SDSS'Rio 2010 STABILITY AND DUCTILITY OF STEEL STRUCTURES
E. Batista, P. Vellasco, L. de Lima (Eds.)
Rio de Janeiro, Brazil, September 8 - 10, 2010

EXPERIMENTAL AND NUMERICAL INVESTIGATION OF POLYURETHANE SANDWICH PANELS

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Keywords: sandwich panels, experimental investigation, simplified numerical model.

Abstract. *Polyurethane sandwich panels are factory made, self-supporting structural elements that are used for roofs and roof cladding, external walls and wall cladding and walls (including partitions). As new profile-shapes of panels are developed, the determination of their mechanical properties is necessary. A series of experiments was performed in the Laboratory of Steel Structures at NTUA, following the provisions of EN 14509. The test specimens, produced by the company ISOBAU, were of trapezoidal as well as of waved profile. Additionally, evaluation of the experimental results was implemented with the use of a numerical model and design tables were conducted for practical applications.*

1 INTRODUCTION

Sandwich panels, consisting of two thin metal sheet faces and an intermediate rigid polyurethane core, are load bearing elements of a structure transferring wind load to the supporting frame. The different material, thickness and mechanical properties of the elements used to compose the panels produce a complexity in the determination of the capacity of the panels. Thus, design tables of such elements must be provided from the producing company. In the present paper the determination of the mechanical properties and load bearing capacity of sandwich panels, through experimental investigation and numerical analysis, is presented. The experimental activity and procedures were based on the current specifications and especially the provisions of the EN 14509 Self-supporting double skin metal faced insulating panels – Factory made products – Specifications. For the numerical analysis, a simplified model is proposed. The investigated panels, produced by the company ISOBAU and used as wall covering for industrial and other types of steel building, have one external profiled metal face and one flat metal face and a polyurethane core. The profiled face is of trapezoidal or of wave form (Figure 1). Different heights of these types of panels are examined.

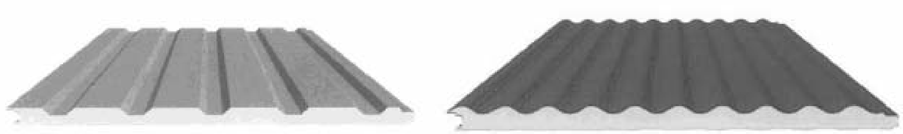

Figure 1: The external face of the investigated panels is of trapezoidal (left) or waved (right) profile.

3 EXPERIMENTAL INVESTIGATION

The aim of the experimental activity is to determine the mechanical properties of the individual materials used to compose a panel (metal sheets and polyurethane core) and the bearing capacity of the composite element. Therefore the following tests were implemented:

1. Tensile test of the metal sheets and determination of the metal thickness
2. Cross panel tensile test of the core
3. Compressive strength and modulus of the core material
4. Shear test on the core material
5. Determination of apparent core density and mass of panel
6. Test to determine the bending moment capacity and stiffness of a simply supported panel
7. Test to determine the interaction between bending moment and support force.

3.1 Tensile test of the metal sheets and determination of the metal thickness

The metal sheets are cut from coils, which have a nominal value of thickness t and yield stress f_y. The steel grade is S320. The aim of these tests is to determine the actual values of the thickness t_{obs} (with an accuracy of 1/100mm) and the yield stress of the metal sheets f_{obs}. These measurements are also necessary for the determination of correction factors used in the results of the tests to determine the bending moment capacity and stiffness of a simply supported panel. The tensile tests were conducted in a universal testing machine INSTRON 300LX, with load effector of 300kN capacity. The imposed force as well as the deformation of the metal sheets are measured and processed with the Instron Bluehill Material Testing Software (version 2.15). Figure 2 shows an indicative experimental stress-strain curve.

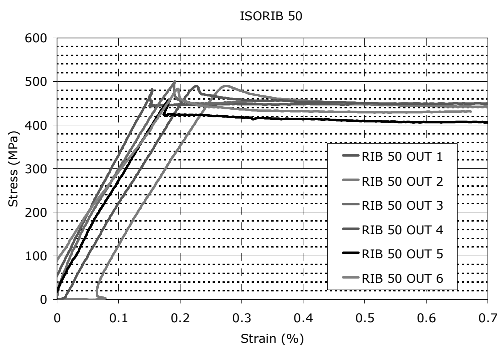

Figure 2: Indicative experimental stress-strain curve.

3.2 Cross panel tensile test, compressive strength and modulus of the core material

The cross panel tensile tests and the compressive strength tests are implemented for the determination of the tensile and compressive strength and the elastic modulus of the polyurethane core. The specimens are of a square cross section of 100mm and for the tensile tests the faces of the panels are intact in order to include the tensile bond strength between the faces and the core. The tensile tests are carried out on specimens under normal temperature (20^0C) and on specimens, which have been heated for 20 h to 24 h in a heating chamber at a temperature of 80^0C. These two types of tests were carried out in the universal testing machine INSTRON 300LX, with load effector of 300kN capacity. Figure 3 shows an indicative experimental stress-strain curve for each type of test and Figure 4 shows the two typical failure modes of the core under tension.

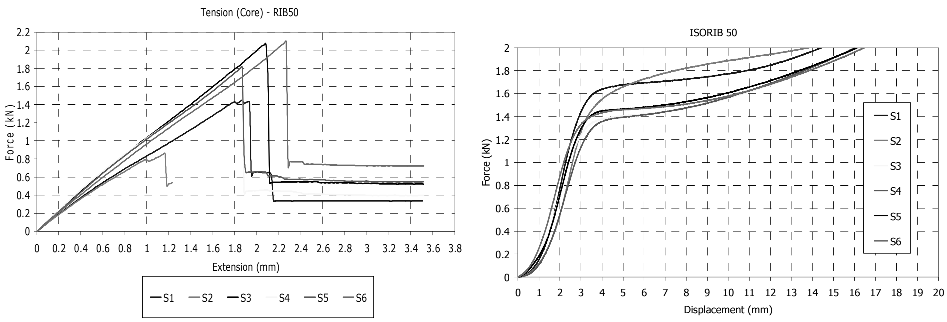

Figure 3: Indicative experimental stress-strain curves of the tension (left) and compression tests (right).

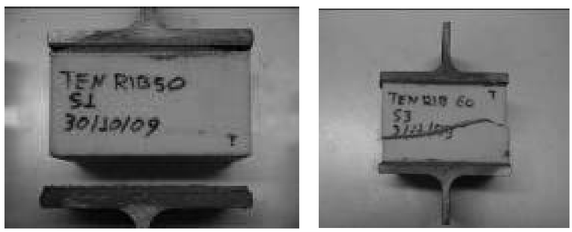

Figure 4: Failure modes of the core under tension: failure of the bond between the faces and the core (left) and failure of the polyurethane core (right).

3.3 Shear test on the core material

The shear strength and shear modulus of the core material is determined using the four-point bending tests on a specimen cut in the lengthwise direction of a panel. The clear span is 1 m, unless no shear failure occurs where the length shall be decreased in 10 cm steps until a shear failure is obtained. The ultimate load carried by the specimen failing in shear is measured and the shear modulus is calculated from the load deflection. The imposed force as well as the deformation of the metal sheets are measured and processed with the Instron Bluehill Material Testing Software (version 2.15). The ultimate shear strength f_{Cv} of the core material is calculated from the maximum load attained in a specimen failing in shear based on the following equation:

$$f_{cv} = k_v \frac{F_u}{2 \cdot B \cdot e} \tag{1}$$

,where F_u is the ultimate load carried by the specimen failing in shear; B is the measured width of the specimen; e is the measured depth between the centroids of the faces; k_v is the reduction factor for cut ends in pre-formed or lamella cores.

Figure 5 shows the force-deflection curve for all tests, where shear failure was achieved (Figure 5). In many tests, especially with specimens cut from panels of lower heights (50 and 60mm), no shear failure was obtained, even after reducing the span significantly. In these cases, the failure of the specimens was obtained due to compression failure of the metal sheet after detachment of the metal sheet from the core was observed (Figure 6).

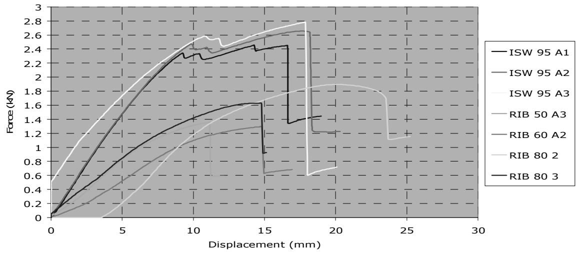

Figure 5: Experimental load – deflection curves for specimen with shear failure.

Figure 6: Failure modes obtained from the shear tests.

3.4 Test to determine the bending moment capacity and stiffness of a simply supported panel

A four-point bending test on a panel (with its full width) is carried out in order to determine the bending capacity of the simply supported panels (Figure 7). In order to obtain pure bending failure, an appropriate ratio length/height of the specimen is chosen based on the recommendations of EN 14509.

In the first series of these tests the force is imposed with a hydraulic actuator (with a capacity of ±500 kN) on the profiled face of the panels. In order to achieve uniform distribution of the line load acting on the trapezoidal profiled face, timber loading platens are used in the troughs of the profile (Figure 8). The loading platens shall be sufficient to avoid compressive failure of the core below the platens. In the case of the panels with waved profiled face, special cuts of the same type of panels were used (Figure 8). In the second series the force is implemented on the flat face of the panels, causing tension to the profiled face. Figure 9 shows an indicative force-deflection curve, where bending failure was achieved.

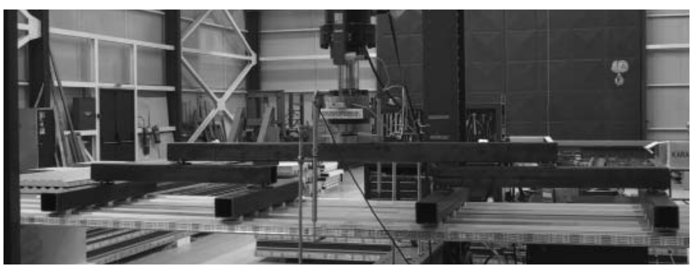

Figure 7: Experimental set-up of the four-point bending tests.

Figure 8: Timber loading platens on the trapezoidal profiled face (left) and special cuts of the panels on the waved profiled face (right).

In the first series of tests, where the flat face is in tension, the wrinkling stress can be determined based on EN 14509 from equation 2, where the ultimate bending capacity is taken into account:

$$\sigma_w = \frac{M_u}{e \cdot A_1} \tag{2}$$

,where M_u is the ultimate bending moment recorded in the tests, after correcting for the effect of the self weight of the panel and the weight of the loading equipment; e is the depth between centroids of the faces and A_1 is the cross-sectional area of the face in compression.
In the second series of tests, where the flat face is in compression, the wrinkling stress can be determined based on EN 14509 from equation 3, where only a moment component M_S arising from the normal forces F_1 and F_2 in the faces multiplied by the distance between the centroids e is taken into account:

$$\sigma_w = \frac{M_s}{e \cdot A_1} = \frac{M_u - M_{F2}}{e \cdot A_1} \tag{3}$$

, where M_{F2} is the bending moment carried by the profiled face and M_u is the ultimate bending moment.
The values of the calculated wrinkling stress are additionally corrected by the correction factors obtained from the tensile and thickness tests of the metal sheets. The final bending strength for both series of tests for all types of panels is presented in Table 1.

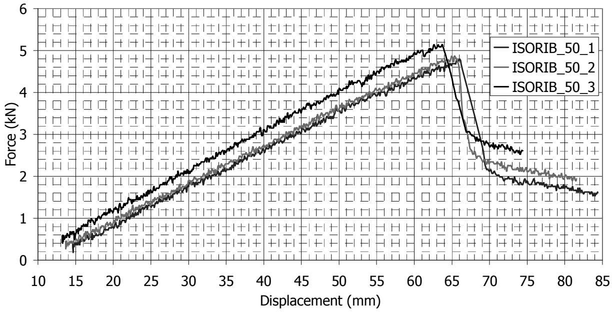

Figure 9: Indicative force-deflection curve obtained from the tests.

Table 1: Bending strength of a single span panel.

Panel type	Bending strength σ_w [MPa] Profiled face in compression	Bending strength σ_w [MPa] Flat face in compression
ISORIB 50	198.14	100.90
ISORIB 60	209.52	150.33

ISORIB 80	214.89	152.40
ISOWAVE 65	311.72	174.83
ISOWAVE 95	280.94	110.42

3.5 Test to determine the interaction between bending moment and support force

The bending strength at an internal support of a panel which is continuous over two or more spans is determined from tests of a single span panel subject to a line load. Similar to the tests performed to determine the bending moment capacity and stiffness of a simply supported panel, two types of test are carried out in order to simulate downward load (compression of the flat face) as well as the uplift load (compression of the profiled face). For the uplift load tests the number and type of screws and washers are similar to those used in practice. The corresponding wrinkling stress for flat or lightly profiled faces or the buckling or yield stress for profiled faces is then determined by calculation.

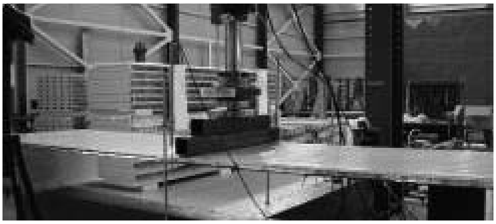

Figure 10: Experimental set-up of the test on of a single span panel subject to a line load.

The load and deflection of the panels, for which bending failure is achieved, is obtained from the experiments. Figure 11 shows an indicative force-deflection curve. The wrinkling stress is then calculated with the use of simplified numerical model, which is presented in the next chapter. The final bending strength for both series of tests for all types of panels, presented in Table 2, are the ones obtained from the numerical simulation corrected by the correction factors obtained from the tensile and thickness tests of the metal sheets.

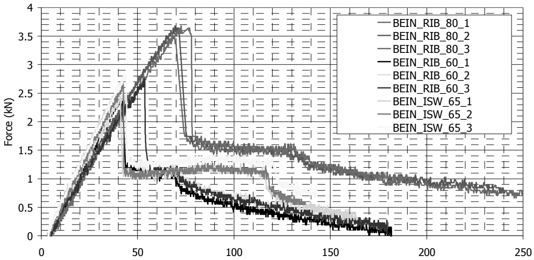

Figure 11: Indicative force-deflection curve obtained from the tests.

Table 2: Bending strength of the panels at an intermediate support.

Panel type	Bending strength σ_w [MPa] Profiled face in compression	Bending strength σ_w [MPa] Flat face in compression
ISORIB 50	170.72	116.33
ISORIB 60	147.27	103.12

ISORIB 80	179.76	124.21
ISOWAVE 65	236.50	139.81
ISOWAVE 95	161.92	93.35

4 NUMERICAL SIMULATION

4.1 Numerical model

For panels with one profiled face an analytic approach is simple and feasible only for uniform loaded single span beams. In order to calculate the bending strength of the panels at an intermediate support an elastic numerical analysis is applied, where the sandwich panel is simulated as a truss beam. The upper and lower chords are beam elements with the cross section of the profiled and flat face of the panel respectively (Figure 12). The core of the panel is simulated by the diagonals whose axial stiffness is defined by equation 4:

$$EA = \frac{G_c \cdot A_c}{2 \cdot \sin^2 \alpha \cdot \cos \alpha} \quad (4)$$

, where G_c is the shear modulus determined from the experiments, A_c is the area of the polyurethane core and α (alpha) is the angle of the diagonals defined by equation 5:

$$\tan \alpha = \frac{\Delta z}{\Delta x} \quad (5)$$

, where Δz is the height of the truss (distance between centroids of the faces) and Δx is the length of one unit of the truss (Figure 12). The distance Δx is chosen almost twice the height Δz in order to obtain an obtuse angle.

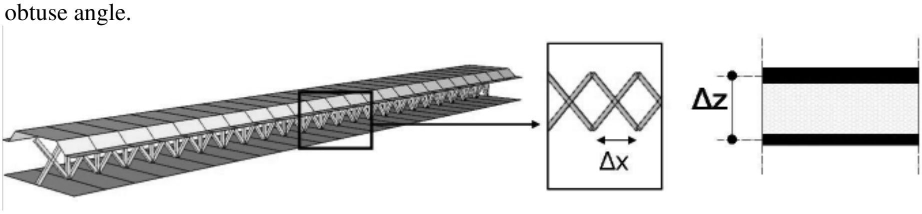

Figure 12 Model for a panel.

The shear stress of the core is equal to:

$$\tau_c = \frac{V}{A_c} \quad (6)$$

, where V is the shear force and A_c is the area of the polyurethane core. The axial stress of the diagonals is equal to the shear stress of the core:

$$\sigma = \tau \rightarrow \quad \frac{V}{A \cdot 2 \cdot \sin a} = \frac{V}{A_c} \quad (7)$$

and the area of the diagonals can be determined from equation 8:

$$A = A_c / 2 \cdot \sin a \quad (8)$$

The elastic modulus of the diagonals can be determined by equations 4 and 8:

$$E = \frac{2 \cdot \sin a}{A_c} \cdot \frac{G_c \cdot A_c}{2 \cdot \sin^2 \alpha \cdot \cos \alpha} = \frac{G_c}{\sin \alpha \cdot \cos \alpha} \quad (9)$$

4.2 Verification of numerical model

The verification of the numerical model is achieved by comparing the numerical results in terms of stress and deflection with the analytical method proposed by EN 14509 for a single span panel with uniform loading. The results presented in Table 3 are for 3 types of panels with the same trapezoidal profiled face but with different heights (50mm, 60mm, 80mm). All panels have a length of 4m and have a uniform load of 1kN/m. The difference between the numerical and the analytic results are within acceptable design limits (99-103%).

Table 3: Comparison of numerical and analytical method.

Panel type		Analytic method	Numerical method
ISORIB 50	Deflection w (mm)	48.20	47.50
	Compression stress of profiled face σ_w [MPa]	155.00	153.20
	Tension stress of flat face σ_w [MPa]	105.00	106.00
ISORIB 60	Deflection w (mm)	39.00	38.00
	Compression stress of profiled face σ_w [MPa]	130.00	123.00
	Tension stress of flat face σ_w [MPa]	100.00	97.00
ISORIB 80	Deflection w (mm)	22.50	23.20
	Compression stress of profiled face σ_w [MPa]	89.70	87.20
	Tension stress of flat face σ_w [MPa]	72.60	71.80

5 CONCLUSION

An experimental investigation of two new types of panels, produced by the company ISOBAU has been performed. The aim of the tests is to determine and certify the mechanical characteristics and bearing capacity of these sandwich panels. The experimental procedure is based on the provisions of EN 14509. For the determination of the internal forces, the interpretation of the experimental results and the design of panels an innovative simplified numerical model is proposed, where the sandwich panel is simulated as a truss beam. The profiled and flat faces of the panel are simulated as beam elements (the upper and lower cords of the truss beam) and the core of the panel is simulated by the diagonals. The axial stiffness of the diagonals is defined by the shear modulus of the core and the angle of the diagonals.

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