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Shake table test of a 1:2 scale historical unreinforced masonry building

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Abstract

Most unreinforced masonry structures are vulnerable to seismic actions. Due to the poor shear and bending resistance of masonry walls, seismic actions can sometimes produce mechanisms that may lead to the collapse of the building. This paper presents the results of a shaking table test performed on a 1:2 scale unreinforced masonry building. The results consist of a map of cracks that appeared after the test and some numerical values regarding the dynamic characteristics. The accelerations and displacement recorded show the behaviour of the structural model and the maximum seismic capacity of the system.

Key words: unreinforced masonry, seismic action, shake table test

1 Introduction

In order to experimentally simulate the effects of earthquakes and the behaviour of constructions subjected to this type of action, the tests performed on seismic simulators such as seismic platforms are recognized for the realistic scenarios that can be reproduced in laboratory conditions. A major advantage of the tests on the seismic platform is that they can capture the way in which deformations occur and develop and that is significant information in evaluating the behaviour of certain types of structures such as those made of concrete or masonry [1, 2].

In addition to the benefits that this type of test offers, there are also a number of technological limitations related to the size of the vibrating mass and the maximum pay load of the platform. These limitations introduce certain restrictions on the use of scaled models for testing. In the field of civil engineering, a general problem that intervenes in experimental testing is the size of the model. The structures to be investigated and assessed are normally large, which makes them impossible to test at a natural scale. Consequently, testing is performed either on only certain parts of the structure itself or on small, scaled-down models [3, 4].

Scale modelling involves reducing the size of a structural model without losing important features related to the behaviour of the prototype. A structural model is defined as any element or set of structural elements constructed at a small scale, designed to be tested, for which the laws of similarity must be used in order to interpret the test results. The purpose of the physical tests is to obtain as accurate data as possible on the behaviour of the prototype in normal loading conditions, on the response in the form of displacements, accelerations, failure mechanisms, etc. In the case of small-scale models, this scaling can affect its physical properties, so it is important to consider these changes in order to draw conclusions as close to reality as possible in terms of prototype behaviour [5].

2 Materials and test set up

The model designed for the experimental program aims at the most accurate replication of the structural typology, using masonry made of solid ceramic bricks and weak mortars based on lime and local aggregates. These construction materials (masonry, lime mortar, wood) as well as the structural typology were very common in the constructions of the past centuries, especially in the region of Iasi but also in other areas of Romania.

The structural model proposed for testing represents a building made of unreinforced brick masonry, ground-floor only, with a flexible ceiling supported by wooden beams and a classic roof, as shown in Fig. 1. Regarding the geometry of the structure, they had to fit within the size and weight limits of the shaking table. Thus, a box-type structure with four walls has been designed: two load-bearing walls, with door and window openings and two solid transverse walls, Fig. 1 a), b). The footprint of the building resulted in 2383 x 1914 mm, with a storey height of 1490 mm and a roof height of 390 mm.

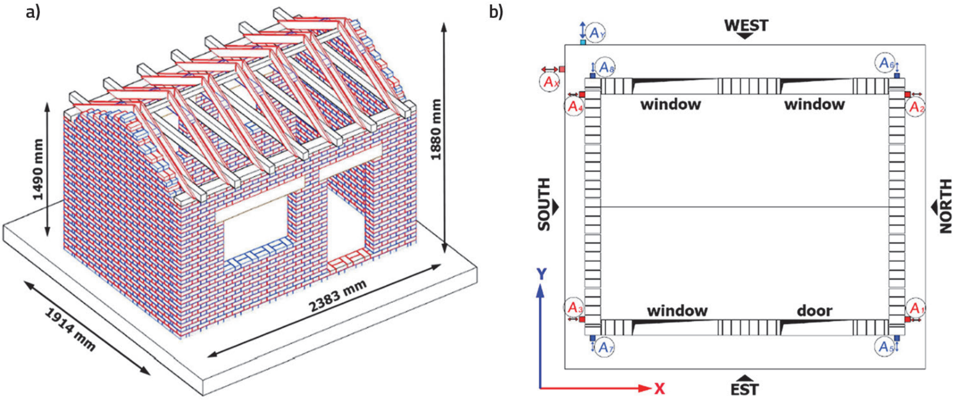

Figure 1. a) Building perspective view b) plan view of the model

The process of constructing the structural model had to follow the original typology of execution of heritage buildings and to respect the principles of geometric similarity that have to be considered in the case of scaled-down models. The bricks used have been designed to 1:2 scale with respect to a traditional unit standard ceramic brick. The scaled bricks represent about a quarter of the total volume of the original brick, having nominal dimensions of 117 x.62 x 36 mm (Fig. 2).

Figure 2. Normal and scaled bricks

The mortar used was a combination of lime and pufar (a calcareous sand obtained from a nearby area of Iasi). The proportion of the mixture was 1:1 by volume. The scaling process continued with the joints between the ceramic blocks that have been reduced to a thickness varying between 5 and 8 mm. Fig. 3 presents the aspect of the structural model with the additional masses mounted at the level of the ceiling.

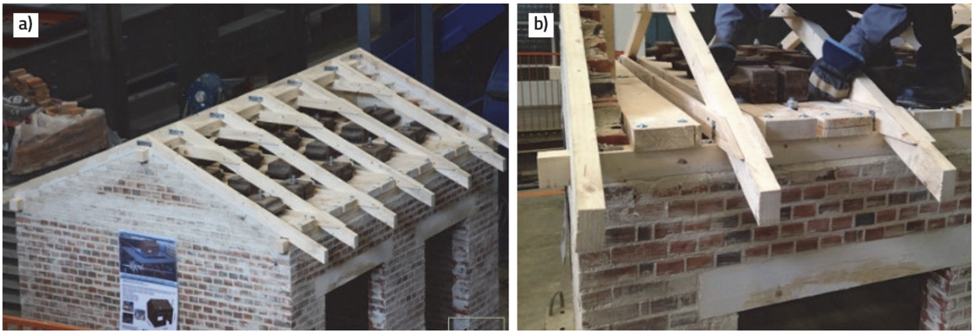

Figure 3. a) Aspect of the prepared structural model; b) Mounting the additional masses

3 Shaking table test of the structural model

In order to carry out the experimental test for seismic actions, the built model was mounted on the 160 kN shaking table of the Faculty of Civil Engineering and Building Services of Iasi. The shaking table has the following characteristics:

- capacity: 160 kN or 16 metric tonnes;
- platform base dimensions: 3.05 m x 3.05 m with a grid (20x20 cm) of M24 threaded holes;
- maximum acceleration (with a payload of 10 tons): ± 3 g;
- maximum frequency with a payload of 10 tones: 50 Hz.

The acquisition of experimental data (seismic action) and the response of the model tested were digitally recorded. Two types of transducers were used: accelerometers - Dytran 3202A1 LIVM (up to ± 10g) and PT5AV displacement transducers - (up to ± 0.5m). Their location on the scaled-down model is presented in Fig. 4.

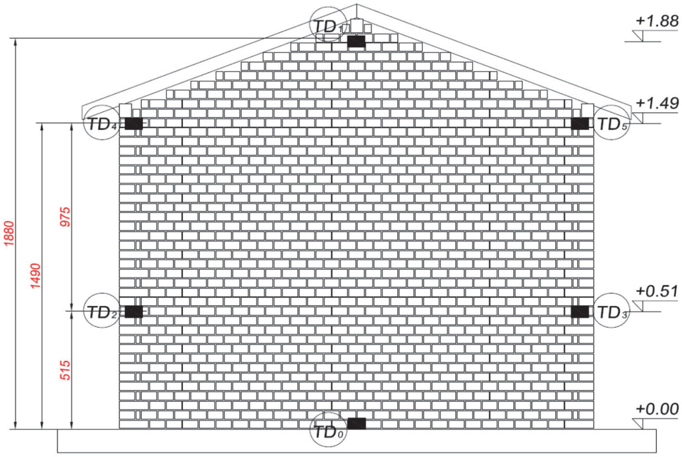

Figure 4. Position of the displacement transducers on the north wall of the model

The experimental tests were carried out by testing the structural model with different types of sinusoidal actions. These are presented in Table 1.

Table 1. Unidirectional shaking table types of action

Test no.	**Action type**	**Frequency** [Hz]	**X direction**	
			PGA [g]	**PGD** [mm]
1	Sine beat	3.6	0.05	1.74
2	Sine beat	3.6	0.10	3.54
3	Sine beat	3.6	0.15	6.69

4 Results and discussion

Before and after each simulated action, the structural model was carefully examined and evaluated in order to observe the occurrence of the type of degradations, their location and their size.

Table 2 shows the response of the model in terms of accelerations and displacements. Thus, the maximum values recorded by each accelerometer and displacement transducer are observed.

Table 2. Maximum recorded values

Test no.	**Action type**	**Accelerometers**				**X direction Displacements**				
		A1 [g]	**A2** [g]	**A3** [g]	**A4** [g]	**TD$_1$** [mm]	**TD$_2$** [mm]	**TD$_3$** [mm]	**TD$_4$** [mm]	**TD$_5$** [mm]
1	Sine beat	0.19	0.315	0.125	0.146	2.56	1.86	1.65	2.11	2.05
2	Sine beat	0.26	0.28	0.26	0.29	5.20	4.20	3.48	4.55	4.55
3	Sine beat	0.31	0.29	0.28	0.24	29.22	8.98	7.86	19.48	15.14

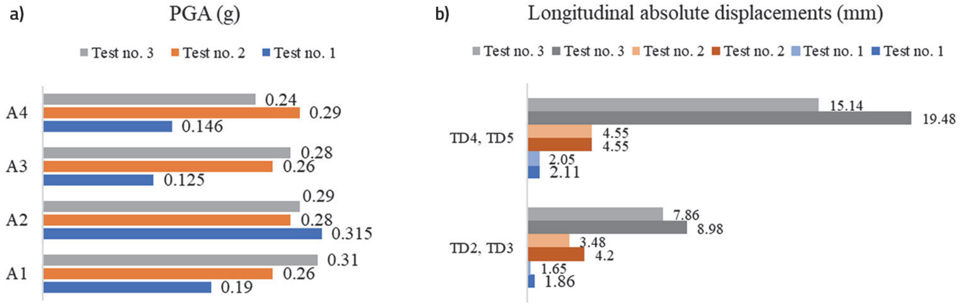

Figure 5. a) Variation of accelerations; b) maximum absolute displacements recorded

From the graph shown in Fig. 5b it can be observed that in case of Tests no. 1 and no. 2 with the maximum level of acceleration of 0.19g, the relative displacement between TD2 and TD4 is less than 23.5 %. However, in the case of Test no. 3, the level of acceleration was 0.315g, which leads to an increase in the values of the absolute displacement. The relative displacement is also higher by almost 54 %. Fig. 6, 7, 8 present the aspects of the model after the tests. Multiple cracks that occurred in different positions can be observed in the drawings next to the photo taken during the experiment for each of the Fig. 6, 7 and 8. The identified cracks and their location match the observations reported in the scientific literature [6]

The identified cracks were marked with different colours. Each colour used represents the moment of its occurrence: light blue - degradations occurred during the first sine beat test shown in Table 1; dark blue – the previously produced cracks widened during the second sine-beat loading scenario with increased amplitude; orange - degradations occurred during the second sine-beat loading scenario, their distribution being generally diagonal, following the path of the mortar joints; green - degradations occurred during the third sine-beat loading scenario along the mortar joint; red - degradation in bricks occurred during the third sine-beat loading scenario [6, 7].

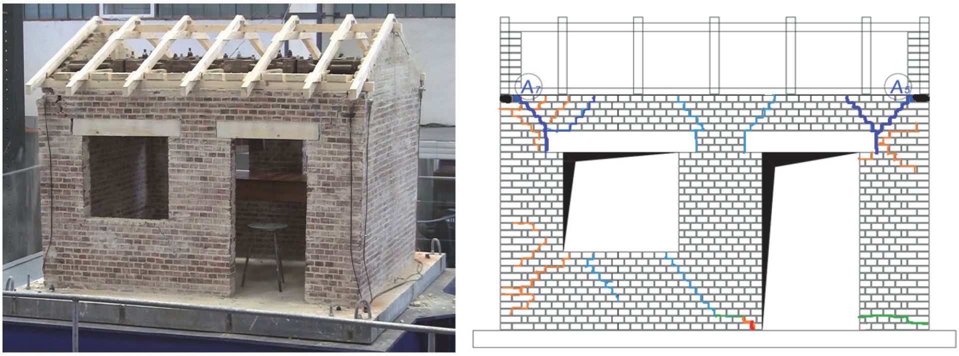

Figure 6. East wall with inclined cracks highlighted along the corners

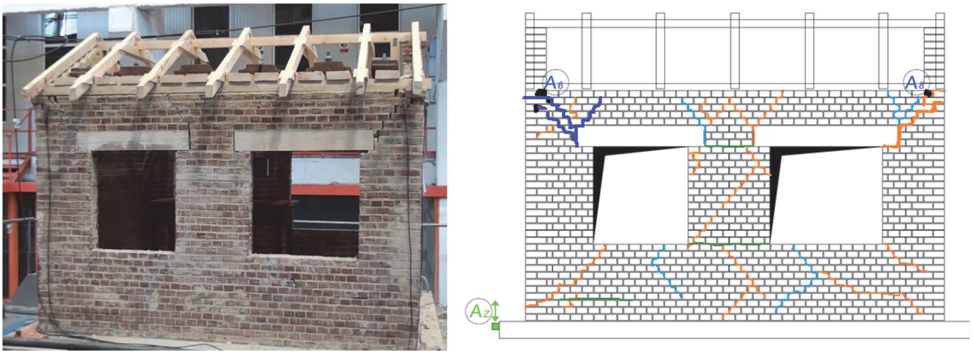

Figure 7. West wall with inclined cracks highlighted along the corners

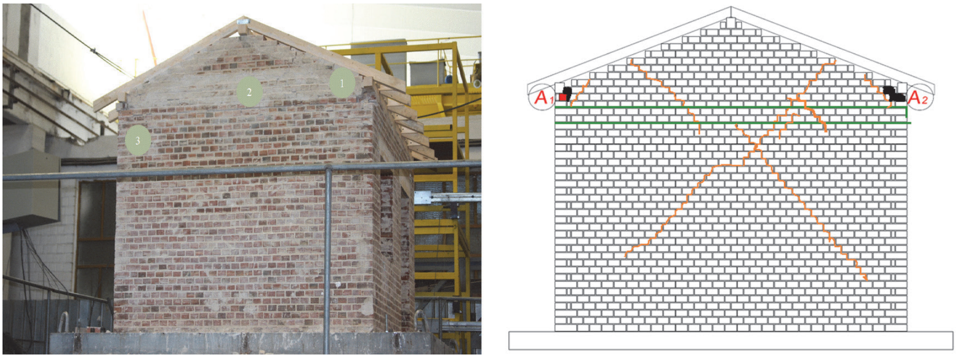

Figure 8. South wall with inclined cracks highlighted

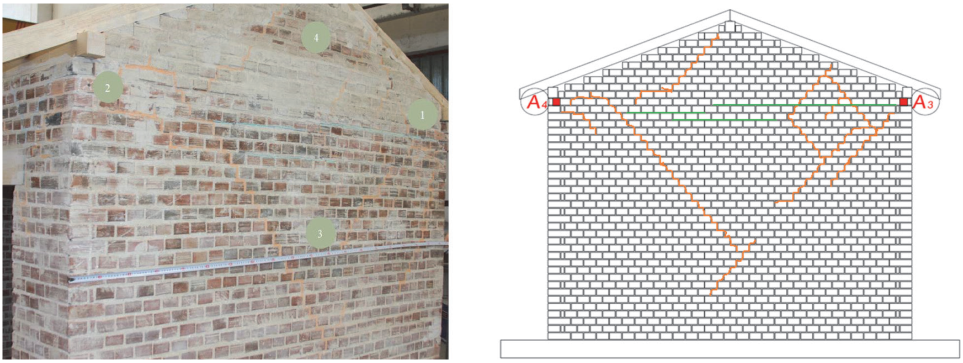

Figure 9. North wall with inclined cracks highlighted

The values recorded by TD2 and TD3 are very close to one another, which means that the model moves uni-directionally and the torsional effects are negligible. However, when the PGA of the input shaking motion increased, the difference in the values recorded by the displacement transducers located on both sides of the model, Fig. 4, started to significantly differ from one another, meaning that torsional effects became more important. This was particularly noticed for the displacement transducers located at the gutter level [8]. This could be explained by the position and the dimensions of the gaps for door and windows in the two longitudinal walls in the direction of the seismic motion which lead to different stiffness.

5 Conclusions

The experimental results indicate that unreinforced brick masonry walls with lime-pufar mortar have been damaged in the masonry plane. Most of the cracks were concentrated in the areas where shear stresses occur, at the level of the parapets and at the corners of the window openings. In the case of actions outside the walls plane, the upper areas of the walls have exhibited larger displacements. These tests indicate that the rocking mechanism can cause a stable nonlinear response of the structure, both to the actions perpendicular to the plane and in the case of those in the masonry plane, provided there is a good connection between the brick layers. However, in the case of low strength mortars, such as traditional mortars, this is very difficult to obtain due to the poor adhesion between the mortar and the brick.

Keeping a good connection between the orthogonal walls and ensuring that both window and door openings are within normal values, as well as the wall openings and their height, can significantly remove the failure of the walls due to out-of-plane stresses.

The damage to the corner area of the walls depends on two factors: the first is related to the way the floor is anchored to the structural walls (lack of shear transfer connections can lead to lateral forces acting perpendicular to the wall plane) and the second factor is determined by the existence of window and door gaps in the immediate vicinity of the corner area. The latter is produced due to the in-plane motion for the longitudinal walls leading to the occurrence of a rocking moment at the joints that connect the parapet and the lintel related to the gap. The moment generates stresses in the vertical and horizontal joints at the intersection area of the parapet and the lintel. As a direct consequence, the diagonal cracks occur and extend at an angle of approximately 45 degrees.

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