Earthquake engineering education through distance learning using advanced synchronous and asynchronous technologies

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Abstract: - Experiments play an essential role in teaching earthquake engineering because the response of the structures is of dynamic nature and students are not usually accustomed to earthquake loads. Fortunately, severe earthquakes have long return periods, thus testing models in a shaking table until collapse is the best way to make the students understand the effects of earthquakes on structures and stimulate their interest on the field. However, testing a structure on a shaking table up to collapse can be dangerous and it is not feasible in the physical presence of a large number of inexperienced students. This paper presents an innovative approach for teaching earthquake engineering, based on an enhanced distance learning system, that uses synchronous ("video streaming") and asynchronous ("e-learning platforms") technologies. An extensive use of online educational tools are proposed to motivate students' participation in dynamic tests and competition for predicting the responses. As an example of implementation, a recent experience at the University of Granada is described. Here, several shaking table tests on two half scale models are combined with numerical simulations aimed at predicting the observed response. Based on this experience, the advantages and practical problems from the perspective of engineering are identified. In closing, several recommendations are made for improving the results of this teaching method.

Key-words: computer simulation; distance learning; dynamic tests; earthquake engineering; online; model.

1 Introduction

In many countries, the syllabus of architecture or civil engineering studies include learning to design structures in earthquake prone areas. Commonly, teaching structural analysis courses requires the inclusion of two thematic units: theory and experiments. In the case of earthquake engineering, the experimental part is especially important because, fortunately, students are not usually accustomed to experience earthquake loads. In contrast to gravity loads, destructive earthquakes have long return periods and students have sometimes wrong ideas: they tend to think that learning how to prepare structures for this type of accidental events is not that important.

The author believes that the best way to enhance the interest of the inexperienced students on learning earthquake engineering is to expose students to the physical behavior of a model structure subjected to an earthquake up to collapse, through shaking table tests simulated in a laboratory. This experience triggers out students' desire of knowing more about the phenomena, of learning how to predict the response and how to prepare the structure for such type of scenario. Studying the mathematical and mechanical theories which are indispensable to design structures against earthquakes is much more stimulating if the real phenomena can be observed in advance. Our experience proves that, the more involved the students are in the experiment, the more effective is the shaking table test as an educational tool. This involvement can be achieved giving the students the opportunity of participating during the preparation, and by providing the students with the detailed information about the test (i.e. characteristics of the model, earthquake wave to be used etc).

However, testing a structure in a shaking table up to collapse can be dangerous: it requires restricting the access to the laboratory and giving special attention to safety issues. In contrast to testing structural models under static loads, a shaking table tests cannot be carried out with the physical presence of inexperienced students. It is the technologies used in distance education that can play an important role. In this paper an innovative educational project for a distance learning of earthquake engineering is proposed. This project involves synchronous and asynchronous technologies. The proposal is grounded on an on-going experience conducted at the University of Granada. The synchronous technology involves "video streaming" to transmit the real-time online broadcasting of the shaking table tests, which are taking place in the laboratory. The asynchronous technology consists of a web platform that allows students to: (i) participate in test preparation, (ii) download information measured during the test (i.e. history of acceleration measured in the shaking table etc.); (iii) upload a prediction of the response of the tested structure carried out by the students using the theory that they have learned online with the guidance of the instructor; (iv) compare their prediction with the test results provided online; and (v) discuss the predicted and test results. This distance learning can be further enhances by organizing a "contest" among the students in which they compete in submitting the prediction of the response of the tested structure.

The idea for this educational project is based on three past studies. However, it should be noted that there is an important difference between these studies and our experience, because (1) the former used traditional, not distance, learning schemes, and (2) tested small models under static loads. The first study deals with a course in mechanical engineering at the Imperial College of London. The students developed a project with steel plates, beams and rivets, in which they had to span the distance between two points with a bridge, using the least material possible. The final experiment was conducted by the instructor, who had to walk across the bridge of the students. The second study explains the experience of the college of Architecture in Madrid, Spain. The students had to build a structure with small timber bars by themselves, and it was tested under gravity loads in a competition scheme. The third study was derived from an educational project conducted at the University Jaume I, in Spain [1]. It combined the use of a plastic toy called K'NEX and a well-know computer program for structural analysis.

American universities also used models as teaching tools. Setareh [2] describes a class in which a set kits of small-scale building components were used, accompanied by computer software that guided the user through the process of building assembly and construction. Behr [3] proposed a project in which computer simulations were compared in nearly real time with physical measurements made on bench-scale model experiment. Electronic sensor were employed to record the physical response of the loaded model, and numerical and experimental data were compared.

Web-based learning has been investigated by many authors. Rong-Jyue et al. [4] developed a theoretical framework on the perception of web-based self-directed learning environment. As a result, they identified 3 system categories (system environment, interactive relationship, and personal development), 5 dimensions (internet resources, web-based functions, peer interaction, learning content type, and self-directed learning), and 13 aspects in the framework. The use of e-learning platforms is becoming more a more widespread. Several universities are currently involved in using e-learning systems, although several problems related to e-learning activities still remain open. Campanella et al [5] analyzed the e-learning technologies used in the Italian Universities and investigated the most widespread open source and commercial Learning Management Systems (LMSs). Among the various platforms, Moodle is the most utilized, it is followed by Blackboard, the IBM LMS and the Oracle LMS. In some Universities more than a single platform is adopted, according to specific needs and particular requirements. For illustrating purposes, figure 1 shows the home page of University of Bari.

The web can also be useful to work with "virtual laboratories". In the areas of engineering education due to various shortcomings of the traditional laboratories, virtual laboratories have appeared as a potential solution. Any system (mechanical, electrical etc) can be accurately described by a mathematical model, and the models can be applied in practice because the computers allow us to solve it in a numerically way. Numerical experiments carried out in "virtual laboratories" through the web (i.e. linear and non-linear dynamic analyses) are the perfect complement to the "real" tests conducted in the laboratory, and to the theoretical contents of earthquake engineering. In this context, Petropol et al [6] investigated the theory of the modeling applied on the areas of electrical machines, and identified three key problems: the purpose, the content and the impact of a "virtual laboratory" in studying and learning the scientific and engineering principles.

The web is being used in many other applications such as test design and evaluation [7]. The web can be also a good tool for evaluating the results of the teaching-learning process, as an alternative to the traditional written or oral exam. However, many problems must still be solved to be sure that the evaluation is fair and that it provides a "real" picture of the knowledge of the student.


Fig. 1: Web-learning page of University of Bari

2 Synchronous and asynchronous tools

Synchronous is the transfer of information without delay. Traditional stand up teaching can be considered totally synchronous. In distance education examples, synchronous education tools include audio and/or video transmitted "live" among instructors and students via TV, Internet ("video streaming") or radio. Synchronous communication between instructor and students is always desirable since this creates the most spontaneous interaction. This enables the instructor to adapt and respond to questions without delay. Synchronous delivery has several advantages: (i) it is motivating, focuses the energy of group and encourages students to keep up with their peers and continue with study; (ii) it helps create a feeling of community and classroom cohesion; (iii) it fosters a rapid feedback consensus-building in group activities etc.

The asynchronous teaching tools include all archived and stored material (CD-ROM, web pages, email, fax, videotape, and so forth). There are several advantages to the asynchronous of delivery system: (i) it allows a flexible access to the teaching material can take place at any time; (ii) the student has time to reflect, and there is not need to react instantly; (iii) it allows the learner to reflect over ideas and the reply to questions; (iv) if the teaching session is recorded and archived then students can go back and review the lesson; (v) it allows access from home or work; (vi) it can be cost effective because text based systems require little bandwidth and low end computers to operate.

Synchronous and asynchronous technologies must be considered when preparing a distance education course. The most appropriate delivery system depends upon the needs of the students and the type of subject matter. In the case of teaching earthquake engineering, we believe that the experimental aspects require synchronous teaching tools, with the physical presence or not of the students. On the other hand, the theoretical knowledge can be delivered by means of asynchronous technologies, particularly through e-learning or web platforms. Each student has different backgrounds and abilities, and therefore different needs in terms of time to understand the theoretical concepts.

3 Problem formulation and scope

The educational experience described in this paper is aimed at: (i) motivating the inexperienced students of architecture or civil engineering that engage in the earthquake engineering for the first time; (ii) increasing the students' awareness of the importance of seismic design, (iii) showing the students that predicting the response of a structure under seismic loads is much more cumbersome that under gravity loads, because the response is largely within the inelastic range.

To achieve these objectives, the following propositions are formulated: (i) the active participation of the students in the preparation of the tests increases their level of involvement in the education process; (ii) observing first the physical phenomena makes easier understanding later the mathematical modeling and the underlying theories; (iii) experiments improve students' motivation.

The educational scope of the experience are architecture or civil engineering students without any background in earthquake engineering, except basic courses in solid mechanics and structural analysis. The syllabus for the structural analysis courses includes the principle of virtual work, the stiffness method, and basic dynamics of single and multi degree of freedom systems.

4 Development of the project

The project is organized in the following order:

1. Through the e-learning platform, the instructor proposes the type of structure to be studied and explains the objectives and possible constraints of the experiment (space limitations, maximum capacity of the shaking table etc). In the education experience conducted at the University of Granada, a flat slab was selected. The objectives were to observe the displacement pattern, the failure mode an the efficiency of including an innovative technology known as energy dissipating devices (EDD). As for the constrains, the test model shall not exceed $3\times3\times2\text{m}^3$, and the shaking table could not be accelerated beyond 15m/s^2.

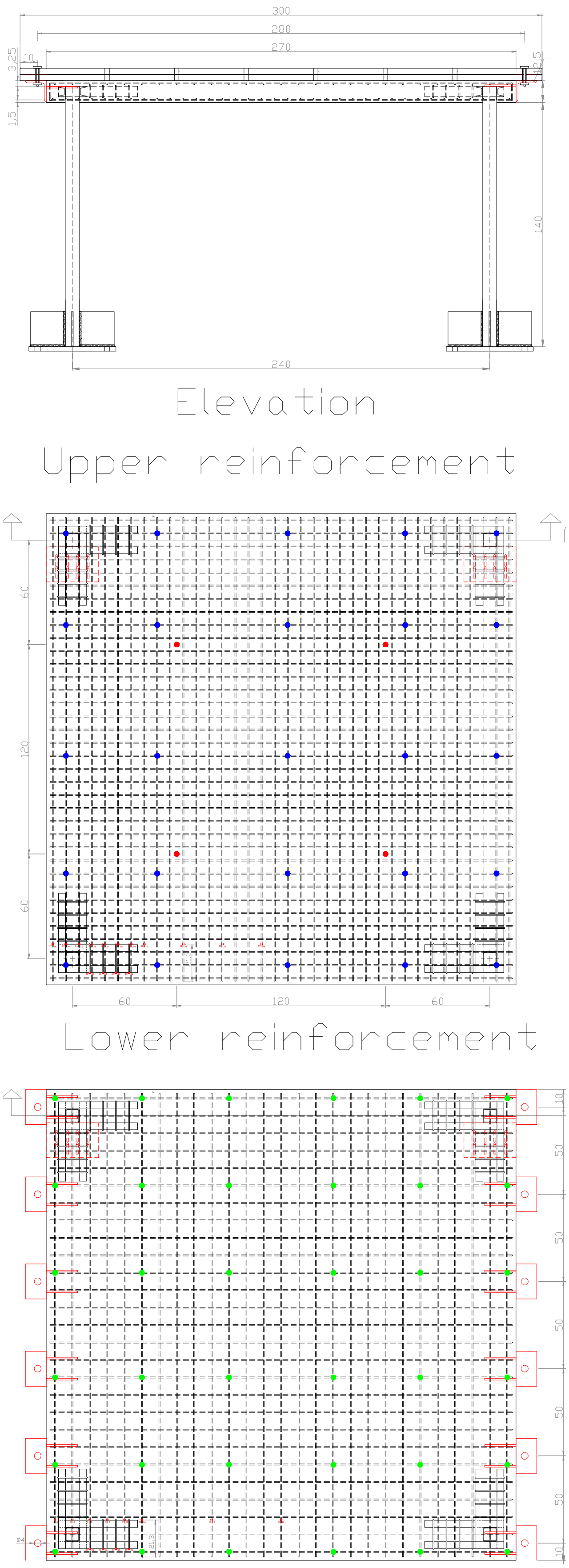

Fig. 2: Test model FS: slab without dampers

2. An online discussion group is created on the e-learning platform for exchanging suggestions about the design of the test model, the test set-up and the instrumentation. The students exchange sketches and text files. The final test model is approved by the instructor. In the education experience conducted at the University of Granada, two test models were designed as shown in figures 2 and 3. The test model FS was a reinforced concrete flat slab structure without energy dissipating devices (dampers). The slab was 12.5cm depth and it was made with concrete of compressive strength 25MPa, reinforced with deformed bars which yield stress was 400MPa.

The test model FSD, was a flat slab structure with seismic dampers. The seismic damper used have the form of a conventional brace (brace dampers), and they are intended to be installed in a framed structure as a standard diagonal bar. They are constructed by assembling several short length segments of wide-flange or I-shaped sections which constitute the energy-dissipating device or damping device, and two steel bars that remain elastic and function as auxiliary elements. The assemblage is arranged in such a way that when the brace damper is subjected to forced deformations in the axial direction, the web of the wide-flange or I-shape section undergoes out-of-plane flexural deformations. All the information related to the experiments (drawings, material properties etc) are provided online to the students since it will be necessary later for studying and interpreting the results of the tests.

3. After that, the physical model is prepared in the laboratory. To enhance the involvement of the students, they can follow the process of construction by using the video streaming technology. Figures 4 and 5 show images of the construction stage. The students can also "safely" participate in this process sending emails to the discussion group. Figures 6 and 7 show the test models already instrumented and installed on the shaking table ready for the tests. The instrumentation consisted on accelerometers fixed to the slab in two directions, displacement transducers and more that one hundred strain gages fix to the reinforcing bars before casting the concrete.

Before conducting the shaking table tests, component tests were carried out to investigate the energy-dissipative characteristics and the hysteretic law of the damping device. In total six component tests were carried out. In each test, 90mm length specimens cut from a single segment of a structural wide-flange section of 140×73mm2

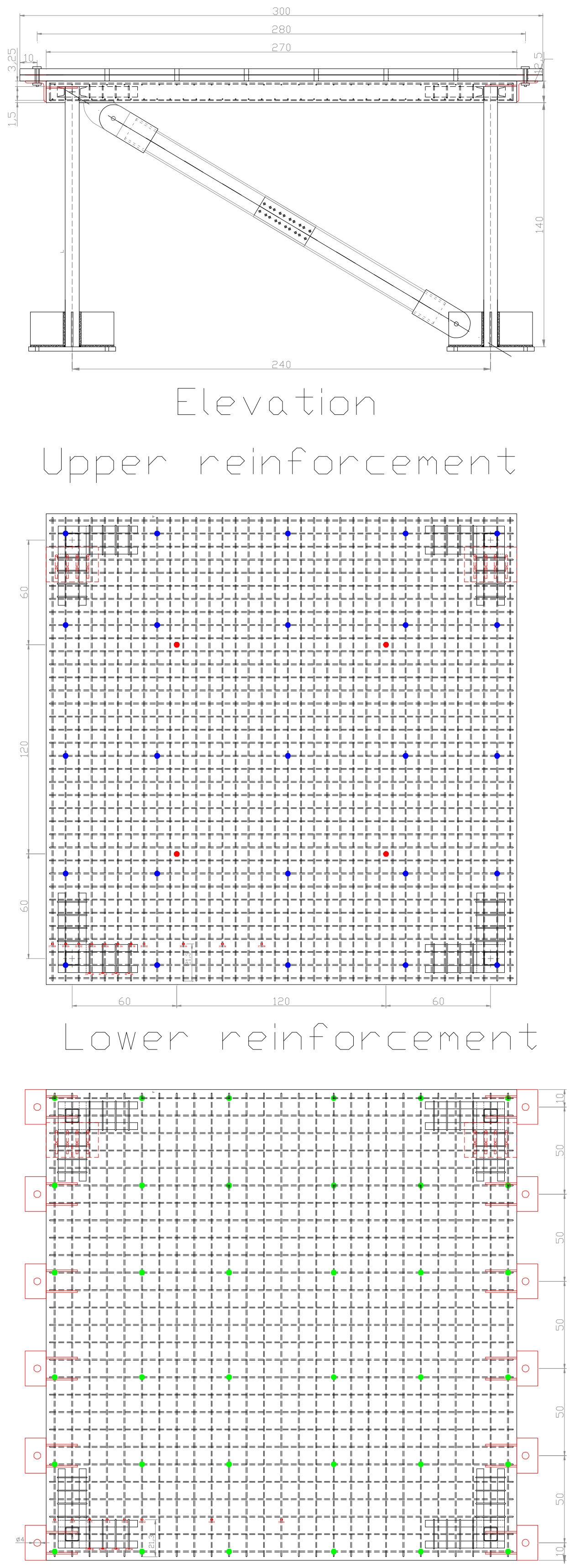

Fig. 3: Test model FDS: slab with dampers

(total depth×flange width) referred to as the IPE-140 section hereafter were used. The specimens were mounted in the small set up shown in Fig. 8 and subjected to static cyclic loading until failure. A load cell installed on the actuator measured the applied force, and two displacement transducers provided the relative horizontal displacement between the upper and lower flanges of the IPE-140. These component tests are simple, static —not dynamic— and they are conducted on specimens of small size. The possibility of accidents is small. Consequently they can be done with the physical presence of students. Commonly, component tests are always needed before the definitive shaking table tests, and they can be used also as an efficient teaching tool.

4. Once the test model is completed and installed in the shaking table, the instructor uploads the latest information about its actual characteristics, material properties, set-up and instrumentation schemes to the e-learning platform. The date and time of the test is also announced online. It is worth noting that the final characteristics and properties of the test model always differ from the original drawing, and the students must be aware for conducting the predictions of the following steps.

5. The shaking table test is conducted in the laboratory and followed online and in real time by the students through the "video streaming" technology. In the experience conducted in the University of Granada, the tests were carried out using the MTS 3×3m2 shaking table of the University of Granada (Spain), which has a payload capacity of 100kN. The scaling factors used were 1/2 for the geometry, 1 for the acceleration and 1 for the stress. The test model FD was tested without dampers and subjected to a series of six seismic simulations with increasing peak ground acceleration (PGA) of the values 0.16g, 0.31g, 0.47g, 0.62g, 0.78g and 0.94g (here g is the acceleration of gravity). The model collapsed in the last simulation. The shaking table applied a unidirectional translational displacement to the test model, which reproduced the NS component of the 1980 Campano-Lucano earthquake recorded at Calitri (Italy).

In the second test model FSD two seismic dampers were installed. The energy-dissipating devices of these seismic dampers were identical to those used for the component tests. The test model FSD was subjected to two series of seismic simulations using the same earthquake record. In the first series, referred to as FSD1, the test model was subjected to six seismic simulations having the same levels of PGA as those applied to test model FS. The objective was to compare the responses with and without seismic dampers. After the last seismic simulation (i.e. that with PGA=0.94g), a detailed inspection of the test model FSD1 was conducted and it was found that both the reinforced concrete slab and the steel columns had behaved within the elastic range and were completely undamaged; in contrast the seismic dampers had undergone severe cumulative plastic deformations.

6. Through the e-learning platform, the instructor states the problem that the students must address in relation to the experiments, and provides them the additional data measured during the test that they need to solve the problem. In the experience conducted at the University of Granada, these data were basically the actual accelerations measured on the shaking table during the test. Commonly, the problem stated consists in estimating some response parameter of the structure measured during the experiments. The students must conduct this estimation on the basis of their previous knowledge in structural mechanics, and the theoretical texts and assistance provided by the instructor. He also provides helpful "in house" software for conducting the prediction. This software is not intended to solve the problem, it only avoids the students from loosing time in secondary aspects and to concentrate on the neuralgic aspects of the seismic problem staged with the shaking table.

In the experience of the University of Granada, the students were required to predict the maximum displacements of the slab. The "in house" software was a subroutine for calculating response spectra. The challenge for the students was to make the best approximation to the actual response measured during the test, which strongly relied in (i) choosing an adequate mathematical model for representing the specimen tested and (ii) identifying the locations where plastic deformations took place.

7. After giving the students a reasonable amount of time, the instructor asks them to upload their prediction to the e-learning platform, in form a brief report. A new discussion topic is opened on the platform, so that the students can discuss the results, and the appropriateness of the approach used by each student to make the estimation. In the education experience conducted at the University of Granada, one of the key issues that determined the goodness-of-fit was the estimation of the stiffness of columns and slab, and the damping of the system. Finally, the students are asked to upload a brief report in which they evaluate (i) the solution submitted by their peers; and (ii) their own work. They are also encouraged to discuss how the solutions could have been improved.

On a competitive basis, after reading all the students' reports, the instructor selects the best solution to the problem stated. The experience at the University of Granada shows that the opinion of the students provides often valuable feedbacks to organize future experiences. Encouraging the students to write reports, makes the distance learning no only a way to transfer knowledge but also to enhance competence in communication skills and group work—an important goal of the European Space of Higher Education. The reports presented by each student or group of students, are uploaded in the web, so that each one can analyze the answer provided by his colleges.

Emphasis must be put here on the importance of teaching the student how to write the reports. Lab reports are commonly hard to write for the students. Teachers and professors frequently assume that their students know how to do it, but usually this is not the case. It is important that the instructor uploads on the web some basic and helpful information regarding how to write a report: the report must follow basic scientific method, the problem to solve and the hypothesis must be clearly stated, results and conclusions must be consistent with the previous analysis, references must be correctly indicated etc.

Finally, the instructor uploads in the web platform the relevant result of the tests and a brief explanation. The students can compare these results with their predictions. In our experience at the University of Granada these results were basically the displacements and accelerations measured by the transducers. Figure 9, 10 and 11 show examples of this type of information. Figure 9 illustrates the history of displacements of the slab relative to the shaking table, and figure 10 the corresponding maximum values for each level of the seismic simulation. Figure 11 shows maximum response acceleration. Together with this graphical information, a rough description of the results must also be provided by the instructor to "guide" the students. In the case of the experience conducted in the University of Granada, this description indicated that the seismic dampers reduced the maximum displacements of the slab from approximately one-third to one-fifth of the value measured in the test model FS without dampers, and that the test model without dampers FS yielded for PGA=0.47g and consequently the lateral strength —and obviously the maximum absolute response acceleration— remained almost constant in the seismic simulations with PGA larger than 0.47g.

Fig. 4: Process of construction of the test model

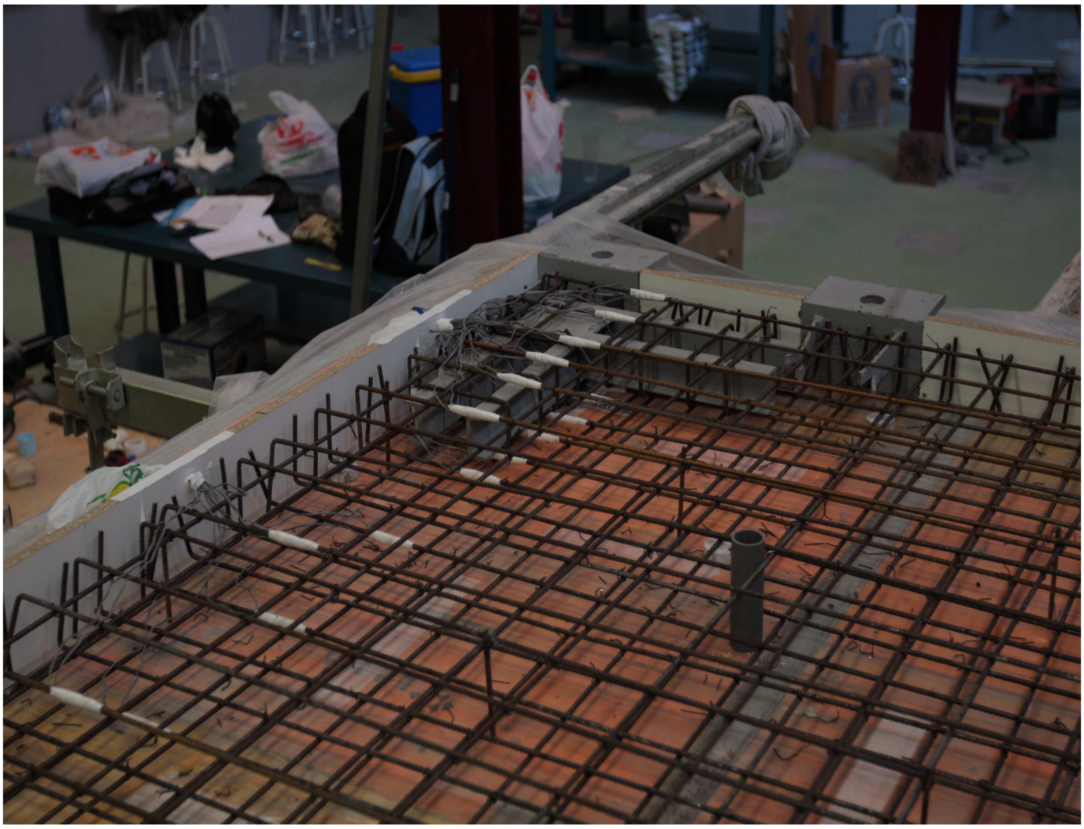

Fig. 5: Process of construction of the test model

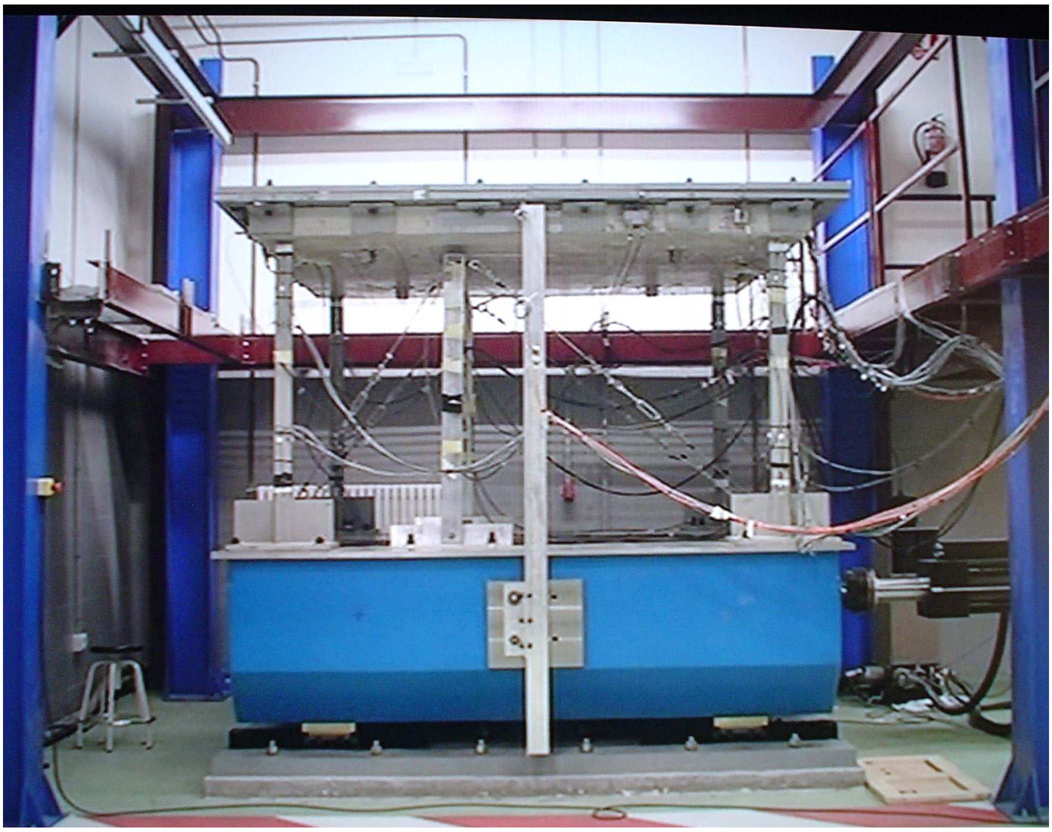

Fig. 6: Test model FS tested on the shaking table

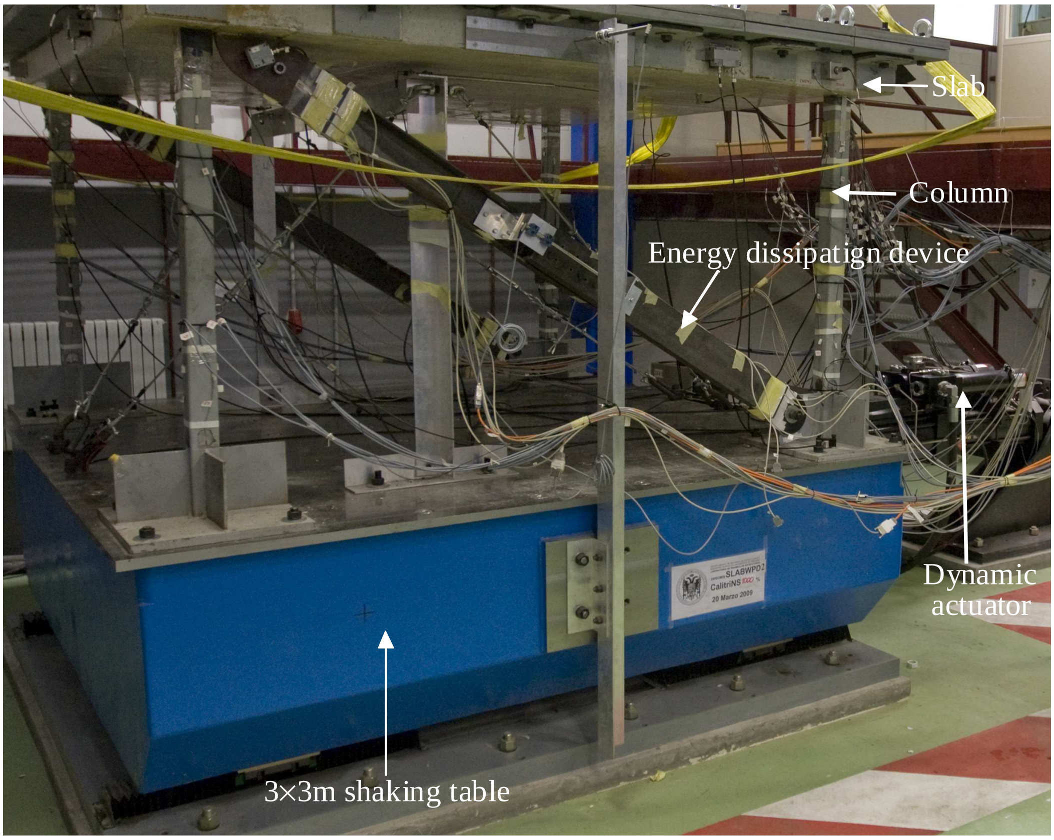

Fig. 7: Test model FDS tested on the shaking table

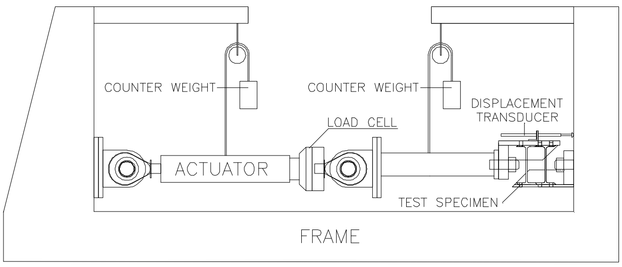

Fig. 8: Test set up used for the component tests

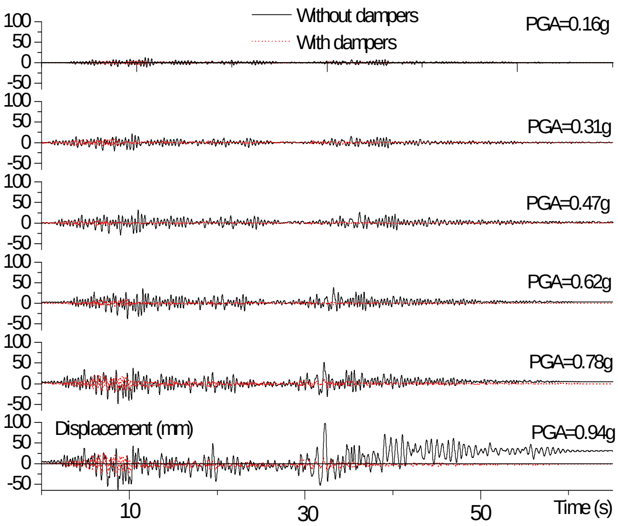

Fig. 9: Displacement histories

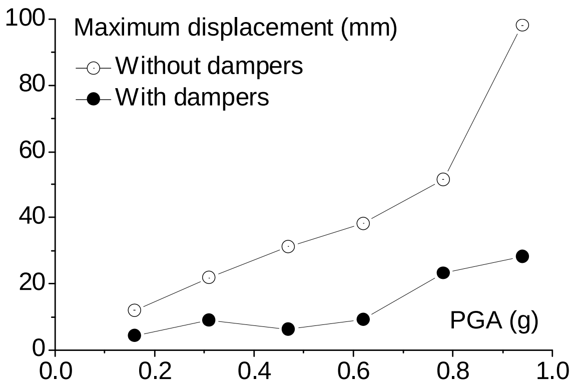

Fig. 10: Maximum displacements

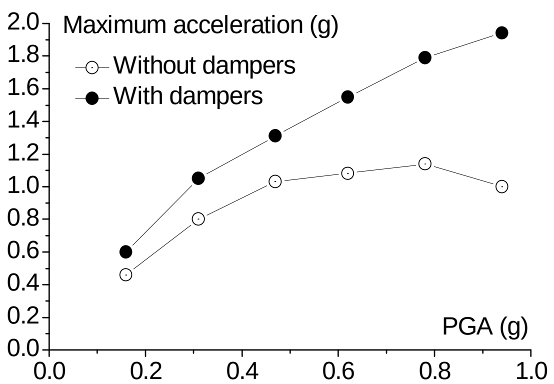

Fig. 11: Maximum response acceleration

5 Conclusion

In this paper, an innovative educational project for distance learning of earthquake engineering is proposed. It is based on enhanced e-learning tools that (i) stimulates the students' participation in designing and preparing the specimens; (ii) provides "real-time" observations of the actual response of a structure subjected to an earthquake up to collapse through a simulation on a shaking table; and (iii) encourage brain-storming on the prediction of some parameter of the response. The entire process consists of the web-based e-learning platform. The students observe the test though video streaming technology and predict the response with the knowledge acquired by the study of the theoretical texts uploaded by the instructor on the web, and basic "in home" software.

From the experience at the University of Granada, the main advantages of this educational approach of earthquake engineering are that: (1) the students are fully satisfied with this kind of experiments; (2) they understand better the theoretical aspects that underlie the physical phenomena; and (3) the special features of the earthquake loads, in comparison to gravity load, are fully acknowledged. The author would like to point out here that a significant number of students —larger than in previous years when this experience was not realized— decided to join advanced earthquake engineering courses taught in the University of Granada.

The main limitation of this educational approach is that it is expensive and requires sophisticated equipment. Furthermore, the results of the project might be improved by: (1) increasing the number and degree of complexity of the "in house" software provided online by the instructor to the students; and (2) making the students to calculate also the response by applying different seismic codes.

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