EARTHQUAKE ENGINEERING PUBLIC ENGAGEMENT ACTIVITIES IN TAIWAN

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ABSTRACT :

Since 2000 an earthquake engineering design competition has been running in Taiwan for high school students and undergraduates and for the last three years this activity has been expanded to include a competition for postgraduates. The scope of the competition, originally developed in the UK to inspire school children about mathematics and physics using the medium of earthquake engineering, has been extended in Taiwan specifically to encourage a greater awareness of good earthquake resistant design practice. The high school and undergraduate competitions require the design and construction of a model of a three storey building. These buildings are then loaded and tested to destruction on a large shaking table at NCREE (Center for Research on Earthquake Engineering), Taipei. The winning design being the model with the best efficiency, which is calculated as the size of the earthquake survived divided by the mass of the structure. The postgraduate competition, developed by NCREE, is more challenging than the other competitions requiring the students to develop and install a retrofit solution for a non-seismically designed two storey building. The competitions have been very successful and have generated a lot of press and TV publicity for the NCREE facilities and the research activities underway in Taiwan. It is hoped that the development and use of activities such as this will increase general awareness of the importance of good design and help reduce the likelihood that inappropriate structures are built where earthquakes are a hazard.

KEYWORDS: Student, competition, shaking table, education, seismic awareness

1. INTRODUCTION

Since 2000 an earthquake engineering design competition (IDEERS – Introducing and Demonstrating Earthquake Engineering Research in Schools) has been running in Taiwan for high school students and undergraduates and for the last three years this activity has been expanded to include a competition for postgraduates. The competition was originally developed in the UK in order to inspire school children, some of whom who may become the engineers of the future, about mathematics and physics using the medium of earthquake engineering and to increase public understanding of earthquake engineering (Daniell & Crewe 2005). To do this a web-based project was created to promote understanding of the value and process of earthquake engineering activities. The website describes the effects of earthquakes on communities, the need for research to improve the earthquake resistance of structures, and the fundamentals of the seismic behaviour and design of earthquake resistant buildings. The website (http://www.ideers.bris.ac.uk) also provides details of the competition requiring the design and construction of a model of an earthquake resistant building.

The key requirements for the original competition models were based on the following criteria:

- Models must be representative of real structures.
- The competition rules must be flexible enough to allow a large number of different designs.
- It must be possible to test and destroy models using a typical shaking-table so students can observe failure modes and experience the fun of seeing the destruction.
- Materials for models must be cheap and readily available to schools.
- No special equipment must be needed to construct the models.
- The model making skills needed must suit the target age group.

The use of cheap materials, and the ability to destroy the models on a typical shaking-table, within its performance limits, drove much of the development of the competition requirements (Crewe & Daniell 2004a).

Since the start of the project, thousands of students, between the ages of 12 and 25, have built and tested their models to destruction on earthquake simulators around the world. Posters produced by the students have shown that, thought participating in the project, they have come to understand the importance of earthquake engineering activities and that they have learnt a number of the basic principles of good seismic design and construction.

In addition to events elsewhere, IDEERS currently runs as an annual two-day design, build and test event in Taiwan, in conjunction with NCREE, Taipei. The event runs with one day to build the models (figure 1) and one day of testing (figure 2) and this format has proved very popular both with the teachers and the students taking part. Before the competition students can make use of the NCREE and IDEERS websites (http://www.ideers.bris.ac.uk and http://w3.ncree.org/ideers/2008/) to research some of the techniques used to make earthquake resistant buildings and then plan their designs (Crewe & Daniell 2002). Then, on the first day of the competition all the models are built and on the second day the models are tested to destruction.

Figure 1: Models created by High School (left) and undergraduate students (right).

Figure 2: High school models on the shaking table ready for testing.

2. THE HIGH SCHOOL AND UNDERGRADUATE IDEERS COMPETITIONS

Originally the high school and undergraduate competitions in Taiwan required the design and construction of a model of a simple three storey building, based on the rules originally developed for the UK competition. These buildings were then loaded and tested to destruction on a large shaking table at NCREE (Center for Research on Earthquake Engineering). The winning design being the model with the best efficiency, which is calculated as the size of the earthquake survived divided by the mass of the structure (eqn. 2.1). Students from all over the world, including Chinese Taiwan, USA, China, Malaysia, New Zealand, Australia and many other countries/regions have produced many different and innovative structural solutions for the competition.

This competition was very successful but after a few years teams from those Universities and schools that entered every year were starting to home in on the most successful designs (Crewe & Daniell 2004b). Therefore, for the competitions in 2007 and 2008, the brief was modified to allow more creativity in the solutions and this has opened up the competition again. The key changes to the competition were allowing the models to have a larger plan area and a change in the way that the efficiency of the models was calculated. The original calculation for the efficiency ratio is shown in eqn. 2.1

$$\text{Efficiency ratio} = \frac{\text{size of max earthquake survived}}{\text{mass of model including penalties}} \tag{2.1}$$

This calculation simply encourages the students to design a strong but lightweight model. The efficiency ratio for the modified rules is shown in eqn 2.2.

$$\text{Efficiency ratio} = \frac{\boldsymbol{I} \times \boldsymbol{W}}{\boldsymbol{M}_{\mathrm{M}} - \boldsymbol{M}_{\boldsymbol{B}} + \boldsymbol{M}_{\boldsymbol{P}}} \tag{2.2}$$

where:

- I = Intensity of the maximum earthquake that the model survives.
- W = Number of weights fixed on the floors. For weights on 2nd and 3rd floors, each weight counts as 1. For weights on 4th floor or higher, each weights counts as 1.5 (note that the 1st floor is the ground floor). It should be noted that, as in the original rules, the mass applied to each floor of the model is not completely arbitrary as the models must be designed to carry at least 10g/cm^2 at each floor level.
- M_M = Total mass of the model system (excluding steel blocks).
- M_B = Mass of the base board.
- M_P = Penalty mass (if any of the competition rules are broken).

This modified calculation still encourages the students to design a strong but lightweight model but it also encourages the students to design a larger building (carrying more mass) and to keep the floor areas at the top of the building as large as possible (getting the 1.5 factor on a larger number of masses). Effectively. the use of the additional factor W places a value on the floor area within the building. This mimics real life where clients require the best use of space for an available site and get more return on the upper floors in a building. However even this modified set of rules was not felt to be challenging enough for postgraduate students. Therefore a new competition has recently been developed by NCREE specifically to encourage a greater awareness of good earthquake resistant design practice and retrofitting techniques.

3. DEVELOPMENT OF THE POSTGRADUATE COMPETITION

The postgraduate competition, developed by NCREE, is much more challenging than the other competitions and asks the postgraduates to develop and install a retrofit solution for a non-seismically designed two storey building. The challenge in this competition is therefore the design and construction of a lightweight energy dissipation and/or seismic isolation system for the building.

The non-seismically designed building or “benchmark” model is a two-storey building with 250x400x6mm floors and overall height of 400mm (figure 3). The benchmark model has 6 columns (each 6x6x400mm) which connect into 8mm diameter holes pre-drilled through each floor plate. The benchmark model is connected to a base board 350x500x6mm）which is used to fix the model on to the shake table.

The teams are encouraged to use any types of material for improving benchmark model by retrofitting, energy dissipation, base isolation (figure 4) etc. Finished products (e.g. dampers), and semi-finished parts and components are also permitted. The only real limitation is that the actual construction of the benchmark model and its subsequent upgrade must be completed on the day of the competition.

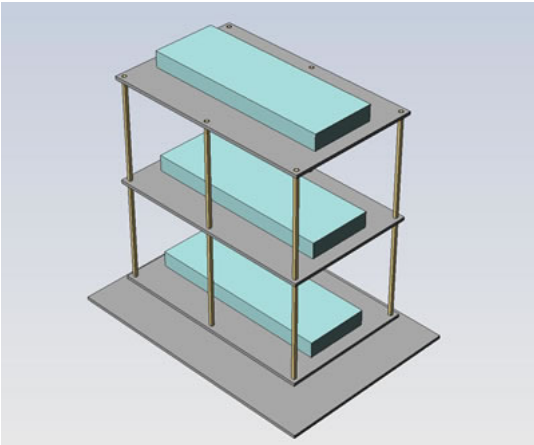

Figure 3. The benchmark model for the postgraduate retrofit competition

Figure 4. Part way through the construction of a base isolation system

3.1. Structural rules for the postgraduate model competition

The following key rules were developed for the postgraduate competition which define the form of the finished structure and the retrofitting solution:

- Once built, the non-seismically designed "benchmark" model can not be taken apart, i.e. the strengthening solution must be a retrofit rather than a rebuild.
- In a real building, there is generally a need for windows and doors in every storey. Therefore, for each storey of the strengthened model, space for at least eight windows and two doors needs to be left, the windows being 60mm wide, 120mm high and 6mm deep and the doors 40mm wide, 180mm high and 6mm deep. The horizontal position of the widows and doors should be under the beams. The vertical positions of the windows are flexible, but all the windows in the same storey should have the same vertical position. If a team does not leave enough or the correct sized spaces for windows and doors, penalties are applied to their model score. This rule effectively stops teams providing too many shear walls such that the models become excessively strong and cannot be broken on the shaking table.
- At least 22 mm needs to be left clear around the edges of the baseboard so that the upgraded model can be fixed onto the shaking-table using screws. This allows the models to be fixed to the shaking table.
- The upgraded model will be weighed and compared with the weight of the pre-upgraded "benchmark" model to get the total mass (Mt) of the retrofitting system.
- Before the shaking-table tests, masses will be glued onto each of the three floor plates (1F, 2F and roof). The mass of the steel block to be attached to each floor is 10 kg, and the dimension of each steel block is 350x120x30 mm. This effectively simulates the building mass when making small scale models.

3.2. The competition

The form of the competition is then based on the following concepts:

- Teams start by giving a marked presentation (see 3.3.1) about the concept of their energy dissipation system and/or base-isolation system for upgrading the model. It should be noted that some form of energy dissipation or base isolation must be included in the design and part of the marking scheme (see 3.3.2) assesses the effectiveness of the system used.
- Once constructed the benchmark model is checked and weighed (Mb), and then teams can start the seismic upgrade (figure 4). The quantity of additional permanent material used in the upgrade is assessed and forms part of the marking scheme (see 3.3.3).
- The design seismic strength of the upgraded model is 1000gals (1g) with shaking table test amplitudes

of 400, 800, 900, 950, 1000, 1050, 1100 and 1200gals. The models should not be over designed and the marking scheme (see 3.3.4) assesses accuracy of the seismic performance.

- Various types of damage are considered to count as failure of the models including complete collapse of the model or failure of more than half the columns and a displacement of the isolation system exceeding 50mm if a base-isolation system is used. These are all representative of the types of damage that might be experience in real buildings during earthquakes.

3.3. Marking the postgraduate model competition

The marking scheme for the postgraduate competition is more complex than for the high school and undergraduate competitions as it aims to test the performance of the models against the predictions of the postgraduates as well as the overall design concept. The overall score (S), eqn. 3.1, is therefore the multiple of a mark for a presentation (P1), a mark for the performance of the model (P2), a mark for the weight of permanent materials used in the retrofit (M) and a mark for the accuracy of the predicted model performance (A).

$$S = P1 * P2 * M * A \tag{3.1}$$

The highest score possible is 1.0 for S and the calculation of the individual components of the score is detailed below:

3.3.1. Mark for presentation, P1: (0.7~ 1.0)

As part of the competition the postgraduates give a presentation explaining the development of their retrofit concept and providing outline of any numerical simulation and experimental validation they have done to validate their proposed solution. This encourages the students to do some research on earthquake engineering and present their work in a form that would be appropriate for a conference presentation. The mark for the presentation is broken down into several components as shown in eqn. 3.2.

$$P1 = 0.7 + (A1 + A2 + A3 + A4) / 100 * 0.3 \tag{3.2}$$

where:

A1: Concept of the energy dissipation and/or base-isolation system (marked from *0~40*)
A2: Numerical simulation (*0~25*)
A3: Experimental validation (*0~25*)
A4: Presentation quality (*0~10*)

3.3.2. Mark for validation of the design concept, P2: (0.0~ 1.0)

In order to show that the retrofitting system is working as predicted the postgraduates must design and build a system that can measure the performance of their upgraded building. The mark for the validation method is broken down as shown in eqn. 3.3.

$$P2 = (B1 + B2) / 100 \tag{3.3}$$

where:

B1, from presentation: The team must outline a validation procedure of their seismic upgrade system *(0~ 40)*
B2, from physical test: The physical validation of the seismic upgrade system *(0~ 60)*

In their presentation the teams are asked to explain how they plan to validate the performance of their models and they must also provide a checklist that can be used during the actual testing to assess the building performance, this concept for validation is given a mark of *0~ 40*. During the shake table test the judges then use the teams' checklists to assess the performance of the upgraded building and give a mark for the actual building performance of *0~ 60*.

The teams need to provide a clear way to validate the behavior (e.g. the deformation of the seismic upgraded system) of their seismic upgraded system when the excitation exceeds 400gals. The simplest, clearest and best quantified methods getting the highest scores. During the shake table test, the behavior of the seismic upgrade system is then validated by the sensing system (designed and constructed by individual teams).

For example, a team with a base-isolation system might propose that the maximum stroke will be more than 30mm when the excitation exceeds 400gals. If they design a clear measurement system B1=40. Then if during the 400~1000gals shake table test, the stroke exceeds 30mm and if this is sensed by the measurement system B2=60.

3.3.3. Mark for mass of the additional non-energy reduction and non-isolation materials, M (0.7~ 1.0)

The form of the IDEERS competition means that it is not practical to calculate the cost of the model (something that would be very important in the real world). Therefore, to get some indication as to how much a particular solution might cost it is assumed that quantity (i.e. mass) of material used is proportional to the cost of the material. By weighing the finished models it is therefore possible to get an indication as to the cost of the retrofit which the students are encouraged to minimize. The mark for the mass (i.e. cost) of the retrofit solution is shown in eqn. 3.4

$$Ma = Mt - Mb - Ms \tag{3.4}$$

where:

Mt =Total mass of the upgraded model (excluding steel blocks)
Mb=Total mass of the benchmark model
Ms=Total mass of the energy dissipation system and base-isolation system which can be easily removed from the original structure.

Ma is then translated into the factor M using the data in table 3.1 below.

Table 3.1 Conversion of added mass (Ma) into factor M for scoring

Ma	Ma≦100g	100g<Ma≦200g	200g<Ma≦300g	Ma≧300g
M	1.0	0.9	0.8	0.7

3.3.4. Mark for the ultimate seismic strength of the model, A (0.3~ 1.0)

The competition asks that the models can survive an earthquake with a horizontal PGA of 1000gals (1g). To discourage over-engineered solutions (which would be more expensive in the real world) a mark is given based on the actual performance of the models. Table 3.2 shows how a mark is assigned based on the size of the largest earthquake that each model survives. In this case the highest mark (of 1.0) is achieved if the model survives the 1000gal earthquake but then fails during the 1050 gal earthquake.

Table 3.2 Conversion of ultimate seismic performance into factor A for scoring

PGA(gals)	400	800	900	950	1000	1050	1100	1200
A	0.3	0.45	0.75	0.85	1.0	0.9	0.8	0.5

3.4. Typical postgraduate models

Although the rules may seem quite complex they have been carefully designed so that they favor good engineering solutions to the retrofit problem and discourage very simplistic solutions that would not be appropriate in the "real world". The effectiveness, but flexibility, of the rules can be seen in the very creative solutions that the postgraduate have come up with some as part of the competition. Two examples are shown in figure 5.

Figure 5 (left) shows a model with base isolation, air dampers and strengthened columns and figure 5 (right) shows a simpler model with strengthened columns and base isolation. Both of these models used a pen to mark a piece of graph paper during the tests to show the extent of movement of the isolation system. The scores achieved by these two models are shown highlighted in table 3.3, with the model in figure 5 (right) coming second in this competition.

Figure 5: Two of models (groups 17 & 5) created for the postgraduate retrofit competition.

Table 3.3 Scores for some of the models taking part in the 2007 competition

Group No.	P1	P2	M	A	S
1	0.926	0.973	1.000	0.300	0.270
3	0.877	0.874	0.800	0.300	0.184
5	**0.957**	**0.962**	**0.900**	**0.750**	**0.621**
6	0.820	0.937	0.900	0.300	0.207
9	0.892	0.960	0.800	0.850	0.582
10	0.940	0.970	0.800	0.300	0.219
12	0.939	0.927	0.900	0.850	0.666
13	0.766	0.783	0.700	0.300	0.126
16	0.916	0.902	0.700	0.300	0.173
17	**0.895**	**0.967**	**0.700**	**0.300**	**0.182**

It is interesting to note that all the teams had difficulty building a model that could survive the 1000gal earthquake and their overall scores were brought down because in many cases the models failed during the 800gal earthquake (resulting in a score A of 0.3). This might have been a result of the conversion factors given in table 3.2 with the postgraduates trying to avoid over-designing the models, but then finding that the models proved to be harder to construct than anticipated and less robust than predicted.

4. PUBLICITY

Although many of the benefits from activities such as this are hard to quantify, it is becoming increasingly important for researchers to be involved in public awareness activities, and competitions like this can provide an enjoyable way for researchers to engage with the public. In Taiwan however more tangible benefits have been realised because the competitions have generated significant press and TV publicity for the NCREE facilities and the research activities underway in the laboratory with several one hour TV programmes about the competition being produced. The main reason that the event has continued to attract the media is the nature of the activity. The whole event is very visual with the construction of the models on the first day and then the testing on the second day (figure 6). The sequence of testing with the earthquake gradually increasing in size also creates a lot of suspense and the students get very involved watching the performance of their models. The TV programmes have therefore been able to combine the excitement of the competition with a more serious discussion about how earthquakes cause damage to structures. The programmes have particularly referred to the damage caused by the 1999 Chi-Chi earthquake and have included information about the technical side of earthquake engineering design in addition to information about the ongoing earthquake engineering research in Taiwan. This sort of activity can therefore directly inspire and educate the students who take part in the competition about the importance of earthquake engineering activities. In addition, through the publicity it generates, it can reach a much wider audience to increase general awareness of the importance of good design and help reduce the likelihood that inappropriate structures are built where earthquakes are a hazard.

Figure 6: The shaking table testing on the second day of the event.

5. CONCLUSIONS

Since 2000 the earthquake engineering design competition IDEERS has been running in Taiwan in various forms for high school students, undergraduates and more recently for postgraduates. The competition has slowly been developing, with some modifications to the original rules so that the challenge of the design continues to stretch the creativity of all the students taking part. The recently developed postgraduate competition has created a much more technically demanding competition asking the postgraduates to develop and install a retrofit solution for a non-seismically designed two storey building. The competitions have been very successful, with thousands of students actively taking part, and they have generated a lot of press and TV publicity for the NCREE facilities and the research activities underway in Taiwan. It is hoped that the development and continued use of activities such as this will increase general awareness of the importance of good seismic design and raise the profile of the earthquake engineering research groups taking part in the events.

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