FEM ANALYSIS OF THE COMPOSITE MATERIALS USED IN CIVIL BUILDINGS

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The paper presents the theoretical and experimental results of an R&D project devoted to assess the use of the composite materials for building different kind of civil buildings. Many kinds of composite materials based on epoxy resin and glass fibers were patented by chemical companies and now they are widely used in different applications like self-supporting family houses, industrial buildings, river barges, cold rooms etc. The objective designed and tested was a kindergarten sited in a cold region of Romania. The numerical simulation with FEM methods were certified by the national authority in civil design.

Keywords: FEM analysis, composite materials, civil buildings, experimental validation.

1. Problem formulation

The increased use of the composite materials in different fields as aerospace and automotive industries and many other domains obliged the designers to assess the real static and dynamic behavior of different types of mechanical components, industrial buildings, bridges, petrochemical tanks etc. Obviously, the results of any sophisticated computations are different from the experimentally ones. The main source of such a discrepancy comes from the hypothesis on the interaction between the reinforcement (shell), which is strong but brittle, and the matrix (or core), which is much weaker, but much lighter and flexible. A wide diversity of such materials is now spreading in the light buildings field, due to many qualities: small overall specific weight, good overall strength for flexure, very small specific heat, moderate price and many quick assembling possibilities by adhesives or fasteners. The extensive use of different types of composite materials generated a special interest in different unexpected field like civil engineering. The high degree of thermal insulation, the very low specific weight, the capability of mixing different components for obtaining different mechanical, thermal, and even aesthetic

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advantages led the engineering community to extensive studies of these modern materials.

Now, composites are used in many industries to enable high-performance products at economic advantage. These applications range from space to sports and include manufactured products for aircraft, transportation, energy, medical use, marine, and construction (Figs. 1 and 2).

Fig. 1. Family house from composite materials only

Fig.2. Holiday house from composite materials on the seaside, powered by solar pannels

There are many composites materials economically accepted, but a solid knowledge of all the physical intrinsically linked properties, including the mechanical, technological, design, inspection, repair, and manufacturing options is required for working with these materials as they are [1].

This paper describes the attempt to explore the possibility of using composite materials for some important civil engineering objectives as isolated residential houses, and their water storage partially buried tanks needed for different purposes. One of the most important properties of the double shielded materials in this second problem is the good resistance of the humidity and microorganisms, commonly found in water technology from any application. The practical computation was performed for a 6 cells water tank made of composite panels, in order to find out the resistance limit of a common composite material produced in U.S.A.

2. Sandwich beam computation

In theory it can be considered that a composite beam, with weak core made of polyurethane foam can ensure flexural strength through the hard-other shell, while the inner core ensure continuous support for the linings. The core sustains the shear stress and overcomes the buckling of the outer shell, or residual deformation in case of a severe loading. The adhesive used, must withstand the stretch and shear stress that occurs at the interface between shell and core [2]. A realistic assessment imposes a good knowledge of the material properties. This information must be obtained experimentally. Even so, for the beginning, a simplified calculus can be made on the hypothesis that composite materials are similar to the isotropic material. For a sandwich beam, simply supported, and loaded with a uniformly distributed load as indicated in Fig. 3,

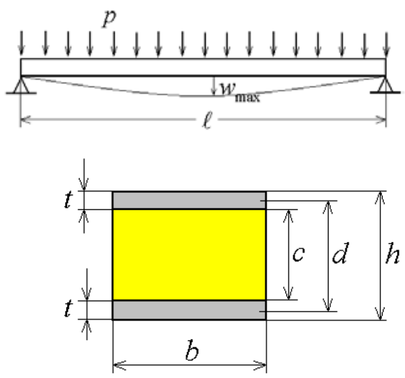

Fig. 3. Computational elements for the beam

if d / t > 6 and

$$\frac{E_f t d^2}{E_c c^3} > 17,$$

results the following equation of maximum deformation [3]

$$w_{\max} = \frac{5}{384}\frac{p\ell^4}{(EI)_{ech}} + \frac{1}{8}\frac{p\ell^2}{(GA)_{ech}}. \tag{1}$$

Here

$$(EI)_{ech} \cong \frac{bt(c+t)^2}{2}E_f \tag{2}$$

and

$$(GA)_{ech} \cong bcG_c, \tag{3}$$

here E_f is the Young's modulus of the shell and G_c is the shear modulus of the core. Maximum normal stress in the shell and core, can be determined using the equations:

$$\sigma_f^{\max} = \frac{M}{btc}\frac{h}{c} \tag{4}$$

$$\sigma_c^{\max} = \frac{M}{btc}\frac{E_c}{E_f} \tag{5}$$

The maximum shear stress in the core can be determined using the relationship:

$$\tau_c^{\max} = \frac{T}{bd} \tag{6}$$

For the following dimensions, *b* = 1 m, *c* = 0.0814 m, and *t* = 0.0013 m, the material properties are:

a) Shell:

E_f = 30000 MPa, ν_c =0.3 ρ_f = 1600 kg/m^3

b) Core (ν_c =0.4):

G_c = 3.5714 MPa, E_c = 10 MPa, ρ_c = 32 kg/m^3

From equation (1) we can obtain the load for which a maximum deformation of (max allowed). Furthermore, the maximum stress is obtained from equation (4) and (5). Table 1 presents synthetically the results obtained for various lengths of the beam. If the mechanical properties (E_c and G_c) of the core are reduced by 10 times, then the maximum load that produces the same deformation is reduced by 5.65 times. If the mechanical properties (E_c and G_c) of the core are increased by 10 times, then the maximum load that produces the same deformation is increased by 1.89 times. If the mechanical properties of the shell (E_f) are reduced by 3 times, then the maximum load that produces the same deformation is reduced by 1.95

times. If the mechanical properties of the shell (E_f) are increased by 3 times, then the maximum load that produces the same deformation is increased by 1.46 times.

Table 1

Results obtained for various lengths of the beam

Length	Load "p" for which max. deformation is $\ell / 300$	Max stress in the shell	Max. stress in the core	Max. shear stress in the core
ℓ [m]	p [N/m]	σ_f^{max} [MPa]	σ_c^{max} [kPa]	τ_c^{max} [kPa]
1.0	6317	7.7013	2.4876	38.197
1.5	3420	9.3818	3.0305	31.022
2.0	**2031**	**9.9043**	**3.1992**	**24.562**
3.0	849	9.3147	3.0088	15.400
4.0	418	8.1588	2.6354	10.117

The results in bold from the above table have been obtained using ANSYS [3]. FEM analysis can be an effective and realistic tool if the mechanical properties of the polyurethane foam are known. For the shell, the estimations can be done much easier, as the materials used to make it have a much narrow spectrum of mechanical properties than the foam [4], [5], [6].

3. Design and results for the building of the kindergarten

The authors designed all the structure of a public building (Figs. 4 - 6) according the specification offered by the panel's supplier - RexWallCore [7]. The components of any panel can be chosen according the role and load in the structure (Fig. 7).

Fig. 4. House from composite panels only, designed as kindergarten

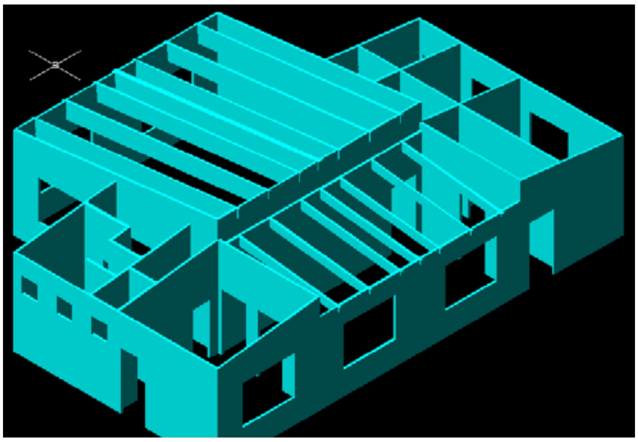

Fig. 5. The internal structure of the kindergarten from composite elements only

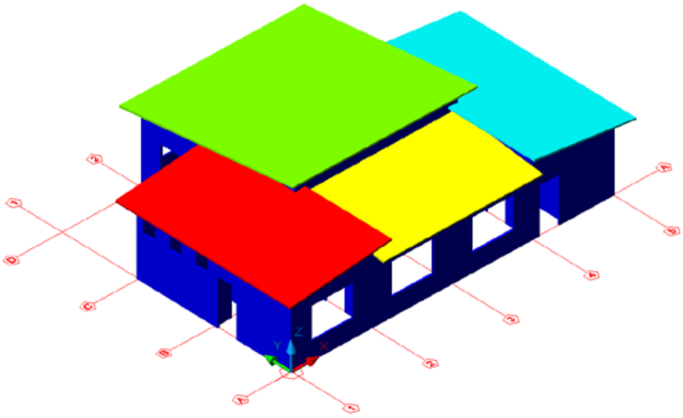

Fig. 6. The 3D model of the kindergarten

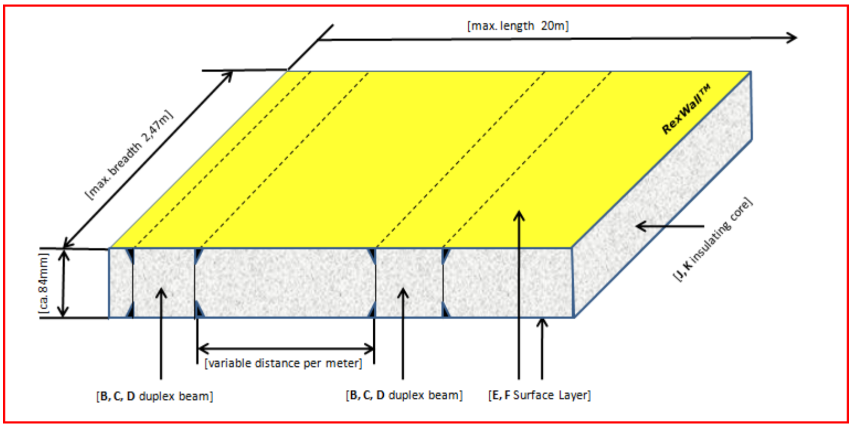

Fig. 7. The RexWall Core Advanced Supported Panel structure [7]

All the panels of the building were assembled by binding with a special glue applied at the room temperature (Fig. 8). RexWall panels are bonded in place using a two-component adhesive that cures in less than two hours. The guarantee for the integrity of such a structure is more than 50 years. The main mechanical load of the roof comes from the old snow (ρ = 451 kg/m^3), which can reach about 1m at an altitude of 800 m. The simulations performed with ANSYS predicted a maximum roof arrow of 46 mm (Fig. 9).

Fig. 8. Internal view of the main room loaded by snow

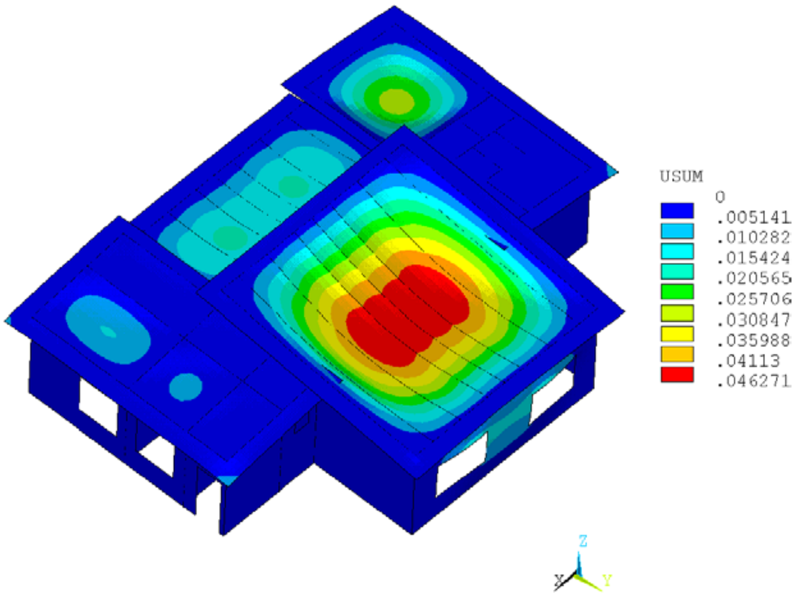

Fig. 9. The main roof arrow simulated for a load of 1 m of old snow

The National Civil Engineering Structures Laboratory - INCD URBAN INCERC [8] performed a measurement campaign of the building integrity during a full year. The maximum displacement on the main roof, measured with a laser beam system and a mechanical one was found a little lower than the predicted one. After 8 years of using as a public space for young people, there was no damage of the structure, and the internal temperature was always around 20°C. The thermal simulations performed with the TRNSYS program [9] have shown a very small energy consumption during the winter for keeping inside the normal temperature. An important contribution to this quality comes from the triple glass windows and double doors supplied by ROMET GROUP from Buzău, Romania [10], the project leader.

4. Design of wastewater tanks from composite panels

The composite panels were certificated by the German Laboratory Aqua House International GmbH both for air and water environmental use. One of the most important properties of the double shielded materials is the good resistance to humidity and microorganisms, commonly found in water technology for any application. In close connection with the kindergarten building, the authors studied the structures of the water tanks of the building. The theoretical evaluation of the resistance limit was performed for a water tank with six cells made of the same composite panels like the ones used in U.S.A. In Fig.10 is presented the basic layout of the tank, with its main components: base, honeycomb structure, vats and cover. We consider the middle plane of all the panels, which is modelled using "sandwich" type elements of an average element size of 250 mm.

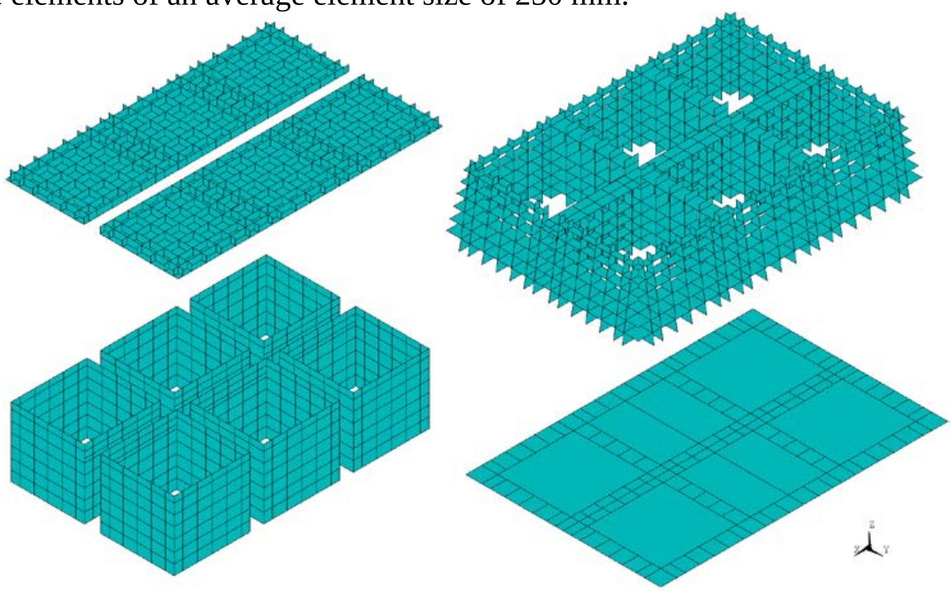

Fig. 10. FEM model of the 4 components: base, honeycomb structure, vats and cover

The computational model considers the structure continuous at joints (glued together). The mathematical model does not include joint details. This model cannot offer information about the crumpling of the shell, and the stress concentrators, even though part of the concentrator's effect is included. The nominal stress in each panel is correctly estimated, especially in areas far from the mathematical joints. The mass of the model is 22.986 kg. We consider a load generated by a wastewater with a density of 1.200 kg/m^3, from a height of 5.05 m from the base. The weight of the structure has also been included. It is considered that the base is perfectly sustained by the concrete foundation (no point of the base leaves the foundation, even though this phenomenon could occur at the edges of the model). The base is anchored by the concrete with screws. The load from wastewater pressure and also the fixed displacement of some nodes is presented in Figure 11. Total vertical reaction force is 1331.6 x 10^4 N from the applied pressure and structural weight.

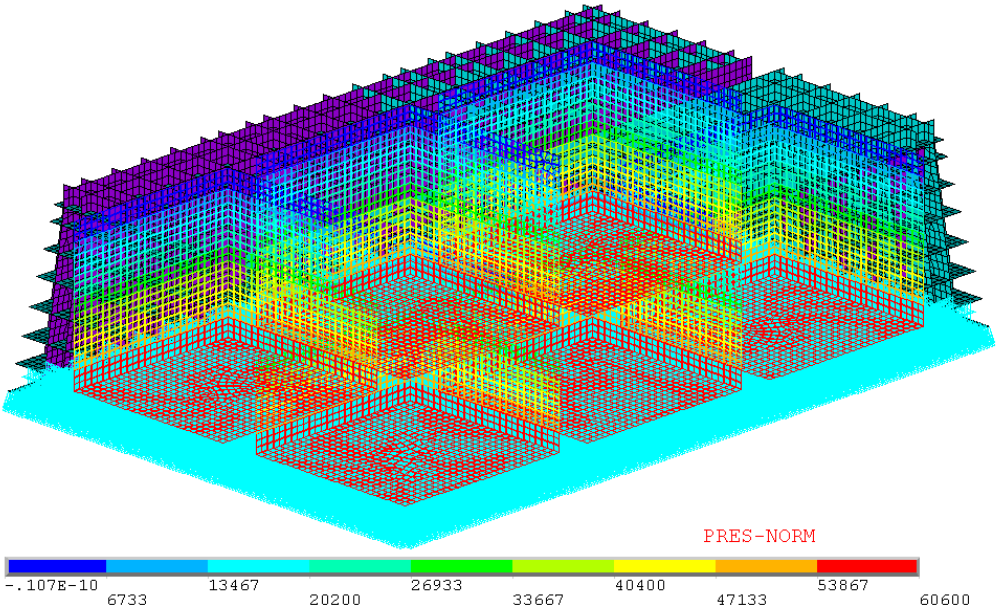

Fig.11. Hydrostatic pressure load (in Pa) from all 6 vats full with waste water.

The total deformation of the model in m (displacement scale factor is 100) is presented in Fig.12. The authors also studied the maximum von Mises stress distribution in all the panels of the model: the equivalent stress represented on the middle plane of the composites, as a maximum value from the two outer shells; the equivalent stress represented on the middle plane of the composites, as a maximum value from the two outer shells etc.

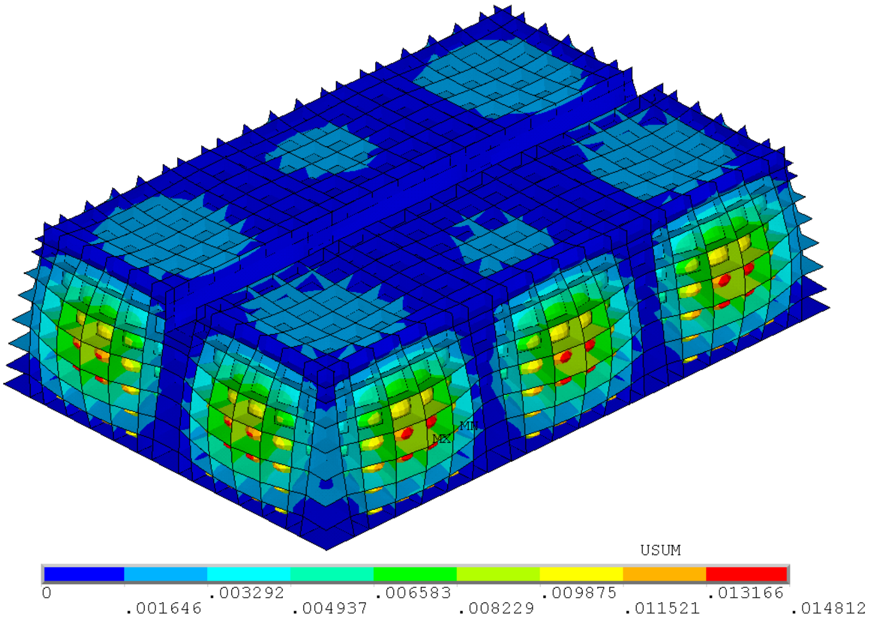

Fig. 12. Total deformation of the model in m (displacement scale factor is 100)

Fig. 13 presents the stretch stress (S1), represented on the middle plane of the composites, as the maximum value from the two-outer shell (the view deformation is amplified 100 times) – only horizontal plates of the honeycomb structure are shown.

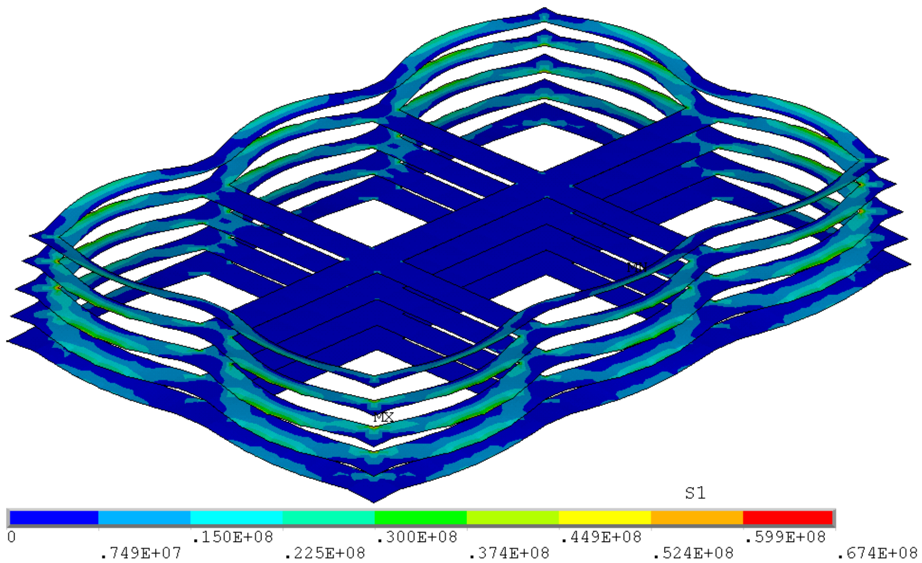

Fig. 13. Stretch stress represented on the middle plane of the composites

Maximum deformation in the model is around 15 mm, and maximum equivalent stress is 135 MPa. This value is obtained in the area where the honeycomb structure is fixed to the foundation. The main stress is compression, and in reality, in that area the tendency is the floor to sink in the foundation. The computational model is not fully adequate for 100% trustworthy results.

In a honeycomb structure, the stress (stretch and compression) is under 70 MPa, value that should be allowable for a quality composite panel. This is a theoretical analysis, and in order to fully trust the results we have to completely characterise the composite material and know its mechanical properties: foam material, joint procedure, glue procedure between the core and the shell, yield strength and ultimate strength for both core and shell etc.

The main problem of using composites in practice is their sensitivity to low velocity impact [11-17].

5. Conclusions

The authors succeeded to validate the FEM computation of the composite materials by measuring the maximum stresses and the maximum displacements generated by very harsh winter conditions on a kindergarten. The National Civil Engineering Structures Laboratory created a full SCADA system in order to find out the behavior of such a building loaded by an unusual snow load, a strong wind and a very low air temperature during a long winter. The continuous measurements have shown a good agreement both with the FEM prediction, and with the natural loading conditions. The difference between the overall real displacement of the roof center, and the predicted one was less than 2%!

This research may be regarded as an important step in the direction of promoting a new generation of robust, time resistant and affordable materials in the small building’s technology. The complexity of the composite materials demands many modeling, simulation, and test efforts, both in laboratory and in real applications. The results of the project were mentioned by the Reinforced Plastics Magazine, an Elsevier review [18].

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