AN INNOVATIVE HYBRID SOLUTION TO IMPROVE THE SEISMIC BEHAVIOUR OF A SHEAR WALL BUILDING MODULE

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Development of new construction materials based on green cement and their combination with reinforcing fibres have led to mineral matrix composite materials and hybrid systems with better mechanical properties compared to those made of traditional building materials. In addition to having high strength and high stiffness shortly after their casting the materials and structural components should have a good capacity of energy dissipation when subjected to seismic loading. A novel combination of a normal cement and super sulphated cement which represent the matrix associated with textile meshes made of glass fibres has been investigated to enable their use in seismic resistant building modules. A full scale model of one storey building made of this novel hybrid material has been seismically tested on a shaking table whose action is based on a specially programmed acceleration time-history. The response of structure consists of accelerations and displacements which are recorded and processed. It has been proven that the building module based on shear walls made of the above mentioned hybrid system represents an efficient structural system when subjected to seismic actions.

Keywords: composite materials, hybrid solution, seismic action.

INTRODUCTION

In recent years, there is a considerable interest in the use of glass fibre reinforced cement as structural material in the construction industry. Normal cements and super sulphated cements used in the construction industry can provide inexpensive matrix for glass fibre reinforcing products which is required for structural elements. Cements and concrete are brittle materials, very weak in tension. This weakness is conventionally overcome by reinforcing concrete with steel. The thickness of concrete cover required protecting the steel from corrosion, and the strength of materials makes these elements relatively heavy. The need to develop a lighter material and light weight structural element based on inexpensive cements or combination of these and having high structural and impact strength has therefore grown in recent years both for engineering and architectural reasons [1, 2].

Recent studies conducted at the Technical University “Gheorghe Asachi” of Iasi, Faculty of Civil Engineering and Building Services has shown that the super sulphated cement in addition with Portland cement and sand, Calcium stearate, Retardant Superplasticizer and only 20% water has lead to high strengths in a short period of time. After 20 days the final strengths were 12 MPa in tension and 40 MPa in compression. This binder with glass fiber mesh alkali resistant has proven to be very efficient in structural elements like shear walls, slabs and in least a complete structure. This paper presents some results of an experimental research program aiming to identify different failure mechanisms and deformation modes of a hybrid solution shear wall building module made of fibre reinforced composite material with mineral matrix. The composite material is formed from E glass fiber meshes and special binder based on super sulphated cement, Portland cement and sand in different proportions.
EXPERIMENTAL PROGRAM

Shaking Table Tests

Shaking table tests have many advantages such as studying the seismic damage mechanics and evaluating the seismic capacity, studying the distribution of seismic forces, locating the weak points in the structure and verifying the dynamic analytical models for the new structural systems [3, 4]. This study investigates the full-scale one-storey building based on a shear wall hybrid solution system on the shaking table. The module was loaded under traditional ground motions with sufficient band-width of frequency content for exciting the system. This action has been applied progressively to the table and structural responses of building have been determined.

Three different shaking table tests have been carried out on the hybrid shear wall module. The tests have been performed on the shaking table at Faculty of Civil Engineering and Building Services Iasi, Department of Structural Mechanics. The test facility has a 3.6x3.6 m platform and a 3.5 m usable height and three-degree of freedom. The physical model has been built from structural hybrid panels with in-plane dimensions 3.42m x 3.42m, Figure 1, and a height of 3.00m.

Model Geometry

The structural model has been realized from hybrid panels with a thermal-insulating material core and fibre reinforced cement composite external layers, obtained by combining the super sulphated cement and Portland cement binder as matrix and E glass fibres meshes. The composite material based on glass fiber reinforced cement matrix represents the load bearing material in facings with 20mm thickness. The panels modulated as 60cm x 300cm have been assembled on the platform and in a couple of days the structural module has been built. To obtain the whole module, the panels have been positioned in their places, Figure 2, and the binder has been cast in the channel.
network existing in panels at 30 cm between vertical ribs and 60 cm between horizontal ribs. The workability of binder enabled an easy cast in place facilitating the covering of all glass fiber meshes and their embedment in the composite layers.

Details from construction process of the structural model are presented in Figure 2. The vertical and horizontal ribs provide a load bearing network very effective in resisting vertical and lateral loading. The monolithic continuity between the columns in the vertical walls and those of the slab is thus ensured. After days from the execution of model the external cover of thermal-insulation was removed. This enables a detailed survey of cracks development during testing under various loading conditions, especially under seismic action.

**Material Properties**

A binder super sulphated cement structural module it has been used with Portland cement and sand. The proportion was 1:1:2 and the water ratio were 0.20 from all quantity. Besides the basic constituents, 2% of a superplasticizer, 1% cement retardant and 2% Calcium stearate was added. The glass fiber mesh used is an E type of glass which is alkaline resistant.

**Experimental Set up**

The structural model has been installed on the shaking table platform with the following performance characteristics: the gravity load capacity=160 kN; the dynamic displacement amplitude=±15 cm; the frequency range=0.5÷50.0 Hz; the action type is triaxial (two in horizontal plane, one in vertical direction); the peak acceleration with a payload 100kN=± 3g and the maximum velocity= ±0.8 m/s. The acquisition of the test data has been digitally performed, by simultaneously recording signals from 2 types of transducers, Figure 3: Dytran 3202A1 LIVM (accelerometer) and PT5AV (displacement transducer).
Fundamental Frequency

An essential step in the seismic design of structural buildings is to determine the natural frequencies of the structure [5, 6]. The response of the shear walls to ground motion is dominated by the fundamental frequency of the structure. In the present study, the fundamental frequency of wall models was determined based on vibration generator tests performed before the first shaking of the model. The fundamental frequency equal of the structural model equal to 7Hz has been determined.

Input Motions

The dynamic loading applied on the specimen by the shaking table started from a set of diagnostic low level tests on intact specimen including impulse loading and white noise excitation; finally, respective low-level to high level seismic excitations were done. The base motion records were applied to the building progressively. The applied ground motion data are shown in Table 1. Accelerations time-histories of selected earthquakes are shown in Figures 4a and b [7, 8].

<table>
<thead>
<tr>
<th>Name</th>
<th>Frequency (Hz)</th>
<th>Duration (s)</th>
<th>X-direction PGA (g)</th>
<th>PGD (mm)</th>
<th>Y-direction PGA (g)</th>
<th>PGD (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sine sweep 7Hz</td>
<td>7</td>
<td>10</td>
<td>0.404</td>
<td>43</td>
<td>0.40</td>
<td>45</td>
</tr>
<tr>
<td>Sine sweep 10Hz</td>
<td>10</td>
<td>15</td>
<td>0.404</td>
<td>40</td>
<td>0.40</td>
<td>42</td>
</tr>
<tr>
<td>Vrancea 1986</td>
<td>1.5</td>
<td>25</td>
<td>1.00</td>
<td>48</td>
<td>0.98</td>
<td>50</td>
</tr>
<tr>
<td>El Centro 1940</td>
<td>4</td>
<td>30</td>
<td>0.92</td>
<td>60</td>
<td>0.96</td>
<td>65</td>
</tr>
</tbody>
</table>
Tests SS7, SS10, ELC100, and VN100 of 20 tests in both E-W and N-S directions corresponded to progressively higher maximum input accelerations ranging from 0.3 to 0.7g. These tests are chosen for the analysis conducted in this paper.

**EXPERIMENTAL RESULTS AND DISCUSSION**

The model has been progressively excited with a peak ground acceleration ranging from 0.1 to 0.9g. At each level of acceleration the specimen behaved completely linearly and no visible cracks were observed in wall panels. In Table 2 a summary of results is given.

<table>
<thead>
<tr>
<th>Run</th>
<th>A0 (g)</th>
<th>A1 (g)</th>
<th>A4 (g)</th>
<th>A5 (g)</th>
<th>TD1 (mm)</th>
<th>TD2 (mm)</th>
<th>TD3 (mm)</th>
<th>TD4 (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS7</td>
<td>0.51</td>
<td>0.48</td>
<td>0.47</td>
<td>0.46</td>
<td>31</td>
<td>30</td>
<td>33</td>
<td>34</td>
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<tr>
<td>SS10</td>
<td>0.35</td>
<td>0.34</td>
<td>0.38</td>
<td>0.37</td>
<td>24</td>
<td>23</td>
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<td>28</td>
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<tr>
<td>VN100</td>
<td>0.72</td>
<td>0.71</td>
<td>0.39</td>
<td>0.41</td>
<td>27</td>
<td>26</td>
<td>32</td>
<td>31</td>
</tr>
<tr>
<td>ELC100</td>
<td>0.32</td>
<td>0.34</td>
<td>0.36</td>
<td>0.35</td>
<td>42</td>
<td>41</td>
<td>47</td>
<td>46</td>
</tr>
</tbody>
</table>

Frequency-spectra analysis is carried out for acceleration responses of each floor, and magnitude-frequency and phase-frequency relationships of acceleration responses are obtained by using transformation function and fast Fourier transformation technique. Figures 5a and b show the results of frequency-spectra analysis for the acceleration responses of the top floor of the structures. The maximum relative displacement produced was 8.00 mm in the case of Vrancea 1986 seismic action, and the maximum acceleration in the same case was 0.72g. Visible damages during the tests were not observed.

Figure 4. Acceleration time history of: a)-Vrancea 1986; b)-El Centro 1940

Figure 5. Response spectra in X direction: a)- Vrancea 1986 action; b)- El Centro 1940 action
CONCLUSIONS

In this paper, an innovative hybrid shear wall solution for building modules is proposed and tested under seismic loading. Shaking table tests to evaluate the structural response have been carried out. A full-scale seismic test of a one-storey module building has been investigated under several ground motions.

The following conclusions are drawn:

The summarized observations through the experimental program are as follows:

– Initial natural frequency of the test building is 7 Hz and 7.85 Hz in X and Y directions, respectively.
– At the 0.3g and 0.5g level of acceleration in cases of Sine Sweep dynamic actions, no visible cracks occurred;
– At the 0.32g and 0.72g the maximum level of acceleration in case of El Centro 1940 and Vrancea 1986 seismic actions, no visible damages occurred, the structure remaining stable and stiff.
– At the 0.72g the maximum level of acceleration, the total displacement was 50 mm and the relative displacement between top floor and bottom floor of structural model was 8 mm.

The new innovative hybrid solution of shear walls 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) have not produced significant damages of structural model.

Acknowledgement

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REFERENCES