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Research Article

Optimization of the Use Time of Shake Table with Specimen Preparation Outside the Table Surface

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Abstract

The shake table test is one of the preferred techniques to understand the dynamic response of a structure. However, due to a limited number of available facilities to perform such tests and their expensiveness, researchers often have to rely on numerical models validated with the results of the static tests only. Moreover, most research papers concerning shake table tests lack details on how the tests were planned and executed. This paper explains the steps used for the preparation and execution of shake table tests on three reduced-scale buildings. These buildings were constructed outside the shake table surface, on a metallic base frame, and later moved to the shake table for the tests to optimize the time of the experimental campaign. It enabled to complete the tests in 6 days only. The approach presented in this paper can be helpful for researchers who want to increase the effectiveness of the available shake table facility and overcome the limitation of time and budget. Moreover, the solution presented in this article helps in displacement of specimens without the use of a crane or other sophisticated hydraulic machinery. Thus, it could also be useful for testing specimens that have been aged and that are sensitive to displacements.

Keywords: Dynamic test; Experimental setup; Shake table; Building test; Masonry structure; Specimen displacement

Introduction

Numerical models are a cost-efficient and convenient tool for the determination of the dynamic behaviour of a structure. However, they require proper validation supported by experimental results. They are often validated at a material scale [1] and, sometimes, just with the numerical reference model [2]. However, numerical models validated with multi-scale experimental tests [3-5] are a powerful tool for parametric analyses. Moreover, the shake table test is a great tool to understand the seismic performance of structures under realistic earthquake signals. Yet, experimental tests with shake tables are rarely performed because of the limited availability of these facilities and their expensiveness. A low-cost shake table with the dimension of 1.5 m × 2.0 m was built with US $45,000 [6], and a shake table with a bigger size of 2.5 m × 3.5 m was built with a moderate cost of less than €250,000 [7]. Hence, even for the cheapest shake tables, the cost investment is significant. Therefore, optimized utilization of such testing apparatus is necessary.

The dynamic shake table tests are performed on various structures built using concrete, wooden, steel, brick, or other composite materials. The structures, which do not require curing time, can be directly assembled on the shake tables like steel frame structures [8]. However, masonry structures require a curing period, and for reasons of availability of the shake table, these specimens cannot be built on the table surface. Moreover, these structures are sensitive to displacements. Therefore, proper construction methods and displacement of the specimen up to the shake table are necessary for them. It is the main focus of this article.

Different campaigns with this problem can be found in the literature. Single half-scale stone masonry was constructed on a rigid steel base connected to the shake table [9]. Three dry stone masonry models scaled by a factor of 0.55 were constructed outside the shake table on a concrete base frame simultaneously [10], but the process of moving those structures on the shake table is missing. A similar concrete base was used to construct two 1:3 reduced scale adobe models [11]; the displacement of the model up to the table was made using the forklift, and the final lifting and placement of the models on the table were made with the help of an overhead crane. The safe shifting of specimens is crucial to prevent damage when placing them on the shake table.

In some cases, the mass of the model constructed and the base support can become too important for the mounted crane to handle it. Hence, the 1:6 scale model with a dimension of 3.54 m x 3.54 m was directly assembled on a steel frame base, fixed to the shaking table [12]. Similarly, the 1:3 reduced scale stone masonry model, weighing more than 6 tons, was directly built on the shake table [13].

Need and scope of work

Cost and time are the two most commonly used indicators when measuring any system's effectiveness [14]. Therefore, the effectiveness of the shake table test can be optimized by proper planning and execution of the tests. The scale of the model to be tested under dynamic test is limited by the size of the shake table and the capacity of the hydraulic jack (force, velocity, and displacement limits). Apart from the technical limitations of the shake table itself, there are other limitations such as availability of scaled-down material, connection, time for construction, and mass of the built model. That is why several dynamic tests on the shake tables have been performed with the reduced scale model. Still, there is a lack of information regarding how to optimize the use time of the shake table and the mechanism of placement of specimens on the shake table. This paper presents a detailed method regarding the shake table tests setup for three building models built simultaneously and later moved on the shake table for dynamic testing as part of Ph.D. research work [15]. This article focuses on the challenge to limit the shake table utilization time in case the sample needs time to be built and is heavy (difficult to move) like the case of the building test.

Shake table specification

The uniaxial shake table available at Forêt Cellulose Bois-construction Ameublement (FCBA), Bordeaux, France, is used to carry out the dynamic test. It is operated using a 250kN servo-hydraulic actuator. The surface area of the shake table is 6 × 6 m^2. The shake table's maximum acceleration, velocity, and displacement capacity are 4g (with a payload mass of 5 tons), 0.75m/s, and ±0.125m, respectively. The spacing between the connecting grid points on the table surface is 250 mm, which must be considered while connecting the samples to the shake table.

Three 1:2 reduced scale adobe masonry structures had to be tested under dynamic loading. The average mass of each structure was approximately 4 tons, which is too high for the gantry crane available on site. Therefore, a new approach was adopted to make the test possible. Figure 1 represents the timeline for the various stages of the planning, construction, and execution of dynamic tests. The planning and purchase of construction materials were the steps that took the most time. The construction of the three reduced-scale buildings was completed in 12 days. Afterward, they were left for drying at the temperature of 23±2 °C and relative humidity of 50 ± 5%. The final dynamic tests were completed in 6 days. Therefore, the shake table was occupied only during those six days. Detailed construction strategies and specimen displacement mechanisms that made it possible to efficiently run dynamic tests on three building models are explained in detail in the following section.

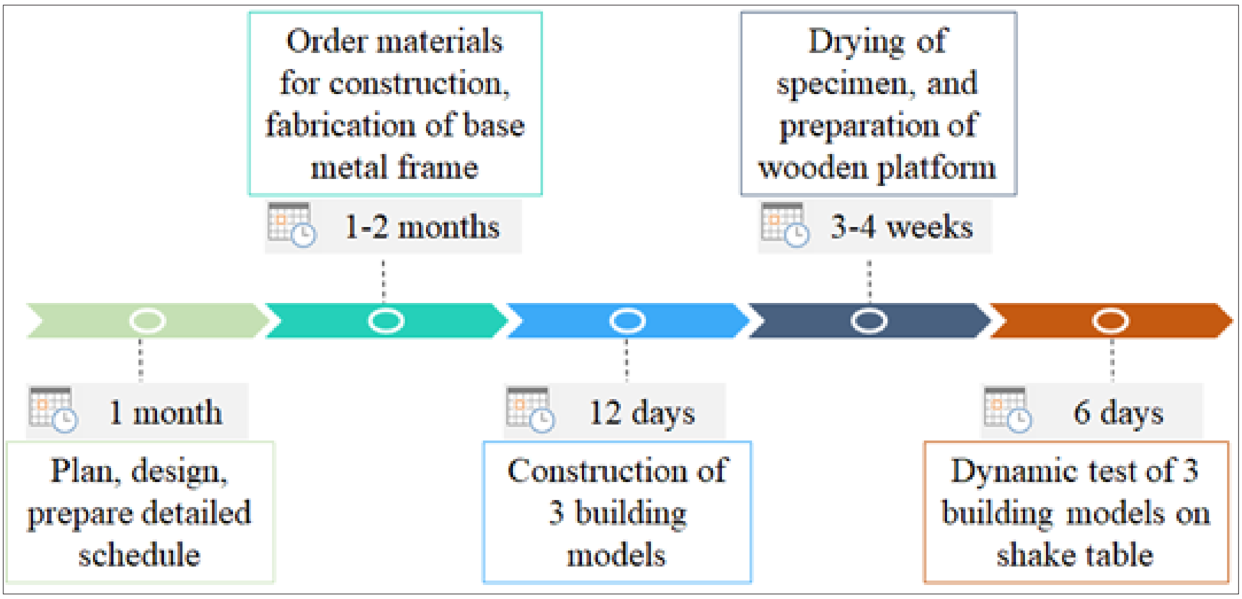

Figure 1: Timelines of the planning, construction, and execution of dynamic tests.

Metallic base frame

The dimension of the reduced-scale buildings was adopted from the reconstruction guideline of Nepal [16]. The external dimension of the 1:2 reduced scale two-room building model was 3230mm × 1575mm. Three metallic base frames made with HEB180 beams were manufactured for their construction. The base frame dimensions were chosen to easily fix it to the shake table with bolts. During the shake table test, this metallic base frame works as a part of the shake table. However, the maximum operating acceleration, velocity and displacement limit of the shake table is influence by the dead mass contributed by the metallic base frame, which needs to be taken into account for the total payload. The top and the bottom views of the metallic base frame are shown in Figure 2. The layout of the base frame corresponds to that of the model building. 50mm high metallic plates were welded on the top part of the frame. They are used for the construction of the base of the structure. On the bottom part of the frame, 10 rollers positions are designed, as shown in Figure 2. Each roller has a 360° degree rotational flexibility and helps displace the building model smoothly on the floor surface. The type of roller was chosen to be adequate with the total mass of the structure and the rugosity of the floor. The metallic base frame has extended support parts on each side of the longer side, as shown in Figure 2. They are used for the positioning and operation of hydraulic jacks for cars. Two metallic rods were welded on the external side of the shorter length. They are used to tie a cable while displacing the building model.

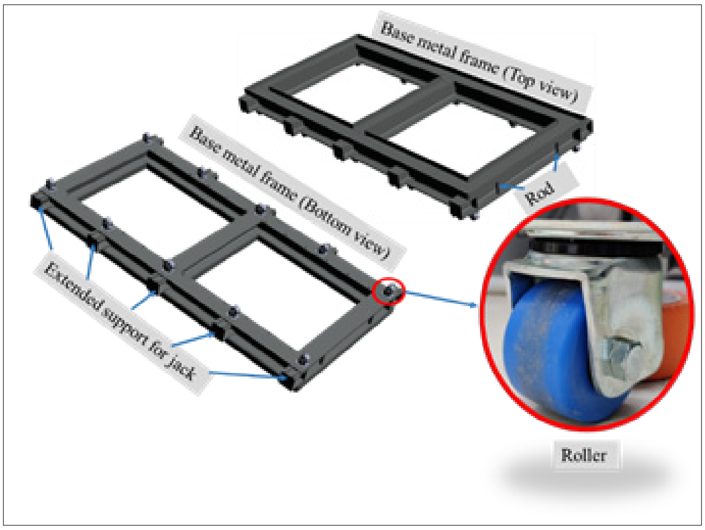

Figure 2: Metallic frame used at the base of the building model.

Reduced scale extruded adobe brick was used with mud mortar to construct three building models- one without a band, one with timber seismic band, and one with the reinforced concrete band. The schedule for building construction was planned such that the construction of all the buildings could be carried out simultaneously on the metallic frame placed on the laboratory floor. The construction started by casting 25mm of plain concrete on the metallic frame, as shown in Figure 3(a). The remaining millimeters of the metallic beam flange was used to lay the first brick layer so that the sliding at the interface between the concrete and the first mortar joint could be prevented during the test. For the construction of the buildings, the metallic frame does not lay on the floor but on timber parts to allow its elevation for the displacement of the samples.

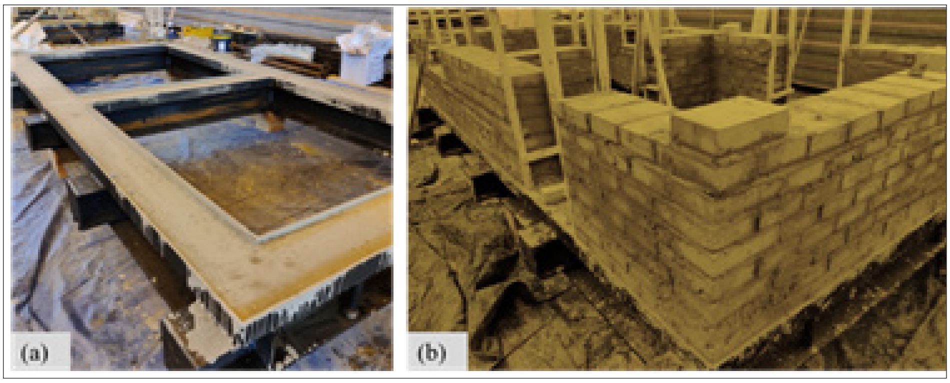

Figure 3: Plain concrete cast on the metallic frame (a) and bricklaying for building model (b)

Wooden platform

A wooden platform was designed to roll the models on the shake table easily. To make it possible, its height matches the height of the table. The wooden platform was built using timber beam and Oriented Strand Board (OSB) panels, as shown in Figure 4. It consists of 4 spring-loaded rollers placed at the corners, three layers of timber beam, and OSB panels placed over each level of timber beams. The all assembly is shown in Figure 4. Two metallic rails were screwed on the top of the platform to guide the roller of the metallic base frame while moving the building model on the shake table. The spring-loaded rollers shown in Figure 4 are designed to allow to move the empty platform. When the building is on the platform, its dead load makes the rollers vanish to help the stability of the whole platform.

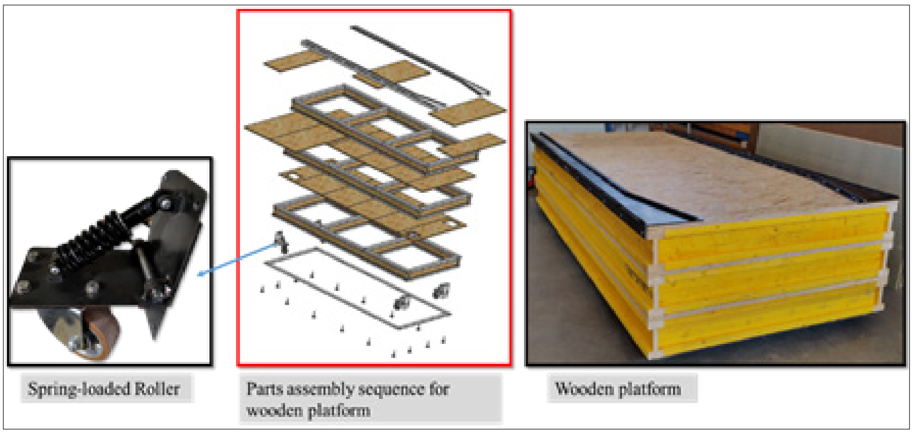

Figure 4: Wooden platform components and assembly sequence.

Building displacement sequence

The building models were conserved for three weeks before being moved on the shake table. The sequences used for transferring the building model from the floor to the shake table are as follow:

A. The metallic base frame was gently elevated from the floor to remove the supporting timber parts and to place the ten rollers (Figure 2) at the bottom of the frame. To do that, four hydraulic jacks (Figure 5) were used at each corner of the building simultaneously to prevent any damage to the structure.

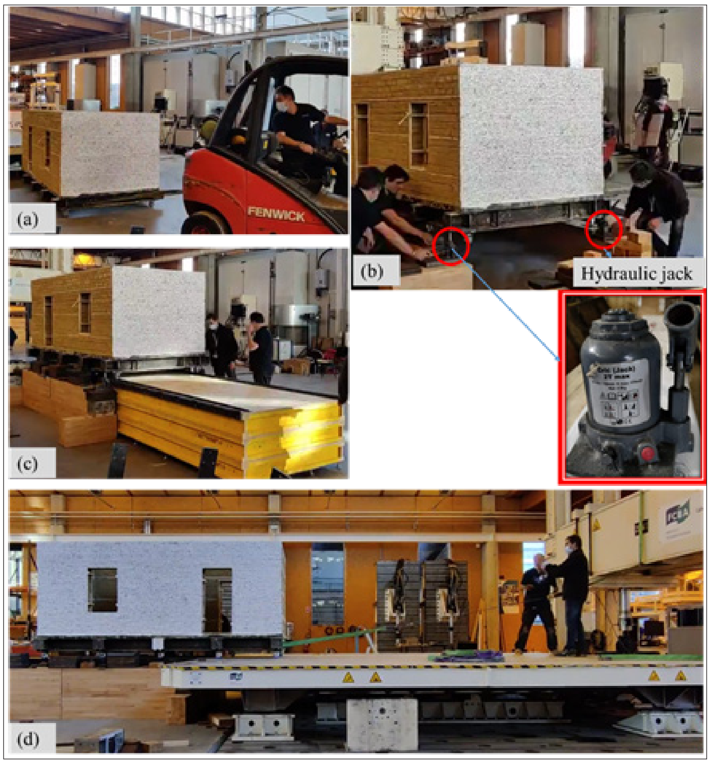

Figure 5: Moving building on the floor (a), elevating the building using car hydraulic jack and timber blocks (b), placement of wooden platform (c) and moving building on the shake table (d)

B. Once the model on its rollers was placed on the floor, a weightlifting belt was passed through the metallic rod (Figure 2) and connected to a forklift truck, as shown in Figure 5(a). With the help of the forklift truck, the building model was moved close to the shake table and aligned parallel to it.

C. The next step was to lift the model building vertically and to elevate it high enough to place the wooden platform under. For elevating the building model, initially, four farm jack, each with a maximum capacity of 3 tons, were used. But this approach was not effective due to the lack of stability of the farm jacks for displacement intervals of 20mm for each lift. Therefore, to improve this process, four hydraulic car jacks, each with a capacity of 2 tons, were used to elevate the building models vertically. The four hydraulic jacks were placed at the four external metal supports. The elevating operation was manually synchronized by counting the pumps (Figure 5(b)). The building was elevated by steps of 3-4cm on all sides simultaneously, and timber blocks were placed under the extended metallic support (Figure 2) to hold the position before beginning each new elevating cycle. Timber blocks are used for security (if one jack got a problem, the building fell only a few centimeters) and because of the limited vertical displacement of the car hydraulic jacks.

D. Once the building model was elevated enough to be slightly higher than the shake table site, the wooden platform was placed under the building model, as shown in Figure 5(c). The rollers' alignment was checked before releasing the hydraulic jacks and putting the building model on the wooden platform.

E. The building model was finally rolled on the shake table using the weight lighting belt attached to the metallic rod on the base frame and pulled using two manual cable pulling sets (also known as come along), as shown in Figure 5(d).

F. The position of the metallic frame was adjusted to fix the base frame on the table before removing the rollers. All the base rollers were removed using a similar approach as in stage 1 (Figure 6(a)). The metallic frame was fixed to the shake table using 12 bolts. To decrease the total mass during displacement, the roof is assembled on the building only after securely fixing the building to the shake table, as shown in Figure 6(b).

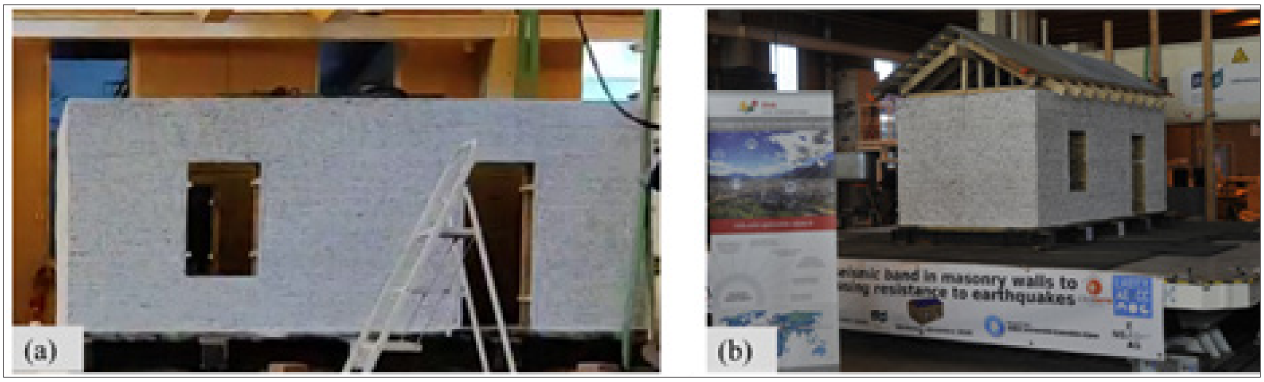

Figure 6: Positioning of the metal frame to fix it with the shake table (a), and roof installation on the building (b).

Conclusion and recommendation

The experimental preparation and setup details for the shake table tests are presented in this paper. With the innovative idea of developing a metallic base frame and wooden platform to move the building model on the shake table, the total cost and time of the experimental campaign were minimized. The metallic base frame is firmly connected to the shake table platform and does not influence the test results of the structure being tested. However, the mass of the metallic base frame contributes to the total payload of the system, which influences the maximum operating limit of the shake table. The construction of the three buildings model was completed in two weeks using the metallic base frames. The placement of the building model on the shake table, the connection of measurement sensors, and carrying out dynamic tests took two days for each building model. Therefore, the shake table was only occupied for six days to complete the three reduced scale building model tests. Hence, the idea of constructing the building structure outside the shake table and moving just before the test helps optimize the shake table utilization time and increase its effectiveness by allowing several tests in a short time. Also, the metallic base frame and wooden platform can be reused for future tests.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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