Composite Structures

INTERSECTII
INTERSECTIONS
http://www.ce.tuiasi.ro/intersections

# ANALYSIS AND BEHAVIOUR OF A COMPOSITE SANDWICH PANEL FOR ROOF CLADDINGS

Nicolae Ţăranu[1], Dorina Isopescu[2], Ioana Entuc[3], Gabriel Oprisan[4]

*[1]Professor of Civil Engineering, Technical University of Iasi,Romania*
*[2]Professor of Civil Engineering, Technical University of Iasi,Romania*
*[3]Lecturer of Civil Engineering, Technical University of Iasi,Romania*
*[4]Lecturer of Civil Engineering, Technical University of Iasi,Romania*

Summary

*Sandwich panels are layered constructions consisting of dissimilar materials assembled so as to utilize the properties of each to attain functional and structural efficiency for the assembly. An experimental prototype sandwich panel made of bitumen impregnated glass mat as upper facing, polyurethane foam core and a bottom facing made of a galvanized cold formed steel sheet has been manufactured and tested at the Department of Civil Engineering of the Technical University of Iasi. The test specimen, a composite sandwich panel 6000mm long and 630mm wide, has been tested under gravity uniformly distributed transverse loads to check its suitability as roof cladding. An appropriate bending stiffness formula has been selected by the authors to determine the values of theoretical deflections and the measured deflections are in good agreement with the theoretical ones.*

KEYWORDS: Load-deflection curve, local buckling, flexural rigidity

## 1. INTRODUCTION

There is an increasing interest nowadays in the use of sandwich panels with facings made of metallic and composite materials separated by a polyurethane foam core. Sandwich panels consisting of upper composite facings and bottom steel sheet facings are presently utilized in industrial, commercial and agricultural constructions as building enclosures; therefore these elements appear to have gained a recognized use. Among their main advantages the following can be mentioned: high structural efficiency, very good thermal insulation properties, good surface finish and resistance to local deformations, ease of mass production, transportability, durability and reusability.

The sandwich elements used for roof cladding should have, among other qualities, good mechanical behaviour under transverse loads from self weight and snow loading. A particular type of layered panel has been designed and manufactured in a joint research and development project carried out by the Technical University of

Iasi and The Research Institute for Buildings and Building Materials (ICPMC) Bucuresti in order to promote light-weight cladding elements in building industry. The panel has been tested under transverse loading on two spans. Deflection readings have been taken and compared to those determined theoretically showing a good agreement between these two sets of values.

## 2. CHARACTERISTICS OF THE SANDWICH PANEL

The composite sandwich panel (Figure 1) has been conceived to satisfy the main functional and structural requirements for roof claddings: strength and stability, resistance to weather, durability and freedom from maintenance, fire safety, and resistance to the passage of heat and sound. The bottom facing of the panel is a 1.00mm thick galvanized profiled steel sheeting that can be fixed across purlins. It provides adequate corrosion protection and is an acceptable finish to the underside of the decking. Also the steel decking provides support for rigid polyurethane core which gives the required thermal insulation. To provide the required resistance to heat transfer a rigid polyurethane foam core 40 mm thick has been selected. A weathering membrane consisting of bitumen impregnated glass fibre mat bonded to the foam core is provided at the upper side of the panel.

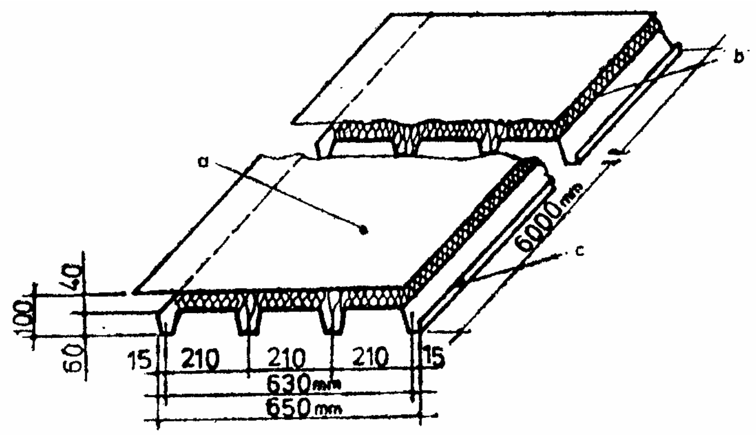


Figure 1 - Sandwich panel of cold-formed galvanized steel facing and urethane foam core
a – bitumen impregnated mat face
b – urethane foam
c – cold-formed steel face

ISSN 1582-3024

## 3. THEORY. STRESSES AND DEFLECTIONS

The assumptions on which the analysis is based are the following:

- the Young's modulus of the galvanized facing is much larger than that of the core, therefore this layer withstands the entire flexural stresses, and the core carries no longitudinal stresses;
- between the core and the steel face an adequate adhesion exists and the sandwich elements acts as an unit, being effective about a common neutral axis;
- the upper bitumen impregnated glass mat facing does not contribute to the flexural rigidity and may consequently be neglected;
- the shear stresses are mostly carried by the steel plate corrugations (unlike the sandwich panels with two flat facings);

The sandwich panel can be considered a wide composite beam and its flexural rigidity about the centroidal axis of the entire cross-section (Figure 2) is given by:

$$D = I_{f,0}E_f + A_f\xi_f^2E_f + I_{s,0}E_s + A_s\xi_s^2E_s \tag{1}$$

where:

| | |
|---|---|
| $D$ | - flexural rigidity of the sandwich panel; |
| $I_{f,0}$ | - moment of inertia of the foam core about its own centroidal axis; |
| $I_{s,0}$ | - moment of inertia of cold formed steel facing about its centroidal axis; |
| $E_f$, $E_s$ | - elastic modulus of foam core and steel facing respectively; |
| $A_f$, $A_s$ | - cross sectional areas of foam core and cold formed steel plate; |
| $\xi_f$ | - distance from the neutral axis of panel to centroidal axis of core; |
| $\xi_s$ | -distance from neutral axis of panel to centroidal axis of the steel facing. |

The geometrical and mechanical characteristics introduced in the above equation were: $E_f = 7\ N/mm^2$, $E_s = 210000\ N/mm^2$, $A_f = 24000\ mm^2$, $A_s = 1000\ mm^2$, $I_{s,0} = 468000\ mm^4$.

Using formula (1) the computed flexural rigidity, $D = 9828 \times 10^7\ Nmm^2$, the first and the second terms amount less than *0.3%* of the next terms and may be neglected, because the error introduced by neglecting the foam contribution is not significant.

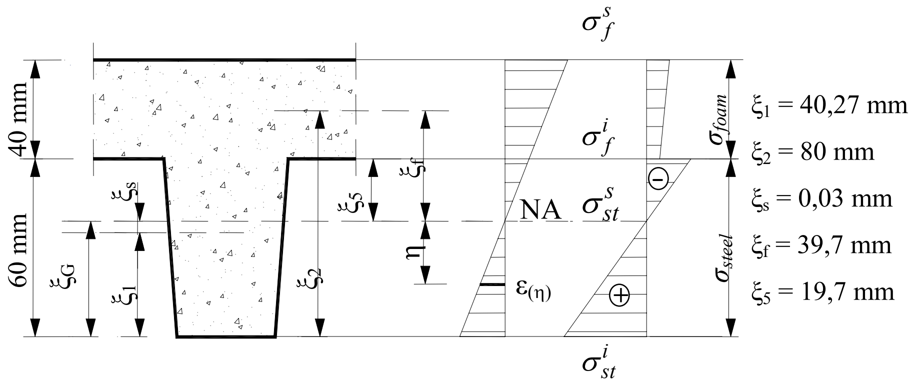


Figure 2 - Notation for equation (1); (f=foam, s=steel*)*

The stress in the foam core and the steel face may be determined using the ordinary bending theory for the composite cross-section of the sandwich panel [1].

Assuming that the sections remain plane and perpendicular to the longitudinal axis, the strain, $\varepsilon$, at a distance $\eta$ from the centroidal axis (Figure 2) is:

$$\varepsilon = \frac{M}{D}\eta \tag{2}$$

The direct stress at any level (Figure 2) may then be computed multiplying this strain by the appropriate modulus of elasticity, i.e.:

a) in the steel facing under the neutral axis:

$$\sigma_s^i = \frac{M}{D}\eta E_s, \quad when \ \ 0<\eta\leq\xi_G; \tag{3a}$$

b) in steel facing above the neutral axis:

$$\sigma_s^s = \frac{M}{D}\eta E_s, \quad when \ \ 0\leq\eta\leq\xi_5; \tag{3b}$$

c) in the foam core:

$$\sigma_f = \frac{M}{D}\eta E_f, \quad when \ \ \xi_5\leq\eta\leq\xi_5+40mm; \tag{3c}$$

When subjected to transverse loads the two spans panel deflects in a cylindrical manner. Since the cold formed steel plate provides almost the entire flexural rigidity and the stresses are below the elastic limit, the moment – curvature relationship can be assumed as linear. Then, moment *M(x)* is related to deflection *y* by:

$$M(x) = -D\frac{d^2y}{dx^2} \tag{4}$$

in which *x* is the distance from the left support where the deflection *y* is calculated.

Taking the span 2-3 (Figure 3), the bending moment at a distance *x* from the left support can be determined with:

$$M(x) = \frac{5ql}{8}x - \frac{ql^2}{8} - \frac{qx^2}{2} \tag{5}$$

where *q* is the uniform load, and *l* is the span length.

By integrating equation (5) two times and using the boundary conditions, the deflections at any point at a distance *x* from the left support is given by:

$$y = \frac{q}{48D}(2x^4 - 5lx^3 + 3l^2x^2) \tag{6}$$

The theoretical deflection reaches a maximum at $x=0.577\cdot l$, from the left support.

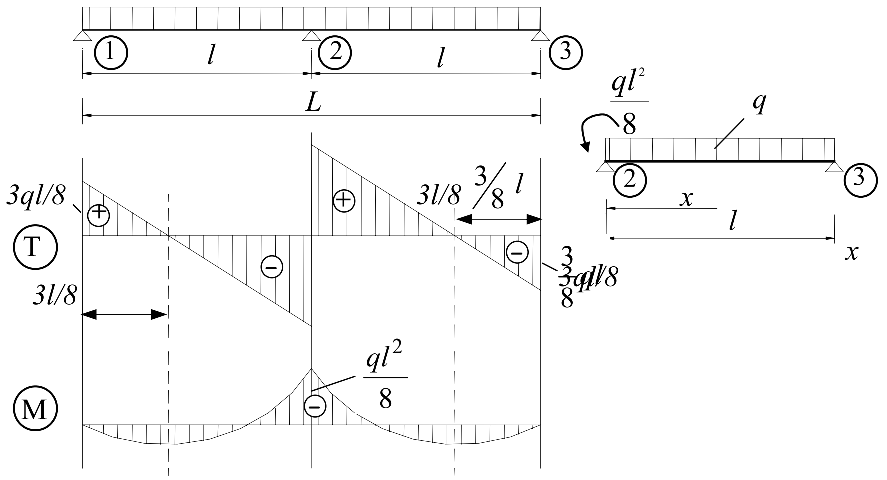

Figure 3 - The scheme of testing the complete panel under a uniformly distributed load

ISSN 1582-3024

## 4. TEST PROCEDURE

Testing methodology was chosen in such a way that the behaviour of the individual panels used as roof elements under snow load could be studied.
The supports were made of **I** or **[** steel sections normally used for purlins [2]. Load increase has been selected at 200 N/m$^2$ (Table 1).
Theoretical computations have been performed to determine the direct stresses (Table 1) and deflection values (Table 2).
Experimental work was performed under laboratory temperature and humidity conditions.

Table 1

| Nr. | Load [N/m$^2$] | On the interior support | | | | Section with maximum positive bending moment ($x=0.577\ l$) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Stresses, [KPa] | | | | Stresses, [KPa] | | | |
| | | $\sigma^i_{st}$ | $\sigma^s_{st}$ | $\sigma^i_f$ | $\sigma^s_f$ | $\sigma^i_{st}$ | $\sigma^s_{st}$ | $\sigma^i_f$ | $\sigma^s_f$ |
| 1 | 200 | -11600 | 5700 | 0.19 | 0.57 | 6500 | -3200 | -0.11 | -0.32 |
| 2 | 400 | -23300 | 11400 | 0.38 | 1.15 | 13000 | -6400 | -0.21 | -0.64 |
| 3 | 600 | -34900 | 17000 | 0.57 | 1.72 | 19500 | -9500 | -0.32 | -0.96 |
| 4 | 800 | -46500 | 22700 | 0.76 | 2.29 | 26000 | -12700 | -0.42 | -1.29 |
| 5 | 1000 | -58100 | 28400 | 0.95 | 2.87 | 32600 | -15900 | -0.53 | -1.61 |
| 6 | 1200 | -69800 | 34100 | 1.14 | 3.44 | 39100 | -19100 | -0.63 | -1.93 |
| 7 | 1400 | -81400 | 39800 | 1.33 | 4.02 | 45600 | -22300 | -0.74 | -2.25 |

Table 2

| Nr. | Load $q$ [N/m$^2$] | Span length [mm] | Deflection at | | | |
|---|---|---|---|---|---|---|
| | | | $l/4$ [mm] | $l/2$ [mm] | $3l/4$ [mm] | $x=0.577\ l$ [mm] |
| 1 | 200 | 3000 | 0.24 | 0.52 | 0.43 | 0.54 |
| 2 | 400 | | 0.48 | 1.03 | 0.87 | 1.07 |
| 3 | 600 | | 0.72 | 1.55 | 1.30 | 1.61 |
| 4 | 800 | | 0.96 | 2.06 | 1.74 | 2.14 |
| 5 | 1000 | | 1.21 | 2.58 | 2.17 | 2.68 |
| 6 | 1200 | | 1.45 | 3.09 | 2.61 | 3.21 |
| 7 | 1400 | | 1.69 | 3.61 | 3.04 | 3.75 |

## 5. EXPERIMENTAL RESULTS. CONCLUSIONS

The deflection readings were taken by means of dial indicators, having a reading precision of 0.001 mm, located as mentioned in Table 2. Load versus deflection is plotted in Figure 4, for a load step of *200 N/m$^2$* up to *1400 N/m$^2$*. Theoretical and experimental results are also shown in Figure 4.

As it can be seen there is quite a good agreement between theoretical and experimental results. Therefore, Equations (1) and (2) can be successfully used for flexural rigidity and deflection computation.

ISSN 1582-3024

Experimental tests under progress at the time being will bring new information on long term flexural behaviour of panels analyzed in this paper under short term uniform transverse load.

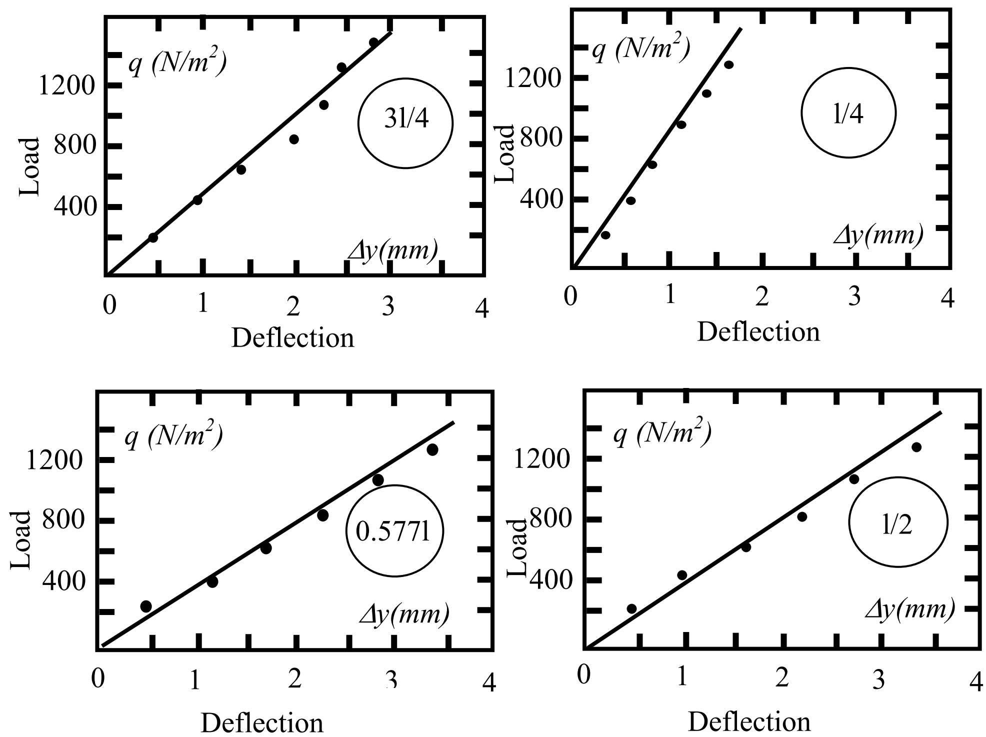


Figure 4 – Load versus deflection for the sandwich panel under uniformly distributed load; (• experimental, — theoretical)

Local buckling of the steel sheeting has been prevented due to the support provided by the rigid foam and the beneficial effect of small longitudinal ribs formed at midway two consecutive ridge corners.

## AKNOWLEDGEMENTS

This research has been partly supported by a Marie Curie Fellowship of the European Community program Human Potential under contract number HPMF-CT-2002-01553

Composite Structures

INTERSECTII
INTERSECTIONS
http://www.ce.tuiasi.ro/intersections



## REFERENCES

[1]. ALLEN, H.G., "Analysis and Design of Structural Sandwich Panels". Pergamon Press, Oxford, 1969.

[2]. TARANU, N. and BUDESCU, M. "Studiul comportarii unor panouri sandvis din tabla cutata si spuma poliuretanica rigida". Contract UTIasi- ICPMC Bucuresti.

ISSN 1582-3024