SMART 2008 Project: Seismic design and best-estimate Methods Assessment for Reinforced concrete buildings subjected to Torsion and non-linear effects
Earthquake blind prediction contest and fragility assessment

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ABSTRACT

In order to assess the capability of structures, exhibiting both 3-D effects (such as torsion) and non-linear behaviour, to withstand earthquake loads as well as seismic loads induced to their equipments, a research project has been set up by CEA and EDF. This paper presents the first part of ‘SMART-2008’ project, which consists in a predictive benchmark of a 3 storeys reinforced concrete structure scaled to 1/4th, which will be tested on AZALEE shaking table in 2008 at EMSI Laboratory – CEA SACLAY.

INTRODUCTION

Reinforced concrete (RC) buildings exhibiting 3D (i.e. torsion) effects and non-linear response are a main concern in the field of earthquake research and regulation. In the last decade, several RC specimens have been tested under seismic excitations as part of “Camus” program in order to study the seismic behaviour of shear walls, but without significant 3D effects. In order to assess the capability of buildings to withstand earthquake loads as well as seismic loads induced to their equipments, a reduced scaled model of a RC building with 3D effects will be tested in 2008 on AZALEE shaking table, which belongs to Commissariat à l’Energie Atomique (CEA) in Saclay (France) as part of “SMART-2008 project” (Seismic design and best-estimate Methods Assessment for Reinforced concrete buildings subjected to Torsion and non-linear effects). This project is supported by Commissariat à l’Energie Atomique (CEA) and Electricité de France (EDF). A blind predictive benchmark will be organised before the tests. The objectives of this paper is to present the aim and the schedule of the benchmark as well as the main characteristics of the specimen.

SMART PROJECT OBJECTIVE

The aim of the present benchmark is (1) to compare and validate approaches used for the dynamic responses evaluation of RC structures subjected to earthquakes and exhibiting both 3D (i.e. torsion) and non-linear behaviours, (2) to evaluate loads induced to internal equipments, and (3) to quantify margins in design methodologies and to carry out realistic methods to quantify variability in order to produce fragility curves.

The benchmark is divided in 3 phases:

1st phase: Blind prediction contest
The prediction contest will be blind and finally compared to test results at various levels of seismic excitation (including “under-design” and high “over-design” levels). The modelling of the structure will be conducted based on conventional data, as usually used for basic design studies. The seismic input motion selected consists in design spectra and bi-axial horizontal accelerograms (real and synthetic accelerograms). The objectives are (1) to evaluate conventional design methods for structural dynamic response and floor response spectra calculations and (2) to compare best-estimate methods for structural dynamic response and floor response spectra evaluation including various practices, depending on participants experiences (linear equivalent approaches, non-linear approaches, …).

2nd phase: Test campaign on Azalée Shaking Table
The 1st phase will be followed by a 1st test campaign at a low seismic level (3 real accelerograms, near and far – pga = 0.05g). The objectives are both (1) to get more experimental datas at low non-linearities to facilitate post-adjustments (cf. phase 3) and (2) to generate artificial ageing in the mock-up. This 1st test campaign will be followed by a second campaign using synthetic accelerograms with increasing pga level (from 0.1g to 1.0g with a 0.1g increase).
Depending on available budget, one or two additional mock-up are also expected to be casted and directly tested at a high “over-design” seismic level in order to evaluate the effect of preliminary tests performed on the previous mock-up (damage accumulation). In that situation, effects of after-shocks may also be studied.

3rd phase: Variability quantification and fragility assessment

Due to high cost and large amount of time needed to assess variability based on experimental approaches, this phase will essentially be numerical. Tests results from phase 2 may be used for post-adjustments of models. For the purpose of this phase, a relatively large number of seismic input motion will be provided and computations are expected to be performed until the failure of the model. The objectives are (1) to quantify variability in the seismic response of the structure and identify contribution coming from uncertainties in input parameters and random variables and (2) to investigate and compare different methods for fragility curves elaboration.

SMART SPECIMEN PRESENTATION

SMART specimen is a 1/4th scaled trapezoidal, three-story reinforced concrete structure, representative of a typical nuclear building. As shown of figure 1, it’s a U shaped building. The thickness of walls and slabs is 10 cm. Due to the specific geometry of the specimen, center of torsion is excentered from the gravity center (more than in each horizontal direction).

![Fig. 1: SMART specimen views](image1)

Materials, that will be used for the specimen, are the ones commonly used in the nuclear French engineering profession (Concrete C30/37 – Steel Reinforcement : Fe500).

SMART specimen was designed according to the current practice of nuclear engineering using the SDD design response spectrum given by figure 2. All the plans describing the structure are available on the website of the project https://www-sismique.cea.fr in the area dedicated to the registered participants.

![Fig. 2: SMART Design Response Spectra](image2)

Additional loads are applied on each slab in order to respect the same structural properties as the real structure. About 12 Tons additional masses will be added on each slab before the tests. The total weight of the specimen is estimated at about 47 T.
BLIND PREDICTION ANALYSIS

As mentionned previously, the purpose of the blind prediction is to compare and validate the current approaches used in seismic analysis of reinforced concrete structure subjected to 3D effects. The proposed analysis will have to be conducted in 3 steps :

- preliminary analyses :
  - Static analysis under gravity loads,
  - Modal analysis.
- conventional basic design study :
  - Dynamic analysis based on conventional participants method,
  - Input: SDD- Design spectrum.
- best estimate methods :
  - Time-history analyses based on participants own experience,
  - Input: 3*2 real accelerograms (pga = 0.05g) and 10*2 synthetic accelerograms (pga $\in [0.1 \, \text{g};1.0 \, \text{g}]$).

Preliminary analysis

A preliminary analysis was made by CEA and EDF to calculate the modal response of the specimen and validate the torsion effect on the structure. The first three modes of the structure are given by figure 3. Participants will have to do the same analysis for the blind prediction contest.

Conventional basic design study

In order to assess conventional design seismic methods, a conventional basic study will be conducted by each participant according to their own standard approach.

Two kinds of seismic input are available at this stage :

- Response spectra for different damping values (Figure 2),
- One set of synthetic Time histories (Figure 4) corresponding to the design response spectrum.

If the participants considered, based on their own standard procedure, that more accelerograms should be used, they can derived their own accelerograms (based on the response spectrum of figure 2), and compute, in parallel, the response of the model with as many accelerograms as they are used to.
Best estimate analysis

The purpose of this analysis is to predict at best the behavior of the specimen during the seismic tests. Participants are invited to simulate each step of the experimental phase which will consist in:
- 3 seismic tests using 3 couples of real accelerograms from European databases of past earthquakes with a PGA of 0.05g. The following accelerograms were selected considering their various characteristics and frequency contents:

![Fig.5: Accélérogram #1: M = 5.2 – Dist = 23 km](image)

- 10 seismic tests using a couple of synthetic accelerograms (defined from the design response spectrum of figure 2) with increasing PGA from 0.1 g to 1.0 g (step of 0.1 g):

![Fig.8: Synthetic accelerograms](image)
AZALEE SHAKING TABLE

Seismic tests will be performed on the 6 DOF AZALEE shaking table at the Seismic Mechanic Study Laboratory of CEA Saclay (France) (Figure 9). The shaking table is a 6x6m square plate with a maximum payload of 100 tons. Eight hydraulic jacks (4 horizontal excitations and 4 vertical) are connected to the plate. Each jack has a maximum force of 1000 kN. Four static pneumatics support under the plate uphold the weight of the table and the specimen. The maximum displacement amplitude range is 250 mm for the two horizontal axes and 200 mm for the vertical axis.

Fig.9 : AZALEE shaking table

INSTRUMENTATION OF THE SPECIMEN AND TESTS PROTOCOL

A preliminary analysis was conducted by CEA in order to define the location of the expected damaged area. Figure 10 shows the envelope strain state of the specimen for a spectral loading corresponding to the design spectrum. A particular attention will be given to the bottom of the specimen, between foundation and the 1st slab, especially for the smallest wall.

Fig.10 : Envelope strain state of the specimen
The project of specimen’s instrumentation is given by table 1.

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| Total     | 69             | 45            | 44           | 54             | 212   |

Table 1 : SMART specimen instrumentation

More than 200 channels will be recorded during each test in order:
- To measure the behavior of the shaking table during all the tests campaign,
- To measure displacements and accelerations at different levels of the specimen and record informations about the global and local behavior of the specimen,
- To measure the local behavior (concrete and steel reinforcement) of the specimen in expected damaged areas of the 1st level (figure 10).

SCHEDULE

Informations concerning the blind prediction, the description of the structure, the accelerograms that will be used during the tests and the results expected from the participants are available on the web [https://www-sismique.cea.fr](https://www-sismique.cea.fr), in the area dedicated to participants. Registration is necessary to get an access to the participants area. It can be done by contacting CEA (thierry.chaudat@cea.fr). Results of the blind prediction benchmark will be collected and synthetized by CEA Team. The expected schedule is the following:

**Phase 1 :**
- Nov. 2007 : Deadline for the submission of blind prediction results (report and CD Rom),
- Apr. 2008 : Synthesis report (blind prediction) available and sent to participants,
- Apr. 2008 : Sep. 2008 : Test campaign,
- Feb. 2009 : Synthesis report (test results vs blind prediction) available and sent to participants.

**Phase 2 :**
- Mar. 2009 : Data and specification report available on the website,
- Jan. 2010 : Deadline for the submission of phase 2 results (report and CD Rom),
- May 2010 : Synthesis report (phase 2) available and sent to participants,

Workshops or technical meetings are planned at key dates along the program. In addition, the final technical workshop may be organised under the auspices of OCDE and IAEA to draw its conclusions.