Advanced Building System

M2 EMMEDUE
Advanced Building System

PANAMA TECHNOLOGY UNIVERSITY
ENGINEERING EXPERIMENT CENTRE
Research and development laboratory

REPORT No. CEI-07-798-2003

Experimental tests on the sample ofl
Panel System type PSM60 and PSM80 by Emmedue

For: ITALPAN, S.A.

Presented by:

Dr. Oscar M. Ramírez
Lic. No.-85/006/014
Director

Panama, September 5th, 2003

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CENTRO EXPERIMENTAL DE INGENIERIA

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EXPERIMENTAL TESTS REALIZED ON THE SAMPLE PANEL SYSTEM, TYPE PSM 60 AND PSM 80

September 05, 2003

1. Scope

This analysis aims at defining experimentally if the structural panel system PSM 60 and PSM 80, tested at CEI upon request of ITALPAN S.A., complies with the requirements of the Panama Structural Regulation (REP-94) as for the use of alternative systems used to construct small-sized houses.

2. Introduction

The REP-94 Panama Structural Regulation, in its section 6.6 concerning alternative systems, defines the following:

"Building systems different from the traditional building defined at section 6.4 can be used on condition that it is proved, by analysis and experimental tests, that the resistance of the alternative systems to gravity, wind and earthquakes is at least equivalent to that of traditional building".

The PSM 60 and PSM 80 panel system (then named as "M2 panels" in this document) is classified as an alternative building system in Panama, and for that reason it has to undergo experimental tests as provided for by REP-94. Then the results of the experimental tests carried out by the Technology University of Panama will be described and submitted; thanks to these, the capacity of the M2 panel system has been determined. The experimental tests executed have been the following:

- Tests executed on single elements (panels and connections)
  - Level shearing test
  - Compression test
  - Bending test
  - Connection test
- Test executed on a model structure (real scale)
  - Lateral load test

2.1 Panel characteristics

The M2 panel presents itself with different denominations and a typical configuration, but with variations of dimensions of the section. The illustration 2.1 shows a diagram of the panel section and the Table 2.1 contains the relevant dimensions of each panel.

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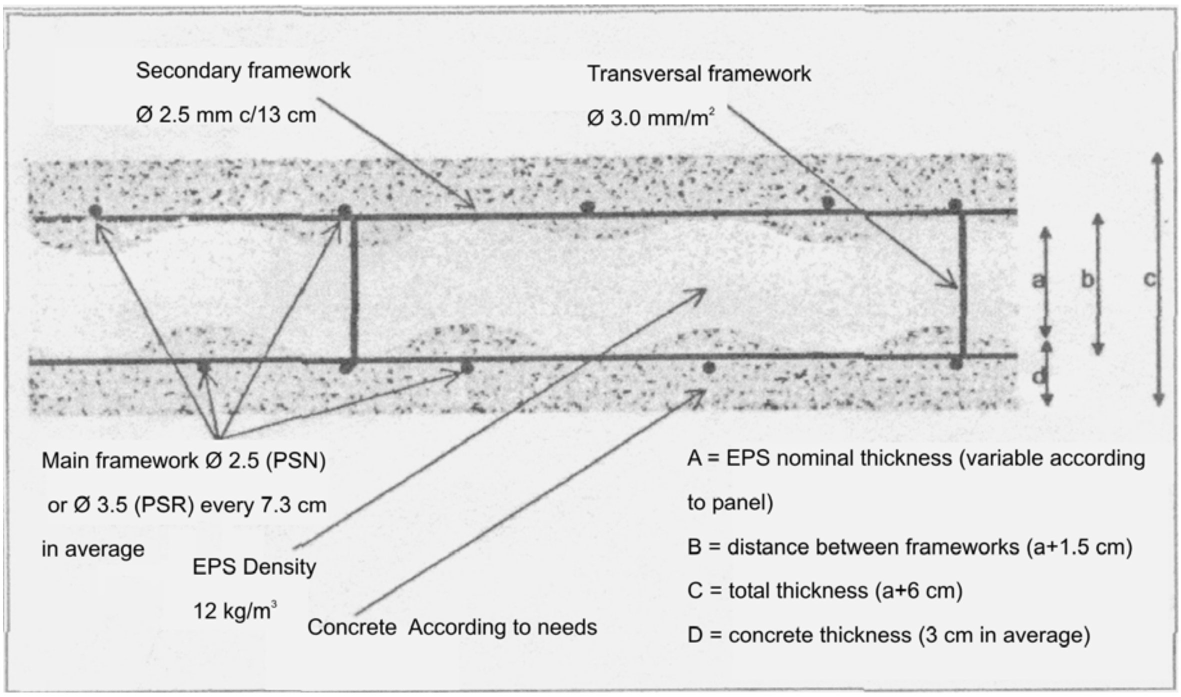

Ilustration 2.1 – M2 panel section

Table 2.1 *– Different types of panel dimensions*

PANEL TYPE	**a* (mm)**	**b* (mm)**	**c* (mm)**
PSN6O	60	75	120
PSN80	80	95	140

* See illustration 2.1

The panel has a section of polystyrene, steel and cement mortar as shown in the illustration 2.1. The structural capacity of the panel is given by concrete and steel. The panel reinforcement consists of two electrowelded steel meshes formed by 2.5 diameter steel wires with horizontal space of 62 mm and vertical space of 67 mm. According to specifications these meshes have an ultimate resistance to tensile stress of 600 MPA (6100 kg/cm^2). The concrete will be 30 mm thick on each face of the panel and its resistance will depend on the mix used for each work.
Numerous denominations exist for this type of panels. Below are shown other names used for the tested panels.

Name used in this document	Equivalent names
PSM 60	PSME 60, PSM 60
PSM 80	PSME 80, PSM 80

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3. Experimental tests

3.1 Tests on the elements (Panels and connections)

The tests on single elements will be made on samples of panels and connections; shearing, bending and compression tests have been executed. In order to verify the panel capacity, 3 modules have been tested for each testing – 1.11 m (3.64 feet) wide, 2.4 m (7.87 feet) high – as for the panels of the PSM 60 and PSM 80 type. The panels have been roughed in on both faces up to the average thickness of 115 mm (4.53 inches) as for the PSM 60 panel, and 135 mm (5.31 inches) as for the PSM 80 panel. The tests have been realized according to the ASTM- E-72 regulation.

3.1.1 Shearing tests on PSM 60 and PSM 80 panels

This test is documented by the Report No. 02-798E-2003 and No. 02-798F-2003 (see Appendix A). The cement mortar used for the panel rough coat has had an average resistance of 119 kg/cm^2 (1696 lbs/inches^2) after 28 days. The load has been applied by means of an hydraulic jack with loading gauge equal to 2721.5 kg (6000 lbs) on one end of the panel, keeping the other end fixed (see illustration 3.1). The tables 3.1 and 3.2 show the results obtained and the illustrations 3.3 and 3.4 show the load-strain diagram for each tested panel. The illustration 3.2 shows the panel at test completion.

The behaviour of the PSM 60 panels during this test can be summarized as follows:

- The panel 1 has begun to crack under a load of 3175.18 kg (7000 lbs). The defect of cement mortar due to disjunction is evident while the mesh begins to yield because of stress on the whole width on the panel close to the connection of the fixed end.
- As for the panel 2, the first crack has appeared under a load of 2948.38 kg (6500 lbs), 7.62 cm (3 inches) from the connection fixing. The second crack appears 1.01 m (40 inches) from the connection under a load of 3175.18 kg (7000 lbs), where the defect of cement mortar is evident; in fact, the disjunction of the latter, the separation by tension of the mesh at the fixed end and the continuation of the first crack on the whole width of the panel can be noticed.
- As for the panel 3, the first crack appears 43.2 cm (17 inches) and 86.4 cm (34 inches) from the connection, under a load of 3401.38 kg (7500 lbs) with disjunction of the cement mortar, yielding of the mesh by tension and separation of the same mesh from the fixed end.

On the other hand the PSM 80 panel has put the following behaviour into evidence:

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- The panel 1 has begun to crack under a load of 2948.38 kg (6500 lbs). The defect of the cement mortar by disjunction is evident while the mesh begins to yield by tension on the whole width of the panel close to the connection of the fixed end.
- As for the panel 2, the first crack has appeared under a load of 2721.58 kg (6000 lbs), 7.62 cm (3 inches) from the connection fixing. The second crack appears 1.01 m (40 inches) from the base under a load of 2948.38 kg (7500 lbs), where the defect of the cement mortar is evident; in fact, the disjunction of the latter, the separation by tension of the mesh at the fixed end and the continuation of the first crack on the whole width of the panel can be noticed.
- As for the panel 3, the first crack appears close to the connection under a load of 3175.18 kg (7000 lbs) with disjunction of the cement mortar, yielding of the mesh by tension and separation of the same mesh from the fixed end. The second crack is 13 cm (34 inches) from the bearing applying a load of 3041.98 kg (7500 lbs).

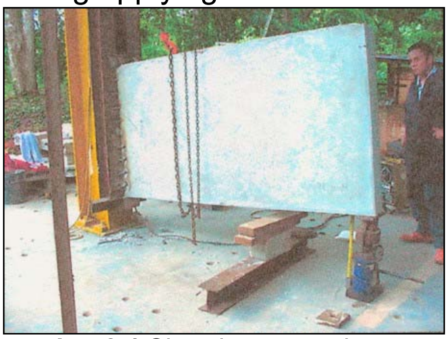

Illustration 3.1. Shearing strength test on panel

Table 3.1 Results obtained by the shearing test as for PSM 60 panels

Metric System				**Anglo-Saxon System**			
Load	**Strains**			**Load**	**Strains**		
	Panel 1	Panel 2	Panel 3		Panel 1	Panel 2	Panel 3
Kg	cm	cm	cm	lb	plg	plg	plg
0	0	0	0	0	0	0	0
453,60	0,160	0,100	0,160	1 000	0,063	0,040	0,063
680,39	0,200	0,200	0,240	1 500	0,079	0,079	0,094
907,19	0,320	0,330	0,320	2 000	0,126	0,130	0,126
1134,00	0,500	0,400	0,480	2 500	0,197	0,157	0,189
1360,50	0,635	0,500	0,640	3 000	0,250	0,197	0,252
1587,59	1,590	0,800	0,950	3 500	0,626	0,315	0,374
1814,39	1,900	1,300	1,600	4 000	0,748	0,512	0,630
2041,19	2,060	2,100	1,750	4 500	0,813	0,827	0,689
2267,99	2,300	2,700	1,900	5 000	0,906	1,063	0,748
2494,78	2,380	3,000	2,060	5 500	0,938	1,181	0,811
2721,58	2,540	3,500	2,220	6 000	1,000	1,378	0,874
2948,38	2,700	3,600	2,380	6 500	1,063	1,417	0,937
3175,18	3,600	4,000	2,860	7 000	1,417	1,575	1,126
3401,98			3,500	7 500			1,375

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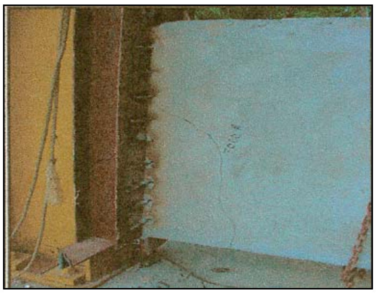
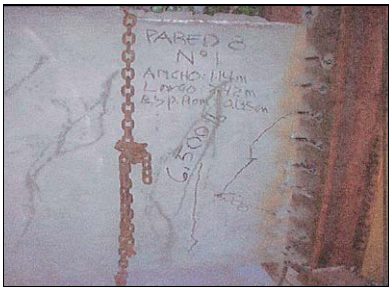
Table 3.2 Results obtained by the shearing strength test for PSM 80 panels

Metric System				Anglo-Saxon System			
Load	Strains			Load	Strains		
	Panel 1	Panel 2	Panel 3		Panel 1	Panel 2	Panei 3
Kg	cm	cm	cm	lb	plg	plg	plg
0	0	0	0	0	0	0	0
453,60	0	0	0	1000	0	0	0
680,39	0	0	0	1500	0	0	0
907,19	0,099	0,099	0,099	2 000	0,039	0,039	0,039
1134,00	0,201	0,248	0,150	2 500	0,079	0,098	0,059
1 360,50	0,500	0,800	0,299	3000	0,197	0,3 15	0,118
1 587,59	0,899	1,199	0,500	3 500	0,354	0,472	0,197
1814,39	1,300	1,801	1,000	4000	0,512	0,709	0,394
2 041,19	1,600	2,400	1,199	4 500	0,630	0,945	0,472
2 267,99	1,999	3,099	1,699	5 000	0,787	1,220	0,669
2 494,78	2,400	3,299	1,999	5 500	0,945	1,299	0,787
2721,58	2,700	3,599	2,298	6000	1,063	1,417	0,905
2948,38	3,200	4,200	2,601	6 500	1,260	1,653	1,024
3175,18			3,200	7000			1,260
3 401,98			3,500	7 500			1,378



a) Panel Type PSM60



b) Panel Type PSM80

Illustration 3.2 Panel shearing defects

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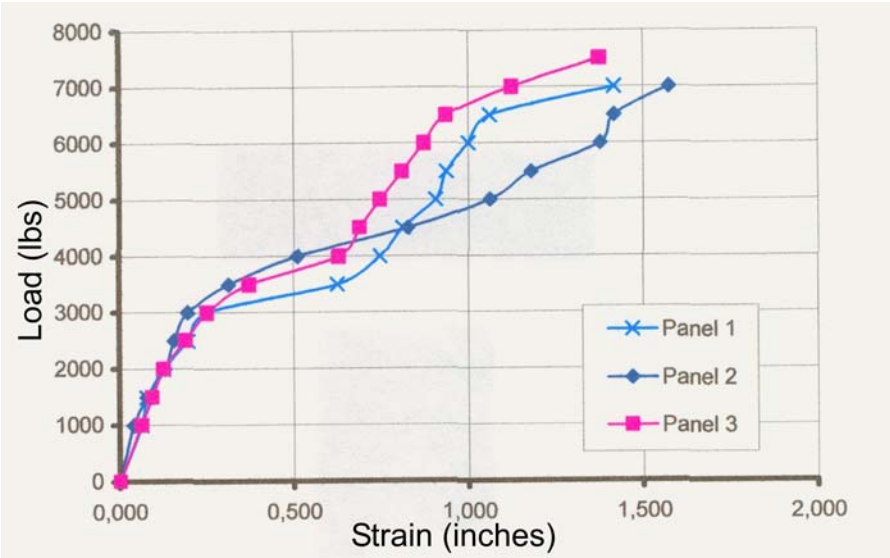

Illustration 3.3 – Load-Strain diagram for the shearing test of the PSM 60 panels

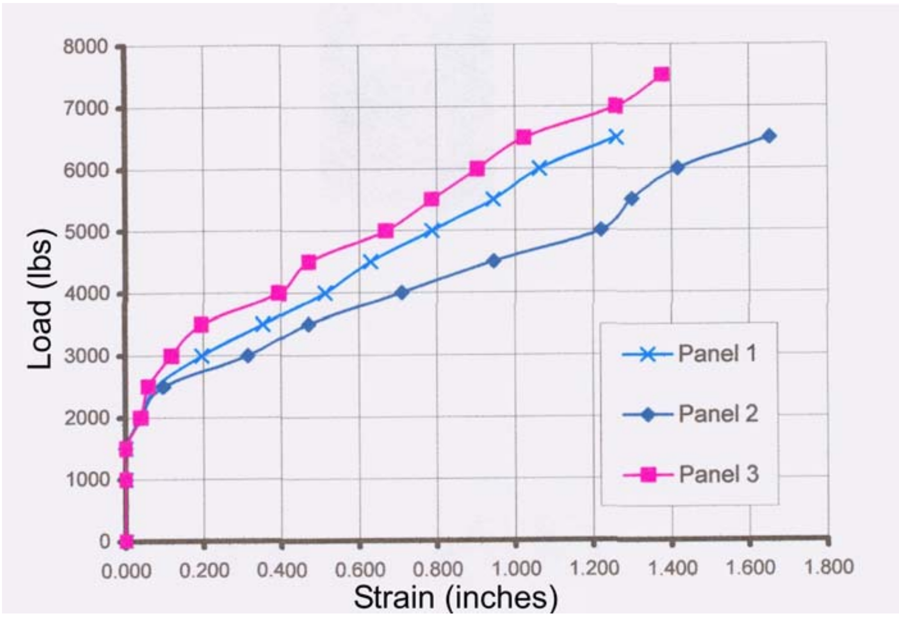

Illustration 3.4 – Load-Strain diagram for the shearing test of the PSM 60 panels

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With the results of this test, the following shearing stress can be proposed for an area with acceptable thickness:

$$\tau_{allowable} = \frac{V}{A_g}\frac{1}{FS}$$

where:
V: shearing strength of the panel in the elastic range
FS: safety factor
A_g: thick area of the panel concrete walls, then calculated:

A_g = 111 cm x 6 cm = 666 cm^2

With reference to the strain shearing, a value equal to 1134 kg (2500 lbs) is proposed as representative value for both panels; the allowable shearing stress is consequently calculated as follows:

$$\tau_{allowable} = \frac{1134kg}{666cm^2}\frac{1}{1.5} = 1.14kg/cm^2$$

3.1.2 Compression strength test of the PSM 60 and PSM 80 panels

Compression strength tests have been executed on the PSM 60 and PSM 80 panels; these tests are documented in the report No. 02-798 H 2003 (see Appendix A).

After 28 days the rough-in cement mortar of the panels has obtained compression strength equal to 119 kg/cm^2 (1696 pounds/inches^2) on one of the faces and 2429 pounds/inches^2 on the second face, for an average of 145 kg/cm^2 (2062 pounds/inches^2). The load has been applied by means of an hydraulic jack with load gauge of 27215.5 kg (60000 lbs) distributed on the shorter cross section of the panel. As for testing, an axial load parallel to the longest dimension of the panel has been applied (see illustrations 3.5 and 3.6). Thanks to this mechanism, it has been possible to register a load of 24948 kg (55000 lbs), trying to measure the strains perpendicular to the plane.

Table 3.3 – Results of the panel compression test

Sample	Thickness	Strain	Load		Remarks
	cm	cm	Kg	Pounds	
PSM6O-1	6	0	24 947,84	55 000	No deformations perpendicular to the plane.
PSM6O-2	6	0	24 947,84	55 000	
PSM6O-3	6	0	24 947,84	55 000	
PSM8O-1	8	0,1	24 947,84	55 000	Slight deformations perpendicular to the plane.
PSM8O-2	8	0,2	24 947,84	55 000	
PSM8O-3	8	0,2	24 947,84	55 000	

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Illustration 3.5 – Panel, perimeter wire and rule for displaying of the strain by compression.

Illustration 3.6 – Application of axial load on the panel.

3.1.3 Bending strength test on PSM 60 and PSM 80 panels with span of 2.13 m (7 feet)

The bending strength test has been documented in the report No. 02-798C-2003 and No. 02-798D-2003 (see Appendix A). The panels have been roughed in with cement mortar with average resistance of 119 kg/cm^2 (1696 pounds/inches^2) after 28 days.

The load has been applied by means of an hydraulic jack with load gauge of 27215.5 kg (60000 pounds), adding the load due to instruments. The load applied to L/2 has been distributed by means of a steel element, with "C" section, to two elements placed at L/4 of each panel side. These two elements, each of which is welded to one solid bar – 1 inch Ø and long as the width of the panel – have distributed the load as requested by the regulation (see illustration 3.10).

Two measurers have been placed on both faces at the centre of the panel in order to verify the deflection from the beginning of each load. The data obtained have been inserted in two load– strain diagrams per tested panel, considering an average between the two deflections taken by both measurers (ill. 3.7 and 3.8).

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***Table 3.4** – Results of the flexural strength test on the PSM 60 panels*

Load applied by the jack		Total load jack + P_0	Deflections, inches x E-3		
Pounds	kg	Pounds	Panel 1	Panel 2	Panel 3
0	0	0	0	0	0
0	108,86	240	0	56,0	30,0
0	164,20	362	0	71,5	33,5
0	176,45	399	8,4	101,0	43,0
500	407,78	899	10,5	109,0	46,5
000	634,58	1 399	20,5	132,0	56,0
500	861,38	1 899	40,0	175,5	64,0
2 000	1 088,18	2 399	42,5	268,0	98,5
2 500	314,98	2 899	44,5	369,5	165,0
3 000	541,78	3 399	54,0	488,5	306,0
3 500	768,57	3 899	62,5	615,5	382,0
4 000	1 995,37	4 399	106,0	704,5	635,0
4 500	2 222,17	4 899	300,0	777,0	730,5
5 000	2 448,97	5 399	360,0		
5 500	2 675,77	5 899	830,0		
6 000	2 902,57	6 399			
6 500	3 129,36	6 899			
7 000	3 356,16	7 399	Breaking	Breaking	
7 500	3 582,96	7 899			Breaking

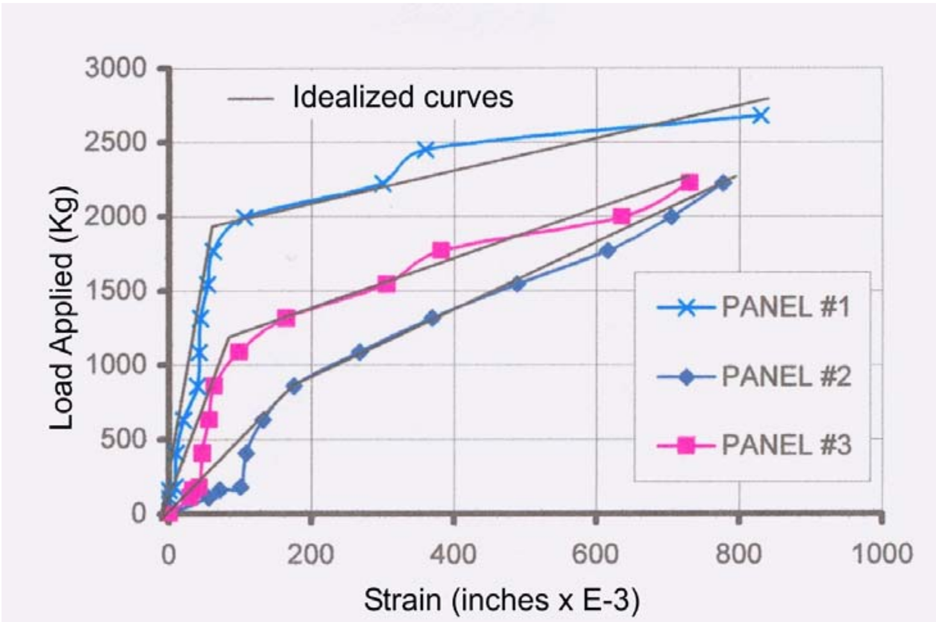

Illustration 3.7 – Load – strain diagram for the PSM 60 panel undergoing bending

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Table 3.5 – *Results of the flexural strength test on the PSM 80 panels.*

Load applied by the jack		Total load jack + Po	Deflections, inches x E-3		
lb	kg	lb	Panel 1	Panel 2	Panel 3
0	0	0	0	0	0
0	108,86	240	26,0	11,5	19,0
0	164,20	362	33,0	15,5	23,0
0	180,98	399	38,5	18,5	29,0
500	407,78	899	42,0	23,0	30,0
1 000	634,58	399	47,0	25,0	32,0
1 500	861,38	899	49,5	28,0	34,0
2 000	1 088,18	2 399	5755	44,5	36,0
2 500	1 314,98	2 899	89,0	76,0	38,0
3 000	541,78	3 399	155,5	109,0	52,0
3 500	768,57	3 899	224,5	147,5	71,5
4 000	995,37	4 399	264,5	196,5	100,5
4 500	2 222,17	4 899	289,0	265,5	138,5
5 000	2 448,97	5 399	331,0	317,5	194,0
5 500	2 675,77	5 899	381,5	401,0	242,5
6 000	2 902,57	6 399	460,5	511,5	300,0
6 500	3 129,36	6 899	541,0	572,0	387,5
7 000	3 356,16	7 399	640,0	664,5	453,0
7 500	3 582,%	7 899	Breaking	806,5	611,5
8 000	3 809,76	8 399			721,0
8 500	4 036,56	8 899			Breaking
9 000	4 263,36	9 399		Breaking	

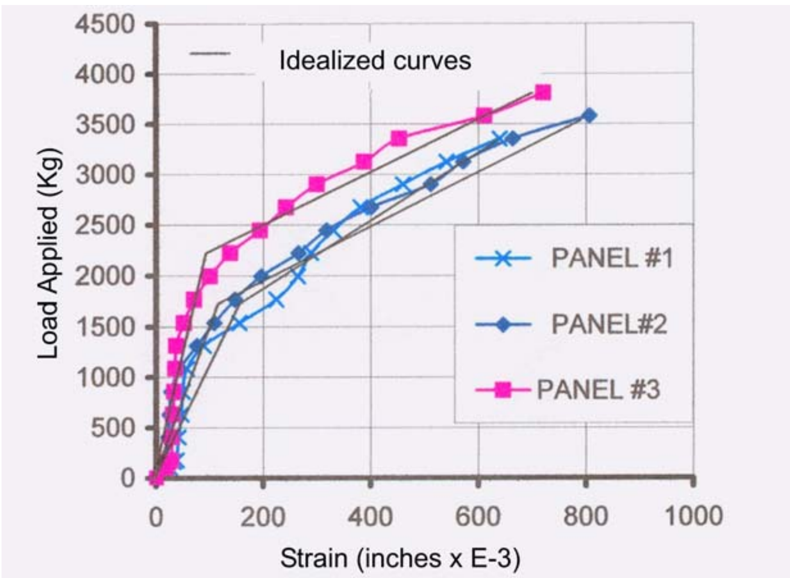

Illustration 3.8 – Load – strain diagram for the PSM 80 panel undergoing bending

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The moment due to external forces corresponding to the panel is defined as follows:

$$M = \frac{P \times L}{8}$$

where P is the applied load and L is the panel length between bearings. The moment per unit of length is obtained dividing the moment by the width of the same, that is:

$$M_{unitary} = \frac{P \times L}{8 \times b}$$

In the illustrations 3.7 and 3.8 the idealized behaviour proposed for the panels undergoing bending is shown, where a point of strain is proposed. In the table 3.6 are shown the values of the moment at the elastic limit and the maximum moment defined with the previous formula.

***Table 3.6** – Maximum flexural capacity registered by the panels, with span of 2.13 m (7 feet).*

Sample	Thickness	Elastic limit		Maximum capacity	
	Cm	Load (kg)	Moment (kg-m/m)	Cm	Load (kg)
PSM60-1	6	1815	436	3356,16	807
PSM60-2	6	910	218	3356,16	807
PSM60-3	6	1 245	300	3 582,96	861
PSM80-1	8	1 815	436	3 582,96	861
PSM80-2	8	1 815	436	4 263,36	1 025
PSM80-3	8	2 270	545	4 036,56	970

An important parameter for the design phase is the strain stress σ_y for the flexural behaviour.
This stress can be associated to the strain moment M_y in this way:

$$\sigma_y = \frac{M_y C}{I}$$

where

- C: distance of the neutral axis from the farthest end
- M_y: strain moment
- I: moment of inertia of the panel section

Panel PSM 60

$$I = 2x\left[\frac{(30mm)^2 x1000mm}{12} + (45mm)^2 x(30mmx1000mm)\right] = 1.2153E + 08mm^4$$

Panel PSM 80

$$I = 2x\left[\frac{(30mm)^2 x1000mm}{12} + (55mm)^2 x(30mmx1000mm)\right] = 1.86E + 08mm^4$$

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When appreciating these parameters, different values of strain stress are obtained for the same panel. Among other factors, these changes depend on the variation of resistance of the concrete used. For this reason, the table 3.7 shows ranges of values in which is situated the strain stress of the tested samples.

Table 3.7 *– Strain stress for the panel flexural behaviour*

Panel	Strain stress (kg/cm^2)		
	Maximum	**Minimum**	**Medium**
PSM60	21,5	10,8	15,7
PSM80	20,5	16,6	17,8

As for these values, using the medium value for both types of panels and a safety factor equal to 1.5, the tolerable stress for the elements undergoing bending can be proposed as follows:

$$\sigma_{tolerable} = \frac{(\sigma_{y-PSM60} + \sigma_{y-PSM80})/2}{FS} = \frac{(15.7kg/cm^2 + 17.8kg/cm^2)/2}{1.5} = 11.2kg/cm^2$$

Comparing this tolerable stress with the compression strength of the concrete used, the following relation can be put into evidence:

$$\sigma_{tolerable} \approx 0.094 f_c^{'}$$

As for the realization of this building system model described at paragraph 3.2 it is important to know the panel flexural rigidity. Thanks to the mathematical model, the panel behavior in the elastic range is analyzed, so it is necessary for each panel to determine the initial rigidity. In the illustrations 3.7 and 3.8 the ideal elastic behavior for each panel tested is shown.

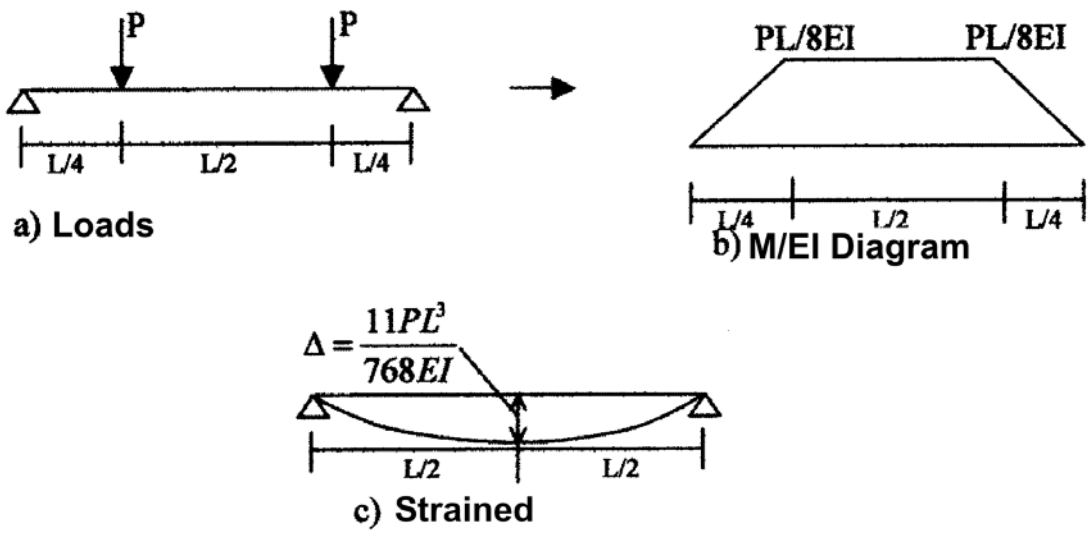

Illustration 3.9 – Panel flexural rigidity determination diagram

In order to determine rigidity, the model shown in the illustration 3.9 has been analysed, and through the area-moment method the following equation has been obtained:

$$\Delta = \frac{11PL^3}{768EI}$$

where:

- Δ is the strain at the medium point of the panel
- P is the applied load
- L is the length of the panel between bearings
- EI is the flexural rigidity of the panel

With this test we can obtain values for Δ and P that comply with the ideal elastic behaviour proposed and, as a consequence, obtaining it from the equation above, we can determine the flexural rigidity. The table 3.8 shows the values determined by this procedure.

Table 3.8 *– Calculation of the panel flexural rigidity*

Panel	Δ (inches E-03)	Δ (mm)	P (kg)	EI (kg-mm²)
PSM 60-1	42,5	1,08	1088,2	1,99E+11
PSM 60-2	132,0	3,35	634,6	3,75E+10
PSM 60-3	56,0	1,42	634,6	8,85E+10
PSM $60_{(medium)}$	-	-	-	1,08E+11
PSM 80-1	57,6	1,46	1088,2	1,48E+11
PSM 80-2	44,5	1,13	1088,2	1,91E+11
PSM 80-3	36,0	0,91	1088,2	2,37E+11
PSM $80_{(medium)}$	-	-	-	1,92E+11

With the purpose of the panel modelling, it is necessary to establish an equivalent thickness of concrete sections in the way below:

The moment of inertia of the equivalent section is:

$$I = \frac{bxh^3}{12} = \frac{1110mm*(t_{equivalent})^3}{12} = 92.5mm*(t_{equivalent})^3$$

The modulus of elasticity of the concrete used for the panels is:

$$E_m = 15100 \times \sqrt{118.7}kg/cm^2 = 164514kg/cm^2 = 1645kg/mm^2$$

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so:

$$EI = 1645 kg/mm^2 \times 92.5 mm \times (t_{equivalent})^3 = 152163 kg/mm \times (t_{equivalent})^3$$

For PSM 60

$$EI = 1.08E+11 kg-mm^2 = 152163 kg/mm \times (t_{equivalent})^3 \Rightarrow t_{equivalent} = 89.2 mm$$

$$t \approx 9cm$$

For PSM 80

$$EI = 1.92E+11 kg-mm^2 = 152163 kg/mm \times (t_{equivalent})^3 \Rightarrow t_{equivalent} = 108.1 mm$$

$t \approx 11cm$

Illustration 3.10 – Installation of the load system for bending test

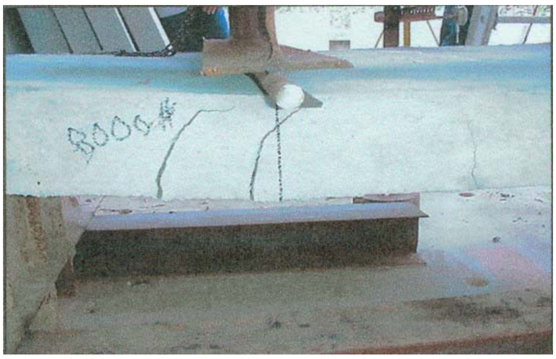

Illustration 3.11 – Crack at one quarter of panel length during the bending test

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3.1.4 **Connection test**

In order to check the resistance of the connections used in the M2 panel system, plane and L connections, such as joining between PSM 60 panels and PSM 80 panels, have been tested. This test has been documented by the report No. 02-798G-2003 (see Appendix A). The concrete used to rough in panels and connections has had a resistance equal to 119 kg/cm^2 (1696 pounds/inches^2) on one face and 170.8 kg/cm^2 (2429 pounds/inches^2) on the other after 28 days.

As for the plane connections, modules with a width of 0.55 m (21 5/8 inches) and a height of 0.80 m (31 ½ inches) have been used, and as for the angle connections, angular modules equal to 0,49 m (19 ¼ inches) by 0.64 m (25 ¾ inches) by 0.80 m (31 ½ inches) of height (see illustration 3.12). The load has been applied by means of an hydraulic jack with load gauge equal to 27215,5 kg (60000 pounds), positioned at one angle of the panel, keeping the opposite side fixed.

For this test a portion of the panel has been delimited while applying the force at the opposite end. Thanks to this mechanism one of the possible behaviours of the connections inside a house has been simulated. The maximum loads that have produced cracks have been registered (see illustration 3.13).

***Table 3.9** – Results of the test on plane connections*

Samples	**Thickness**	**Loads**		**Remarks**
	cm	**Kg**	**lb**	
PSM60-1	10	5000	11 023	The panels have yielded to shearing, out of the connection
PSM60-2	10	5000	11 023	
PSM60-3	10	5000	11 023	
PSM80-1	13	5000	11 023	The panels have yielded to shearing, out of the connection
PSM80-2	13	5000	11 023	
PSM80-3	13	5000	11 023	

Tabla 3.10 Resultados de pruebas a conexiones de esquina.

Samples	**Thickness**	**Loads**		**Remarks**
	cm	**Kg**	**lb**	
PSM60-1	10	1 587,59	3 500	Defect at the internal connection; concrete disjunction at the external connection, 3 inches (7.6 cm) from the angle.
PSM60-2	10	1 587,59	3 500	
PSM60-3	10	1 587,59	3 500	
PSM80-1	13	1 360,79	3 000	Defect at the internal connection; concrete disjunction at the external connection, 3 inches (7.6 cm) from the angle.
PSM80-2	13	1 360,79	3 000	
PSM80-3	13	1 360,79	3 000	

a) standard joining of plane connection b) angular joining

Illustration 3.12 – Joining between panels

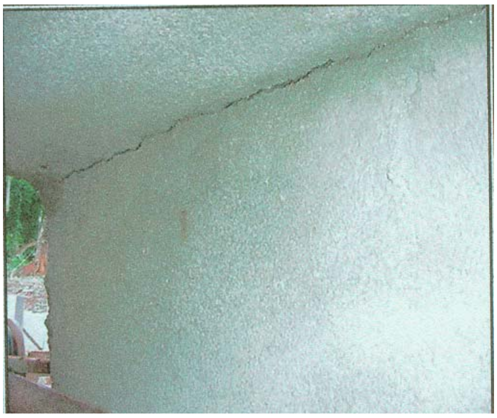

Illustration 3.13 – Typical defect of the angular connection with load equal to 1591 kg (3500 pounds)

3.2 Test on a house

In order to test the behaviour of the M2 panels as a structural system, one house, M2 model, has been built at the Campus Victor Levi Sasso of the Panama Technology University, the architectural design, shown in the illustration 3.14 and 3.15, has been developed by the engineers of the University mentioned above and represents the typical Panama house.

In this section are presented the physical characteristics, the ideal structural behaviour (mathematical model) and the real behaviour of the house structure, M2 model.