SHAKING TABLE TESTS ON FERROCEMENT HOUSES

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ABSTRACT :

This paper presents the dynamic characterization of a full-scale single story housing module built using precast ferrocement panels. The module (test structure) was tested on a shaking table and subjected to a series of harmonic input ground motions with intensity varying from 0.07g to 0.21g at a fixed frequency of 0.95 Hz. The house showed excellent structural response. Roof drift ratios of up to 0.3% were attained with no discernible structural damage. The system exhibited controlled rocking behavior with energy being primarily dissipated by friction between adjacent panels. The model studied as part of this research represent a building system that has potential for use in regions of the world of limited economic development having a high seismic hazard.

KEYWORDS: ferrocement, shaking table, dynamic behaviour

1. INTRODUCTION

Seismic activity in Western South America directly affects all housing structures in the region. Recent strong earthquakes, Colombia 1999 and Peru 2007, demonstrated the poor behavior of most buildings systems utilized for housing projects in the region. Some studies have been conducted on shaking tables to determine the dynamic response of precast housing systems (Hashemi, 2006, Midorikawa, 2006, Turer et al, 2007); the results of these investigations have resulted in a better understanding of the problem and have prompted some code specification for regions having moderate and high seismic hazard.

Ferrocement, a wire mesh reinforced mortar material, has been used for many years for the for the construction of precast low-cost housing projects. Some pseudo-dynamic test have shown adequate behaviour (Bedoya-Ruiz, 2005); furthermore, the performance of these ferrocement structural systems have been simulated, indicating slight damage to properly anchored panels (Bedoya-Ruiz, et. al., 2008).

The response of precast panels based housing structures which are subjected to earthquake accelerations are controlled by rocking of the panels (Prieto and Lourenço, 2004 and 2005). Shaking table testing is usually used to determine the response of structural systems which exhibit rocking behaviour (Midorikawa, 2006).

This article reports on tests conducted on a shaking table to evaluate the dynamic response of an assemblage made with ferrocement panels. The module tested was subjected to a series of harmonic signals with diverse base accelerations. The results obtained represent an adequate performance of the structural system with little damage of the ferrocement panels; these tests also greatly contribute to the understanding of the dynamic behaviour of precast housing systems.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

Ferrocement may be considered as reinforced concrete for which its special distribution and relative size of the reinforcement modifies its structural behaviour. The reinforcement consists of wire-mesh of small diameters which is uniformly placed across the transverse section of the element ; the mortar matrix is generally made of Portland cement, sand, water, and in some cases admixtures and additions. This arrangement facilitates the production of walls with small thickness, with values usually ranging from 20 mm to 50 mm.

2.2 Panels and test structure

The panels were built with typical local materials customarily used for houses and low cost buildings. The mortar matrix was produced with Portland type I cement; its workability was enhanced by adding a superplasticizing admixture. Eleven 1:1 scale specimens were produced having 2.00 m of height, 1 m of length and 20 mm of thickness. Six hexagonal woven meshes were provided as reinforcement for each panel. The mortar mixture was prepared using materials proportions suggested in previous research (Bedoya-Ruiz, 1996) consisting of a water-to-cement ratio equal to 0.4, sand-to-cement ratio equal to 2 and superplasticizing admixture in the amount of 1% of the cement weight.

The test structure, shown in figure 1, has a height of 2 m, plan dimensions of 3 m x 3 m and a total mass of 135 Mg.

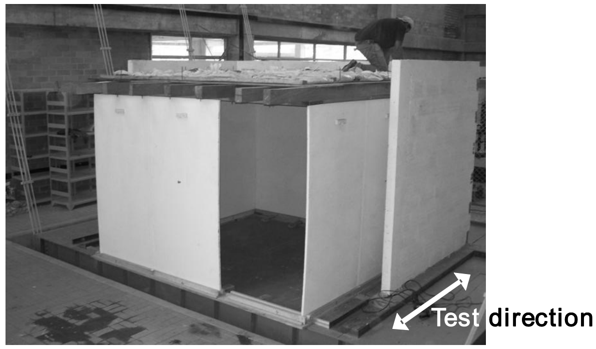


Figure 1. General view of test structure

The panels were placed on U shaped precast concrete elements; these elements were bolted to the shaking table metallic floor through a 20 mm thick wooden plank. The concrete elements configuration is such that restricts the panels movement at the four corners of the module, as can be seen in figure 2a. The panels were not anchored to the floor system nor to each other.

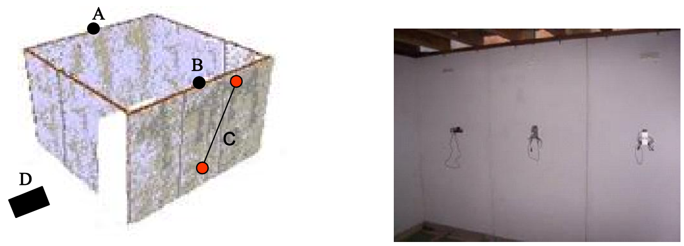
A wooden diaphragm made of 14 mm plywood sheets nailed on eight 80 mm x 30 mm timber beams was bolted to inverted U shaped wooden beams placed on the panels and connected at the corners with steel plates, as shown in figure 2c.

(a) Panels support (b) Panels (c) Upper diaphragm

Figure 2. Test module set up details

2.3 Instrumentation

An accelerometer (D) was installed on the shaking table to measure the input acceleration at the base of the test module. The module itself was instrumented with eight accelerometers in the direction of the movement and one linear position transducer (C) to measure relative displacement between panels. As shown in figure 3a, accelerometers A and B are place at the upper diaphragm. The rest of the accelerometers were placed at mid height on the panels as illustrated with figure 3b.



(a) At the diaphragm (b) At the panels

Figure 3. Instrumentation of test module.

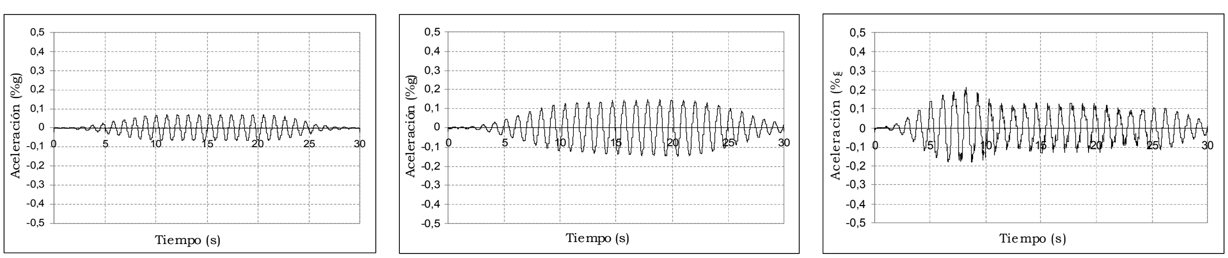
2.4. Input motions and displacements of test structure.

Harmonic signals, with a fixed frequency of 0.95 Hz, were used as input for the tests. Each test lasted a total of 30 seconds: 5 seconds for the signal to attain its maximum intensity, 20 seconds of sustained acceleration and 5 seconds to reduce it until a full stop. The test were conducted with accelerations increasing in steps of approximately 0.07g (0.687 $^{m}/_{s^2}$), until failure occurred or the test was halted.
Signal characteristics and module response are presented in table 2.1.

Table 2.1.1. Input motions and module response

Input acceleration	Reponse acceleration at diaphragm level	Amplification	Relative displacement at diaphragm level
g	g		mm
0,07	0,08	1.1	3
0,15	0,22	1.5	12
0,21	0,63	3.0	50

Input signals at the module's base are presented in figure 4



(a) Maximum: 0.07g (b) Maximum: 0.15g (c) Maximum: 0.21g

Figure 4. Input motions

3. TEST RESULTS AND DISCUSSION

3.1. Displacement at the diaphragm level

To obtain the module's displacement at the diaphragm level, the response signals from accelerometers A and B were processed in order to filter out high and low frequency noise produced by the shaking table engine and panel banging. The obtained frequency range is [0.125 – 1] Hz. Figure 5 presents diaphragm displacements for various frequency cutoff values. Obtained displacements are similar to those registered by the linear position transducer (C).

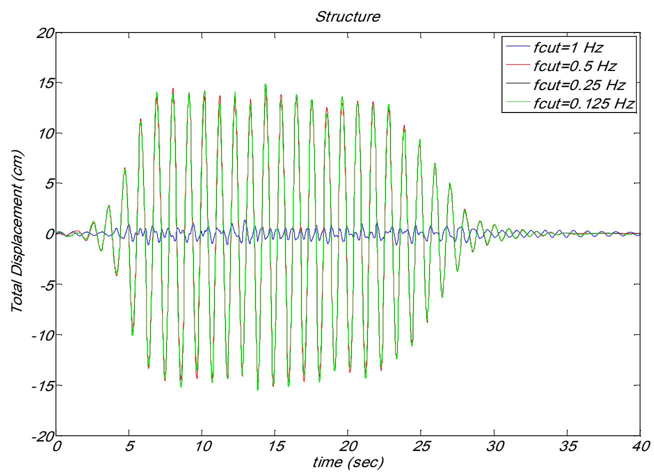


Figure 5. Diaphragm displacement time histories. Maximum input acceleration = 0,21g

3.3 Dynamic characteristics of the test module

Most of the horizontal displacement at the diaphragm leve lis due to panel rocking (rigid body rotation around the panel's tip); therefore, minimum diaphragm horizontal displacement may be calculated as twice the relative vertical displacement between panels measured by the linear position transducer (C), as the panel height to length ratio is 2:1. Consequently, the calculated diaphragm horizontal displacement corresponding to the response accelaration of 0.63 g, was 100 mm. Thus, the structural period of vibration may be estimated as:

$$T = 2\pi\sqrt{\frac{D_{\max}}{A_{\max}}} \quad (3.1)$$

Where D_{max} is the maximum diaphragm response displacement and A_{max} is the maximum diaphragm response acceleration. Thus, on one hand, according to equation 3.1, the test module period is 0.8 s. However, on the other hand, by the dynamic equilibrium of a rigid body with the dimensions of one panel, the system's period of vibration may be estimated as:

$$T = 2\pi\sqrt{\frac{D_{\max} h}{g(d - D_{\max})}} \quad (3.2)$$

Where h and d are the panel's height and length, respectively, and g represent gravity's acceleration. The period of vibration calculated as per equation 3.2 is 0.95 s which differs approximately 15%, from the previously calculated period.

3.3 Damage of test module

Despite the significant acceleration amplification at the diaphragm level, damage was limited to some spalling at the tip of some panels due to stress concentration caused by the panel rocking, as illustrated in figure 6.

(a) No damage at the diaphragm level (b) No damage between panels (c) Spalling at the tip due to rocking

Figure 6. Damages of test module

4. CONCLUSIONS

The tested structural module dissipated energy through rocking of the precast panels. Rocking started at about 0.15 g of input acceleration, for which the amplification at diaphragm level is 1.3. Greater base accelerations resulted in significant response amplifications up to 3 times for base acceleration of 0.21 g. Estimated periods are close to 0.9 s. Little damage was caused to the system even for maximum accelerations.

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