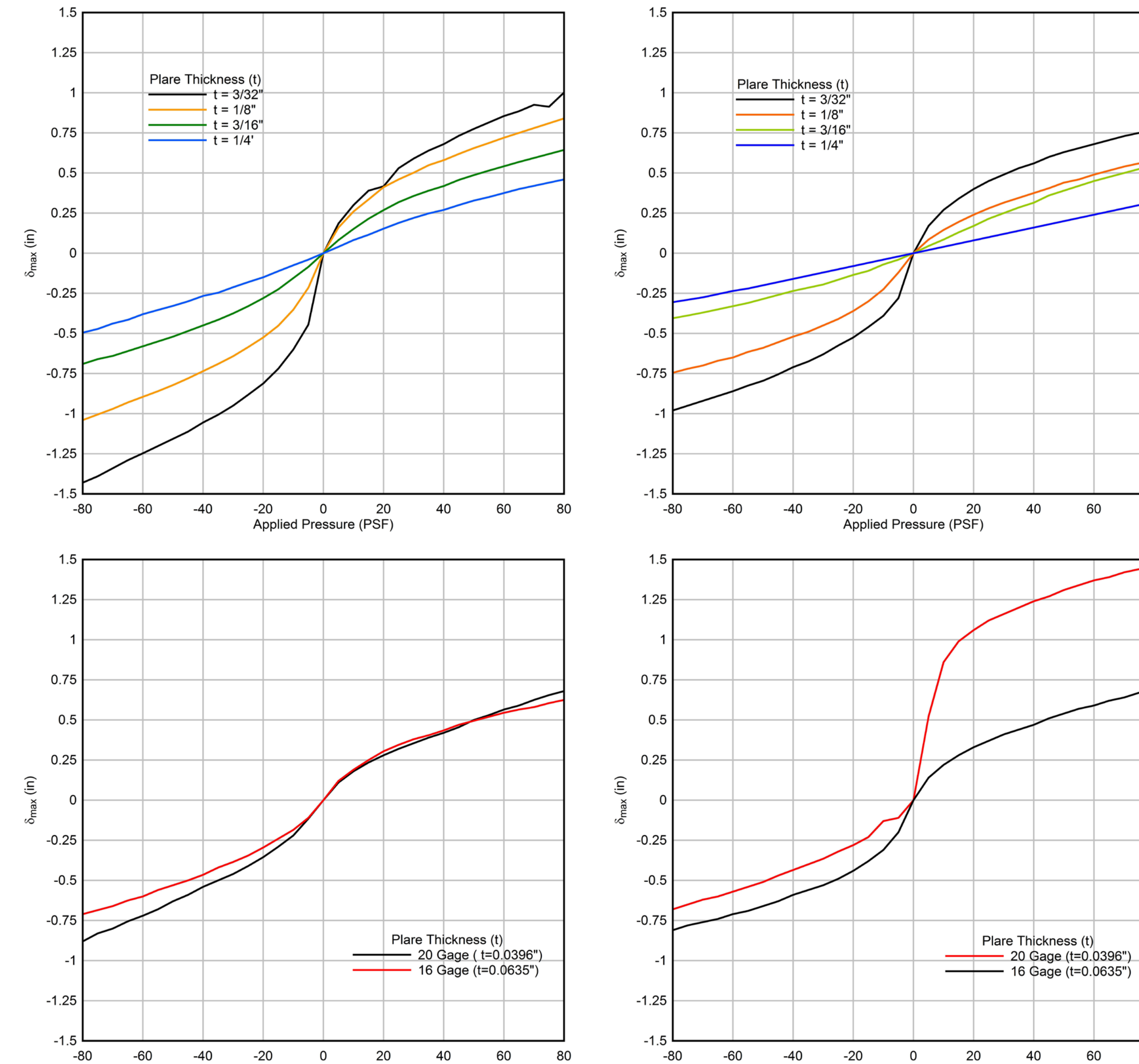

Figure 7. Plot of deflected shapes or various material and boundary conditions. (Top-Left), Silicone sealed flat aluminum plate, (Top Right) Flat-fixed screws with aluminum plates, (Bottom-Left) 4-sided folded fastened galvanized sheet metal, (Bottom-Right) 2-sided folded fastened galvanized sheet metal

CONCLUSIONS

Table 1 summarizes the measurement data from the test samples. The data is then plotted in graphs of Figure 7. From these results and comparisons to the analytical studies it is clear that the shape of the displacement response follows very closely.

However there is not a good corroboration between the measured data and the computer simulations. The results some times vary as much of 80%. It can be concluded that this disparity is due to accurate simulation of boundary conditions. It is possible to use the experimental data to compute the support coefficients. However additional testing is required to gain additional confidence in the collected data.