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SEISMIC BEHAVIOUR OF A HYBRID STRUCTURAL SYSTEM WITH MINERAL MATRIX

BY

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Abstract. The interest towards the ecological materials and the advanced technology have led to the research of a new type of additives and substances that can successfully replace Portland cement, integral or partially. Starting from the obtained results on this type of materials and noticing their capacity to be combined in composite materials that can be reinforced with random glass and polypropylene fibre, an integral hybrid structural system, with multiply panels, for an individual dwelling house, was constructed. The final shape of the panels bearing structure is plate type with stiffening ribs on vertical and horizontal direction. The solution of technical issue consists in total replacing of the steel reinforcing bars with glass fibres (synthetic or natural) and also in the replacement of a Portland cement percentage. This experiment proposes the testing of an innovative one level structure, scale 1:1, under typical seismic loading for Romanian structural design, to note its behaviour, seismic energy dissipation and failing. The experimental model was progressively tested with field acceleration maximum values varying between 0.1 g and 0.9 g.

Key words: structural system; hybrid panel; seismic testing; mineral matrix.

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1. Introduction

In recent years, there is a considerable interest in the use of glass fibre reinforced plastics as structural material in the construction industry. In their present state of development, composite materials are flexible, expensive and flammable unless specially protected, so these materials are not very suitable as structural elements, *e.g.* walls, floors, ceilings and partitions. For these building components it would be desirable to replace the resin by a matrix or binder which does not suffer from these disadvantages. Normal cements and super sulphated cements used in the construction industry can provide such inexpensive matrices which are required for structural elements.

Cements and concrete are brittle materials, very weak in tension. This weakness is conventionally overcome with steel reinforcement. The thickness of concrete cover required to protect steel from corrosion, and for the needed strength of materials make these elements relatively heavy. The result of using these materials is a structure whose weight is significant and thus the seismic force, which is a part of total weight, is considerable. The need to develop a lighter material and structural element based on inexpensive cements or a combination of these with high structural and impact strength has therefore grown in recent years, both for engineering and architectural reasons. Extensive research carried out since the early 1964 in U.S.S.R has shown that a suitable composite material can be produced by reinforcing special cements, such as gypsum-aluminous slag cement and high alumina cement, with low alkali borosilicate glass fibre, commercially available all over the world (*e.g.* E-glass). E-glass fibres are not attacked by super sulphated cement and Portland cement or a combination matrix (Majumdar, 1970).

In 2008, in France, a super sulphated cement was patented. The technology consists in producing a new binder made exclusively from the processing of gypsum ($CaSO_4.2H_2O$). Gypsum is available both from the natural and the by-product of various chemical processes. In nature, gypsum exists with some deposits of anhydrite also. Among the by-product gypsum production, phosphogypsum, fluorogypsum and FGD gypsum are the waste products of phosphoric acid, hydrofluoric acid and the desulfurization of flue combustion gases of coal, foundry, oil refineries or power stations respectively. Gypsum products are known for their fire resistance, thermal insulation and acoustic properties. Gypsum has adequate strength but is not moisture resistant (Singh & Garg, 2005).

Recent studies conducted at the "Gheorghe Asachi" Technical University of Iaşi, Faculty of Civil Engineering and Building Services has shown that the super sulphated cement in addition with Portland cement, sand, and water have obtained high strength in a short period of time. At a curing age of 7 days, the tension strength is of 4 MPa and the compression strength is of 32 MPa, and after 28 days the final strengths are of 10 MPa in tension and 42 MPa in compression. This binder with alkali resistant glass fibre mesh led to the obtaining of structural elements like shear walls, slabs and eventually an entire structure. This paper presents a report of an experimental research program which consists in observing different failure mechanisms and deformation modes of hybrid solution shear wall building module made from composite material with mineral matrix (Hohan *et al*., 2011; Țăranu *et al*., 2011; Grădinariu *et al*., 2011).

2. Experimental Program

Starting from the obtained results on this type of materials and noticing their capacity to be combined in composite materials that can be reinforced with random glass and polypropylene fibre, an integral hybrid structural system, with

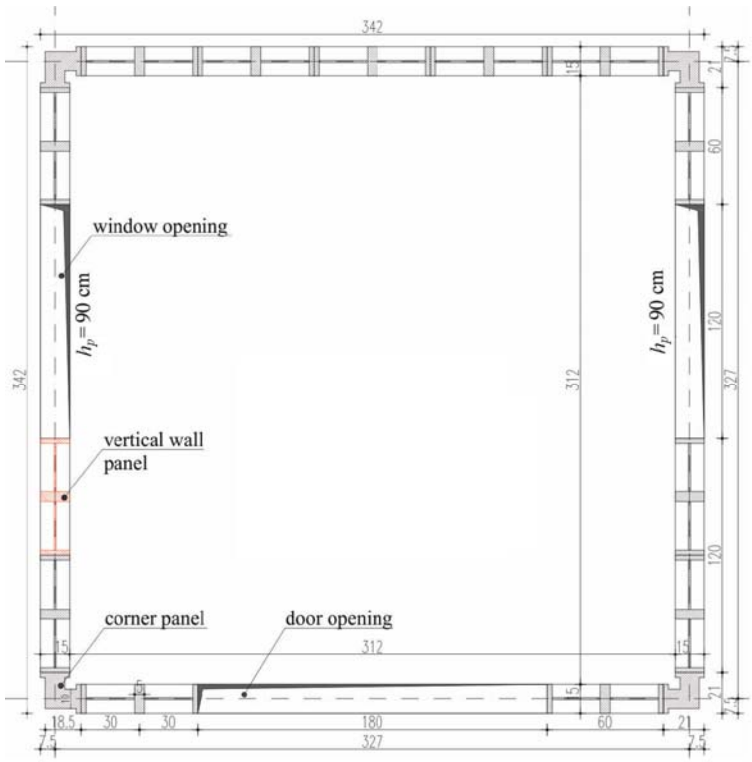

Fig. 1 – Dimensions of the experimental model for seismic testing.

multiply panels, for an individual dwelling house, was constructed. The experimental model proposed for seismic testing represents a one level structure, scale 1:1, with the plane dimensions depicted in Fig. 1.

2.1. Experimental Model Description

The constructive system procedure consists in creating a monolithic structure through the pouring of a Kerysten® based microconcrete in precast panels for walls and slabs. These semi-finished panels become lost shuttering and have a thermal insulating purpose.

The structural system of the model is composed from multiply panels. The final shape of the panels bearing structure is plate type with stiffening ribs on vertical and horizontal direction (Budescu *et al*., 2010). The used panel types are divided in four categories, depending on their location in the structure. Thus there are internal and external vertical load bearing panels (Fig. 2), horizontal panels for precast slabs (Fig. 3), vertical non-bearing panels and vertical corner panels (Fig. 4).

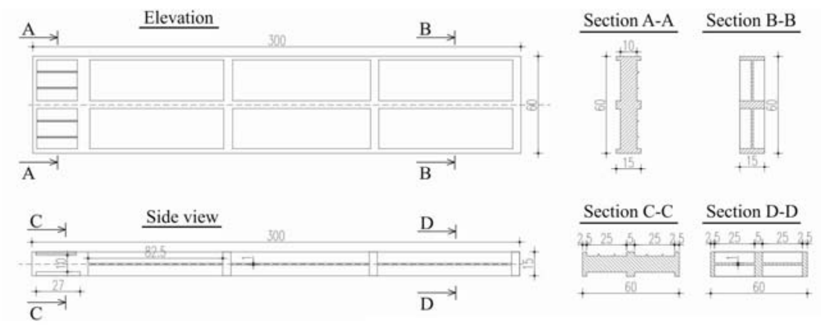

Fig. 2 – Vertical wall panel.

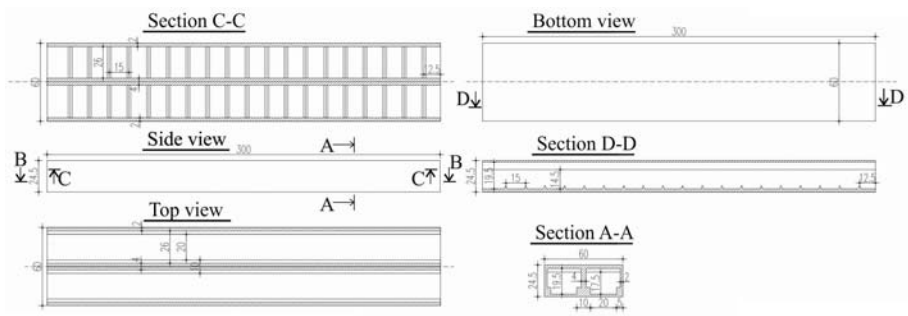

Fig. 3 –Horizontal slab panel.

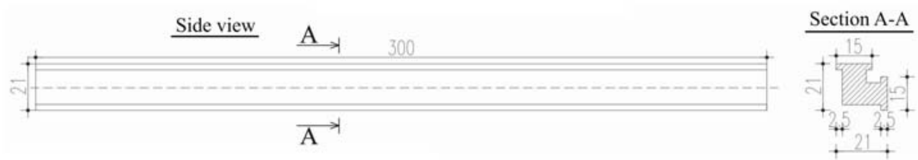

Fig. 4 – Corner panel.

The resulted vertical ribs are disposed at a 30 cm distance between them and the horizontal ones at 60 cm, respectively. The dimensions of the ribs cross-section are of 5 × 15 cm. These multiple panels have semi-finished facings, a width of 60 cm and the height of a usual level.

The solved technical issue consists in total replacing of the steel reinforcing bars with glass fibres (synthetic or natural) and also in the replacement of a Portland cement percentage (INCERC, Iaşi, 2008; Budescu *et al*., 2010).

Fig. 5 – The model load bearing structure.

For better noticing of the map-cracking that could appear after testing the removal of the external thermal insulating material was required (Fig. 5).

2.2. The Properties of the Used Materials

The basic material used in the research study is obtained exclusively from industrial wastes, mostly irretrievable (phosphogypsum, lactogypsum, citrogypsum, FGD, etc.), according to the French patent on Kerysten®. The mechanical properties are summarized in Table 1.

Table 1
Material Properties

Mixture	Density ρ, [kg/m^3]	Tensile strength R_t, [MPa]	Compression strength R_c, [MPa]	Elasticity modulus E, [MPa]
Mixture 1	1,800	9.75	42	25,000
Mixture 2	1,750	10.7	40.5	26,000

The gypsum based material was used combined with Portland cement, sand and water and resulted in a different material from the main constituents with superior workability properties (Grădinariu *et al*., 2011). Glass fibre mesh was used as reinforcement and its properties are presented in Table 2.

Table 2
Glass Fibre Properties

Fibre type	Mail dimension mm	Density ρ, [g/m^3]	Tensile strength R_t, [MPa]	Elasticity modulus E, [MPa]
Glass	5 × 5	160	1.3	69.58

2.3. Rigging of the Experimental Model

The structural response was obtained using displacement and acceleration transducers.

Fig. 6 – Data recording transducers regarding the structure response: *a* – Dytran 3202A1 LIVM accelerometers; *b* – PT5AV displacement transducers.

A number of four transducers were used to record the displacements and a number of eight transducers to record the accelerations. The transducers are shown in Fig. 6. The measuring points were picked in such a way to distinguish some basic deformation shapes.

In Fig. 7 is presented the positioning of the accelerometers at slab level and the array of the displacement transducers at platform and slab level. Thus the measuring points can record a possible twisting due to the model skewness.

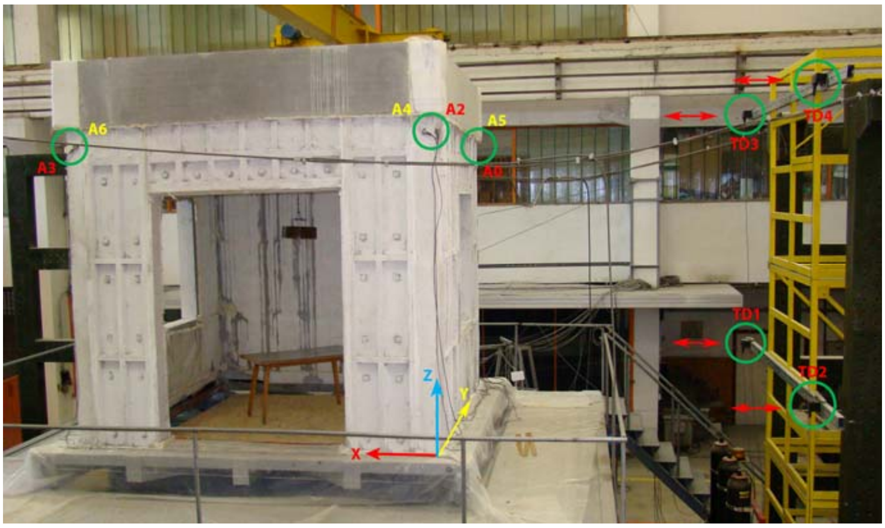

Fig. 7 – Placement of the transducers on the experimental model: A0, A1, A2, A3 – accelerometers on *X*-direction; A4, A5, A6, A7 – accelerometers on *Y*-direction; TD1, TD2, TD3, TD4 – displacement transducers.

2.4. Description of the Simulated Seismic Action

In the present study, the fundamental frequency of wall models was obtained based on vibration generator tests performed before the first shaking. The determined fundamental frequency of the structural model was of 7 Hz.

Preliminary to the seismic testing a low intensity first test was performed, with a maximum acceleration of the seismic platform below 0.1g. The purpose of this test was to verify the entire system, starting from the action and ending with the data recording.

The first tests made with accelerations higher than 0.1g were gliding sinus type actions with amplitudes of 0.2g, 0.3g and 0.4g. The applied ground motion data is shown in Table 3.

Table 3
Applied Ground Motion Records

Name	Frequency Hz	Duration s	*X*-direction		*Y*-direction	
			PGA, [g]	PGD, [mm]	PGA, [g]	PGD, [mm]
Sine sweep 7 Hz	7	10	0.404	43	0.40	45
Sine sweep 10 Hz	10	15	0.404	40	0.40	42
Vrancea 1986	1.5	25	1.00	48	0.98	50
El Centro 1940	4	30	0.92	60	0.96	65

The frequency content of El Centro (Imperial Valley station – 1940), Vrancea (Romania – central of country – 1986) and artificial ground motion records are depicted in Figs. 8,...,10 in *X*- and *Y*-directions.

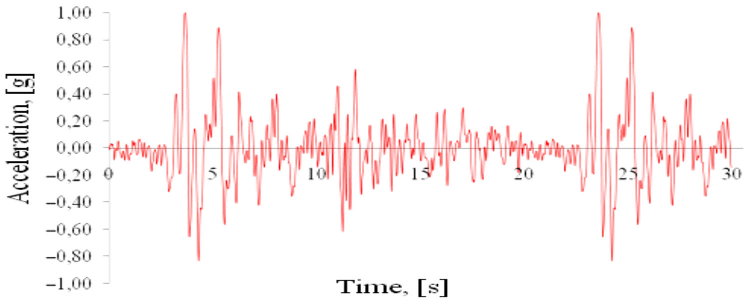

Fig. 8 –Vrancea (1986) accelerogram.

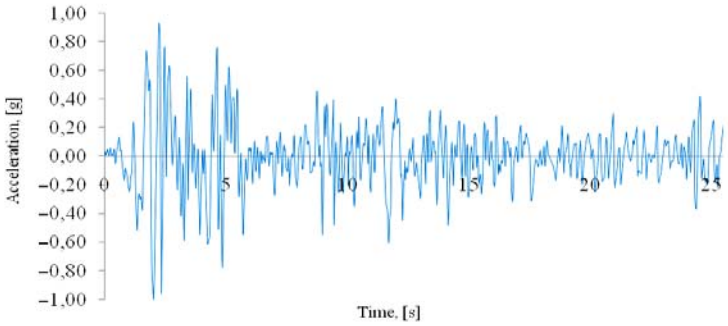

Fig. 9 –El Centro (1940) accelerogram.

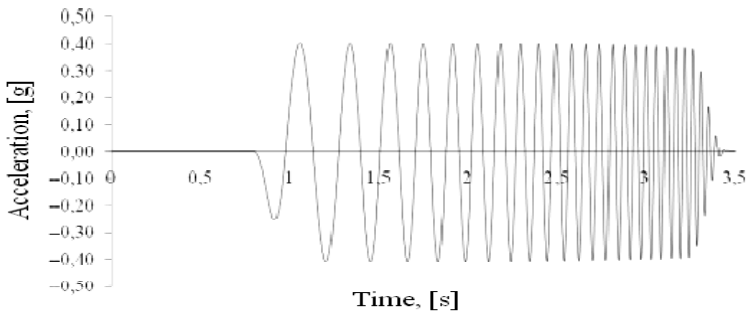

Fig. 10 – Gliding sinus type accelerogram.

The Vrancea (1986) earthquake tests are characterized through accelerations that reach a maximum level of 0.6g on a frequencies domain of 3...5 Hz, an action that affects rigid structures with a natural vibration frequency higher than 5...7 Hz.

The El Centro (1940) action is characteristic to the earthquakes with a maximum level of accelerations of 0.32g on a frequency domain of 1...2 Hz, which means that the structures with a natural frequency of vibration between 2 and 4 Hz are affected by this action.

2.5. Obtained Results

The experimental model was tested progressively with maximum values of ground acceleration varying from 0.1g to 0.9g. At each value of the acceleration the model behaved linear and no cracks were noticed on the surface of the wall panels. In Table 4 are recorded the results of the structure response at the seismic simulated action (Budescu *et al*., 2010).

Table 4
Recorded Results after the Simulated Seismic Actions

Seismic action	Frequency Hz	Period s	Accelerations $g = 9.81\ m/s^2$	Max. absolute displacements $x1/x3$, [mm]	Relative level displacements mm
Gliding sinus 7 Hz	7	0.14	0.5g / 4.90	–	–
Gliding sinus 10 Hz	10	0.10	0.35g / 3.43	–	–
El Centro (1940)	1.5	0.67	0.32g / 3.14	41.17 / 46.18	6.00
Vrancea (1986)	4	0.25	0.7g / 6.87	27.14 / 28.6	8.00

Frequency-spectra analysis is carried out for acceleration responses of each floor. Magnitude-frequency and phase-frequency relationships of acceleration responses are obtained using transformation function and fast Fourier transformation technique. Figs. 11 and 12 show the results of frequency-spectra analysis for the acceleration responses of the top floor of the structures.

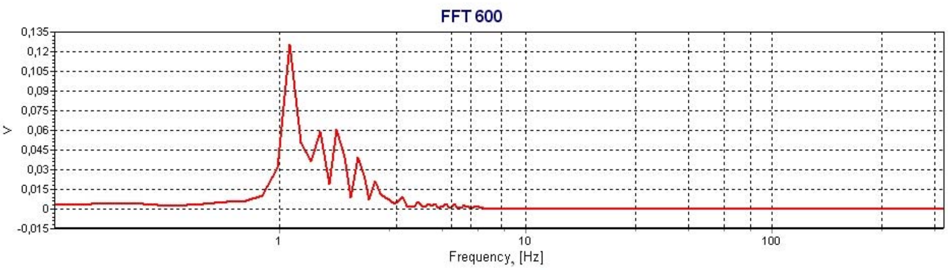

Fig. 11 – El Centro action Fourier spectrum of frequencies.

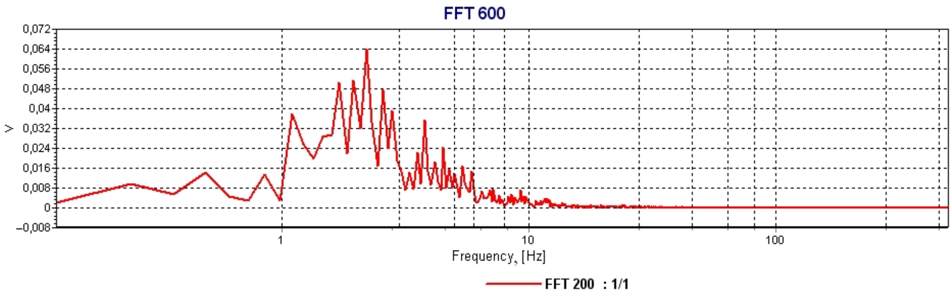

Fig. 12 – Vrancea action Fourier spectrum of frequencies.

4. Conclusions

After processing the obtained data of the structure for all the applied actions, the following conclusions have been established:

1. The structure had no damage under seismic testing with accelerations up to 0.32...0.4g for El Centro actions and gliding sinus of 10 Hz.

2. For gliding sinus of 7 Hz, with a maximum level of the accelerations of 0.5g (4.90 m/s^2), the structure had no visible damage.

3. For the Vrancea (1986) seismic action, in which the maximum acceleration of the model was of 0.7g (6.87 m/s^2), there was no significant degradation at the base level of the model nor in the structural wall panels.

4. The maximum displacements recorded for El Centro (1940) were of 41.17 mm and 46.18 mm for the absolute maximum displacement at base and at slab level of the model, respectively, with a relative maximum displacement of 6.00 mm.

5. The maximum displacements recorded for Vrancea (1986) were of 27.14 mm and 28.60 mm for the absolute maximum displacement at base and slab level of the model, respectively, with a relative maximum displacement of 8.00 mm.

The new innovative hybrid solution made from composite materials with super sulphated cement matrix and glass fibre mesh had a favourable behaviour during the shaking table tests. The application of El Centro and Vrancea earthquakes (which are the typical seismic actions for structural design in Romania) had no significant damages of structural model.

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COMPORTAREA LA ACŢIUNEA SEISMICĂ A UNUI SISTEM STRUCTURAL HIBRID CU MATRICE MINERALĂ

(Rezumat)

Interesul faţă de materialele obţinute ecologic dar şi tehnologia avansată au condus la cercetarea unor noi tipuri de aditivi sau substanţe care pot înlocui cu succes cimenturile Portland, parţial sau integral. Pornind de la rezultatele obţinute pe materiale şi observând capacitatea acestora de a putea fi combinate pentru a rezulta în final materiale compozite ce pot fi armate cu fibre de sticlă şi fibre disperse polipropilenice, s-a realizat un sistem structural hibrid integral din panouri multistrat având destinaţia de locuinţă individuală. Forma finită a structurii de rezistenţă a panourilor rezultată este de tip placă cu nervuri de rigidizare dispuse pe direcţie verticală şi orizontală. Problema tehnică pe care o rezolvă acest procedeu constă în înlocuirea în totalitate a armăturilor metalice cu armături de fibre de sticlă (sintetice sau naturale) şi, de asemenea, în înlocuirea într-un anumit procent a cimentului Portland. Acest experiment îşi propune testarea unei structuri parter realizată la scara 1:1 la acţiuni seismice tipice pentru proiectarea structurală in România, în vederea observării modului de comportare, disipare a energiei seismice si cedare al acestui sistem structural inovativ. Modelul experimental a fost testat progresiv cu valori maxime ale acceleraţiei terenului variind de la 0,1g la 0,9g.