THE ROLE OF SEISMIC SIMULATORS IN EARTHQUAKE ENGINEERING AND PUBLIC PERCEPTION OF STRUCTURAL SAFETY

Vasile MEIŢĂ[1], Emil-Sever GEORGESCU[2], Claudiu-Sorin DRAGOMIR[3], Daniela DOBRE[4]

[1] PhD Arch., National Institute for Research and Development in Construction, Urban Planning and Sustainable Spatial Development "URBAN-INCERC", Email: vasile.meita@gmail.com

[2] PhD Eng., National Institute for Research and Development in Construction, Urban Planning and Sustainable Spatial Development "URBAN-INCERC", Email: emilsevergeorgescu@gmail.com

[3] PhD Eng., National Institute for Research and Development in Construction, Urban Planning and Sustainable Spatial Development "URBAN-INCERC"; University of Agronomical Science and Veterinary Medicine, Email: dragomirclaudiusorin@yahoo.com

[4] PhD Eng., National Institute for Research and Development in Construction, Urban Planning and Sustainable Spatial Development "URBAN-INCERC"; Technical University of Civil Engineering, Email: dobred@hotmail.com

ABSTRACT

Constructions located in various environmental conditions represent physical components of human habitat and earthquakes are often a cause of sudden damage and urban or rural destructuring. In the European Union the seismic safety of structures is ensured by Eurocodes and "performance-based design". However, many existing buildings, and even some newly designed, still have some vulnerabilities. Progress-based vision is undermined by the reality of some unexpected disasters (earthquakes L'Aquila 2009, Murcia-Lorca 2011, Emilia Romagna 2012 etc.). In Romania, constructions safety is achieved by adopting a new seismic design Code P100-1/ 2013, with a new zoning map of the Romanian territory in terms of design ground acceleration values, for earthquakes with mean recurrence interval IMR = 225 years. However, in spite of the automated computational techniques development, some illusion persist, considering that tests on simulators will be fully replaced by the advanced software. The reality of recent decades indicates that the number of shaking tables has increased, both in the European Union and in Japan, USA, China etc. PEER (USA), NERIES (FP6; 2006-2010) and NERA Projects have shown instead that tests are relevant even at small scale and the sophisticated numerical simulations and calculations are complementary. The experimental tests represent a method of investigation necessary to the development of new products and solutions and to performance evaluation of existing solutions. Also the public perception can be influenced positively by participating in such demonstrations.

Keywords: safety structures; seismic simulators.

REZUMAT

Construcțiile situate în diferite condiții de mediu reprezintă componente fizice ale habitatului uman, iar cutremurele sunt adesea o cauză a avariilor bruște și a distrugerii urbane sau rurale. În Uniunea Europeană siguranța seismică a structurilor este asigurată de Eurocoduri și de "proiectarea bazată pe performanță". Cu toate acestea, multe clădiri existente, și chiar unele recent proiectate, au încă unele vulnerabilități. Viziunea bazată pe progres este subminată de realitatea unor dezastre neașteptate (cutremurele L'Aquila 2009, Murcia-Lorca 2011, Emilia Romagna 2012 etc.). În România, siguranța construcțiilor se realizează prin adoptarea Codului P100-1/2013, cu o nouă hartă de zonare a teritoriului României în ceea ce privește valorile de proiectare ale accelerațiilor terenului, pentru cutremure cu interval mediu de recurență IMR=225 ani. Cu toate acestea, în ciuda dezvoltării tehnicilor computerizate automate, unele iluzii persistă, considerând că testele pe simulatoare vor fi complet înlocuite de software-ul avansat. Realitatea din ultimele decenii indică creșterea numărului de platforme seismice, atât în Uniunea Europeană, cât și în Japonia, SUA, China etc. Proiectele PEER (SUA), NERIES (FP6; 2006-2010) și Proiectele NERA au arătat că testele sunt relevante chiar și la scară mică, iar simulările numerice sofisticate și calculele sunt complementare. Testele experimentale reprezintă o metodă de investigare necesară pentru dezvoltarea de noi produse și soluții și pentru evaluarea performanțelor soluțiilor existente. De asemenea, percepția publică poate fi influențată pozitiv prin participarea la astfel de demonstrații.

Cuvinte cheie: structuri sigure; simulatoare seismice.

1. ROLE OF PROFESSIONAL AND DEMONSTRATION EXPERIMENTS

In construction field the experimental tests represent a method of investigation absolutely necessary to the development of new products and solutions and to the performance evaluation of the existing solutions (Meita et al, 2013). Thus, since the 60s, using “shaking tables” or "seismic testing facility" (hereinafter referred to as seismic simulators) allowed the testing of models of structures or equipments, from the natural scale to 1:6 up to 1:40. Seismic simulator is an experimental device and consists of a platform driven by some mechanical, hydraulic or electric actuators, which can induce a movement similar to that of an earthquake, allowing evaluation of performance of structural and non-structural components, or equipment mounted on them. There is a wide variety of such devices; they differ in physical size and number of degrees of freedom to be imposed displacements/ rotations, with loading capacities uni-axial, biaxial and multi-axial.

In terms of structure-model, the theoretical or experimental evaluation of the seismic performance of buildings requires a structural model based on the concept of structural similarity and/or similarity. In general, between a real building and the building model must be geometric, kinematics and dynamics similarity.

2. EXAMPLES OF SEISMIC SIMULATORS FOR STRUCTURAL TESTING IN ROMANIA

Since 1960’s, at the National Research and Development Institute for Building, Urban Planning and Sustainable Spatial Development (INCD URBAN-INCERC), Iasi Branch, there are two seismic simulators (140t and 15t) which allow dynamic testing of structure models (Figures 1, 2). Seismic simulator with the capacity 140t and 10m x10m sizes; movement amplitude ± 13cm; working frequency range 0.5÷20.0Hz; horizontal uni-axial; peak acceleration (in g) 0.6g; maximum velocity 80cm/s; works on the principle of electro-hydraulic system. Pre-recorded acceleration on magnetic tape is reproduced by a dynamic jack that pushes the shaking table unidirectional with alternating horizontal motion. The energy level of the shaking motion is monitored by some control accelerometers mounted on the base and the calibration and performance checking is performed before starting the test program. The primary experimental data acquisition related to the control of the shaking table (seismic action) and mechanical behaviour of tested structural system at earthquakes (answer machine) is digitally by recording simultaneously all the measurement points on the computer, from several types of transducers: accelerometers / displacement transducers (Diaconu, 2006).

Fig. 1. Tests on seismic simulator (140 t) URBAN-INCERC, Iasi Branch (Diaconu, 2006)

Also, in INCERC Bucharest the tests have used vibrators mounted on top of the small scale - model structures 1:4 (Figure 3). Both approaches were later on validated by the good response of the real structures to the earthquake of 1977. In 1980’s, in INCERC Bucharest and Iasi, large investments for seismic shaking tables were initiated (unfortunately unfinished).

Fig. 2. Building of large panels on seismic simulator (shaking table of 15 t) URBAN-INCERC, Iasi Branch (Diaconu, 2006)

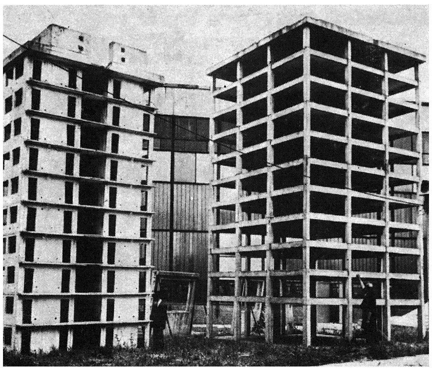

Fig. 3. INCERC Bucharest models of structures subjected to oscillations by a top vibrator (ICCPDC-INCERC, 1980)

3. EXAMPLES OF SEISMIC SIMULATORS FOR STRUCTURAL TESTING IN OTHER COUNTRIES

Internationally, there is a wide range of solutions of American and Japanese companies, which provide high performance seismic simulators. A major challenge was finding a way to move the vibrant platforms, which in general are driven by hydraulic, but a method that has not a high accuracy. Therefore, there have been used the actuators based on electromagnets. In Europe there are seismic platforms in R. Macedonia, Greece, Italy (JRC Ispra, Naples), Portugal (Lisbon LNEC), France, Russia etc. In the US and Japan there are universities and institutes that have the own significant seismic simulators, while China has developed in recent years some innovation and technological development platforms, within which are tested the structures models in 1:40 scale, (Fukuwa et al, 2008; Tobita et al, 2009; Ichimura et al, 2004). The US largest "outdoor" shaking table in the world, of 2000t is operated at University of California at San Diego (Network for Earthquake Engineering Simulation - The PEER Earthquake Shaking Table). In Japan, E-Defense NIED Shaking Table, Miki Town, is a 3D seismic testing platform, 1200t force capacity full-scale tests; 20mx15m dimensions; max horizontal acc. - more than 0.9g; max vertical acc. - more than 1.5g; max horizontal velocity - 200 cm/s; max vertical velocity - 70cm/s; max horizontal displacement +/- 100 cm; max vert. displacement +/- 50 cm (Figures 4a, 4b).

Fig. 4a. Natural scale house model on E-Defense NIED shaking table, Miki Town, Japan

Fig. 4b. E-Defense NIED shaking table, Miki Town, Japan - the powerful actuators

In the new earthquake engineering hall at IEM Yanjiao, China, there is a double shaking table for seismic testing as a double pile-deck bridge assembly with equipment from Italy and a very large centrifuge for geotechnical tests. Models of super-high buildings were tested on seismic simulators at Institute of Engineering Mechanics - IEM Harbin, China and China Academy of Building Research, Yanjiao Science and Technology Platform (Figures 5, 6).

Fig. 5. Models of super-high buildings at scale 1:40, after testing at China Academy of Building Research, Platform Yanjiao (RISKSOLVE Project, 2013)

Fig. 6. Models of buildings in preparation for testing on shaking table/seismic simulator at China Academy of Building Research (RISKSOLVE PROJECT, 2013)

4. SEISMIC SIMULATORS FOR PEOPLE AND FURNITURE, AND EDUCATIONAL MODELS OF BUILDINGS OR PARTS OF BUILDINGS

Apart from pure engineering utility, the main goal of simulation is to train personnel research and intervention, but with free access for students, volunteers and the general public. The use of mobile seismic simulators for public use is widely available in Japan. When the accuracy of the seismic generation mechanism is higher, some simulators can be used both in scientific and educational activities on soils patterns/models, structures, equipments.

Seismic motions by an intensity of VIII + MM scale can be simulated, based on actual or generated records (artificial accelerograms), being projected simultaneously by video the effects.

Motions and effects selection with green/red lights and prerecorded announcements can be combined in many ways, time, content, to create seismic scenarios. The simulator is designed in an independent building, specially constructed and equipped. The seismic simulator of Asia-Pacific Network of Centers for Earthquake Engineering Research, Taiwan is another example.

Fig. 7. Mobile seismic simulator available during WCDRR, Kobe, Japan, 2005. Persons on the platform are subjected to a seismic motion in successive steps

The population can experience a default simulated earthquake on a platform arranged to describe a room or a kitchen and during a simulated seismic motion it is possible to test the self-defense reflexes of individuals at earthquake.

An example of simulator is that of Civil Defense College and Ankara Search & Rescue Unit, connected to the Ministry of the Interior, through the General Directorate of Civil Defense in Ankara, Turkey (Aytun, 2004).

5. SEISMIC SIMULATORS FOR EDUCATIONAL MODELS OF BUILDINGS OR PARTS OF BUILDINGS

Among other to seismic risk awareness activities, a more practical approach is related to the possibility of presenting realistic images about the behaviour of building models during an earthquake, for students and usual people (Georgescu et al, 2006, 2008; ROEDUSEIS Project, 2011; Tobita et al, 2009; Ichimura et al, 2004; Tataru et al, 2013; Research Project, 2011; Toma et al, 2010; Meita et al, 2012).

With a mini earthquake simulator, which creates two types of motions, high or low frequency, oscillations are applied to simple models of buildings (metal, wood, paper), consisting of a framework/structure with or without structural walls or filling, with or without ground/weak level/flexible floor etc. Japan researchers are very active in promoting the use models of stone and earth buildings, with and without perimeter wood belts, as the ones used as educational tools in Nepal, subjected to a seismic motion on mini-simulator & patterns of stone and wood buildings, with/without bracings or collar beams (Figure 8).

Fig. 8. UN – WCDR Conference, Kobe, Japan, 2005. Models of stone and earth buildings, used as educational tools in Nepal, subjected to a seismic motion on mini-simulator, left without bracings or collar beams, right with bracings or collar beams

Simple models were used to explain and understand the influence of foundation soil stratifications on seismic response of buildings (Tobita et al, 2009; Ichimura et al, 2004).

The manufacturers produce educational testing equipments for building components testing, with associated programs and models (Figures 9a, 9b, 10). The students are attracted by such approaches.

A light-weight building model with controlled seismic performance, elaborated by students from Cluj-Napoca Technical University won the first place in the largest international competition dedicated to earthquake-resistant buildings modeled by students, Alaska, USA, organized by ERI.

In Japan, Prof. Fukuwa promoted simple ways of presenting the oscillation of buildings in Japan, by acting on the horizontal arm, and the effects of successive earthquake on wooden buildings; small size card type, consisting of series of images which give the illusion of continuous motion where the pages are turned faster (Fukuwa et al, 2008;Tobita et al, 2009; Ichimura et al, 2004).

Fig. 9a. BUILDING TEST EXPO, Brussels, Belgium, 2014. Educational shaking table – seismic simulator for small building models

Fig. 9b. BUILDING TEST EXPO, Brussels, Belgium, 2014, Educational testing facility – frame for loading and testing building components

Fig. 10. Mini-simulator and wooden structural model shown at The Second European Conference of Earthquake Engineering and Seismology, Istanbul, Turkey, August, 2014

Since 2002, the JICA project in Romania shared teaching simulators from Japan (Georgescu et al, 2006, 2008: Fukuwa et al, 2008) and since 2009 it was studied in INCERC a Center and demonstration platform for education and training on earthquake behaviour (Research Project, 2009).

Recently, in ROEDUSEIS Project (2012-2016), a Seismolab III with JICA didactic simulators and new teaching materials was arranged as in Figures 11, 12 (ROEDUSEIS, 2011; Dobre et al, 2014, Dragomir et al, 2014).

Fig. 11. A Seismolab from URBAN-INCERC within the ROEDUSEIS Project (2012-2016)

A mechanical process to turn the rotation into forward motion and a model of higher building with infilling walls developed in the ROEDUSEIS Project is shown in Figure 12.

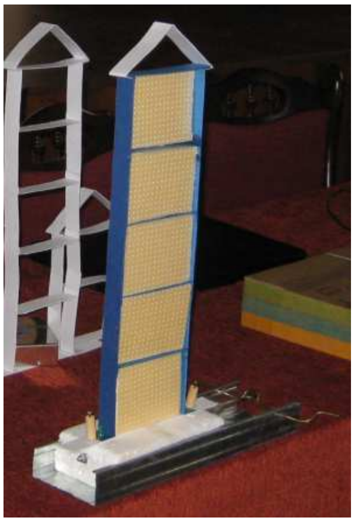

Fig. 12. Seismic mini-simulator "Crank-type"

6. CONCLUSIONS

With the development of automated computational techniques an illusion was created that, through advanced software, tests on simulators will be replaced. The reality of recent decades indicates that the number of shaking tables / seismic simulators increased, both in the European Union and in Japan, USA, China etc. Projects like PEER (USA), NERIES (2006-2010) and NERA have shown instead that tests are relevant even at small scale and the sophisticated numerical simulations and calculations are complementary.

Because earthquake engineering is turning into a complicated mathematical science, physical devices are often necessary to check new solutions, and to draw attention to some typical situations of vulnerability and to convince stakeholders. In many cases, teaching simulators facilitate a culture of disaster prevention in schools or at general public level. Thus, the continuity of seismic simulation demonstrates that, to check some concepts and the structural systems, laboratory work/test is required and their aims can exceed the sole interests of engineering, reaching a specific social role.

At large or natural scales, seismic simulators make it possible to determine the dynamic characteristics of the structure and their evolution and to check the efficiency of strengthening process of structures.

At small scale demonstrations, public perception of structural safety can be influenced in a positive sense by participating in such seismic simulations. This paper provides arguments and it is advocating for a revival or larger use of these facilities.

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