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SMART 2008 : EXPERIMENTAL TESTS OF A REINFORCED CONCRETE BUILDING SUBJECTED TO TORSION

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ABSTRACT :

Reinforced concrete buildings exhibiting 3D (i.e. torsion) and non-linear effects are a main concern in the field of earthquake research and regulation. In the last decade, several reinforced concrete specimens have been tested under seismic excitations in order to study the seismic behaviour of shear walls, but without significant 3D effects.
In order to assess the capability of structures exhibiting 3D effects to withstand earthquake loads as well as seismic loads induced to their equipments, a reduced scaled (1/4th) model of a 3 stories reinforced concrete structure with 3D effects will be tested between June and September 2008 as part of the SMART project on AZALEE shaking table (EMSI Laboratory – CEA Saclay – France).

The aim of this project is (1) to compare and validate approaches used for the dynamic responses evaluation of RC structures subjected to earthquakes and exhibiting both 3D (torsion) and non-linear behaviours, (2) to evaluate loads induced to internal equipments, (3) to quantify margins in design methodologies and (4) to carry out realistic methods to quantify variability in order to produce fragility curves.

This paper presents the main characteristics of SMART specimen, the instrumentation and the seismic tests program, as well as some preliminary experimental tests' results.

KEYWORDS: Seismic tests, SMART, Reinforced concrete structure, Torsion, AZALEE shaking table

1. INTRODUCTION

In order to assess the seismic tri-dimensional effects, such as torsion and non-linear response of reinforced concrete structures, a reduced scaled model (scale of 1/4th) of a typical electrical nuclear reinforced concrete building was designed and built to be tested between June and September 2008 on AZALEE shaking table at Commissariat à l'Energie Atomique (CEA Saclay, France). This test, supported by CEA and Electricité de France (EDF), is part of the "SMART-2008" project (Seismic design and best-estimate Methods Assessment for Reinforced concrete buildings subjected to Torsion and non-linear effects).

The first part of the project is a blind prediction of the structure behaviour under different seismic loadings (the same ones which will be inputted to the specimen tested). It is presented as a contest, opened to teams from the practicing structural engineering as well as the academic and research community, worldwide. This blind predictive benchmark should allow us to compare and validate approaches used for the dynamic responses evaluation of reinforced concrete structures subjected to earthquake and exhibiting both 3-D and non-linear behaviours.

The second part of the project is the tests campaign.

This paper presents the main characteristics of SMART specimen, the instrumentation, the seismic tests program, as well as some experimental preliminary results at design level.

1. SMART SPECIMEN PRESENTATION

1.1. Geometrical description

The 1/4th scaled model to be tested is a trapezoidal, three-story reinforced concrete structure (Figure 1). It is representative of a typical, simplified half part of an electrical nuclear building. It is composed of three walls forming a U shape. Two of those walls have openings. The walls and slab are 10 cm thick.
The specimen has been designed according to the French nuclear methods, with a peak ground acceleration for the response spectrum anchored at 0.2 g. This seismic loading corresponds to a Safe Shutdown Earthquake (SSE) in a low to medium seismic area (equivalent to a magnitude of 5.5 with a distance of about 10 km).

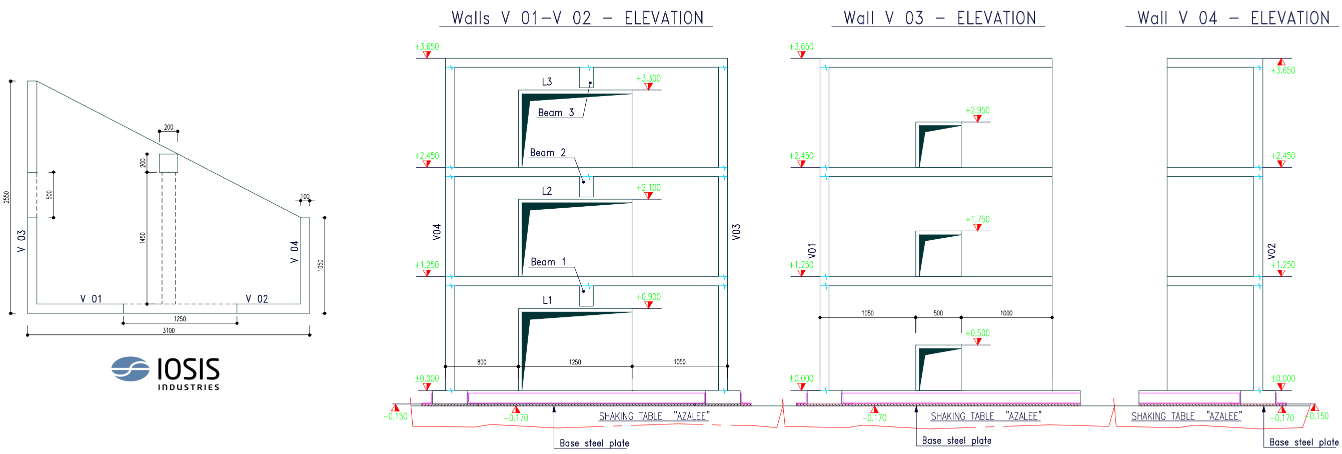


Figure 1 Plan view and elevations of the SMART2008 specimen

The wall's foundations are made of a continuous reinforced concrete footing, lying on a 2 cm high steel plate. The reinforcement steel bars are welded to this steel plate. The reinforced concrete column is directly anchored on a square steel plate. The two steel plates are bolted on AZALEE shaking table.

Table 1 summarizes the main geometrical characteristics of the specimen.

Table 1 SMART specimen geometry

	Length (m)	**Thickness (m)**	**Height (m)**
Wall (#V01 + #V02)	3.10	0.10	3.65
Wall #V03	2.55	0.10	3.65
Wall #V04	1.05	0.10	3.65
Beam	1.45	0.15	0.325
Column	3.80	0.20	0.20

The bare structure weight about 11 T (Figure 2). Additional loading are placed on each slab (about 12 T on slab n°1 and slab n°2 and 11 T on slab n°3) in order to represent the real loading of the referential structure. The total weight of the SMART specimen is therefore of about 46 T (Figure 2).

Figure 2 Photo of the SMART specimen, unloaded and fully loaded

1.2. Construction of the specimen

SMART specimen was cast in place at CEA, outside AZALEE shaking table, by FREYSSINET, in a dedicated area. Table 2 summarizes the schedule of the construction.

Table 2 SMART specimen construction schedule

Beginning : October 8th, 2007	Foundations : October 26th, 2007
Walls of 1st Level : November 21, 2007	1st Slab : November 29, 2007
Walls of 2nd Level : December 10th, 2007	2nd Slab : December 17th, 2007
Walls of 3rd Level : January 10th, 2008	**3rd Slab : January 17th, 2008**

Figures 3 and 4 show different views of foundations and slabs during construction

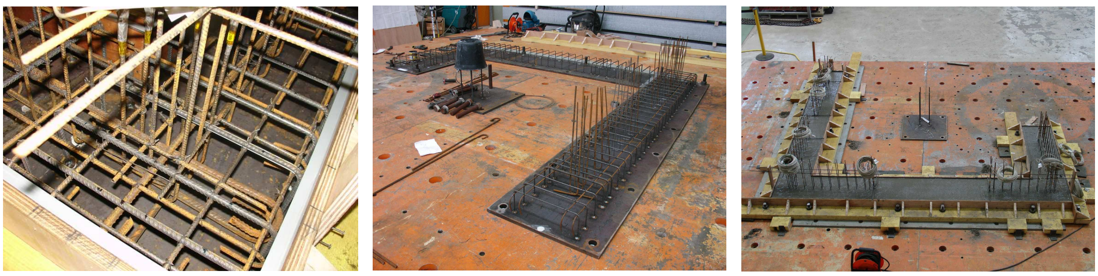


Figure 3 Foundations construction of SMART specimen

Figure 4 Slab construction of SMART specimen

1.3. Materials properties

The materials used for the specimen are the ones commonly used in the nuclear French engineering profession. The main characteristics are given below:

- **Concrete C30/37**

  f_{cj} = 30 MPa *Compressive strength*
  f_{tj} = 2.4 MPa *Tensile strength*
  E = 32000 MPa *Concrete Young modulus*
  ν = 0.20 *Poisson's ratio*

- **Steel reinforcement**

  The steel reinforcement has been defined according to the European design codes (EC2).
  Steel reinforcement: FeE500-3: R_{eH} = 500 MPa *Yielding stress*

Table 3 gives the minimum required values of the mechanical properties of steel bars used for the specimen.

Table 3 Minimum mechanical characteristics of FeE500-3

Yielding Stress R_{eH} (MPa)	**R_m/R_{eH} *(1)***	**Maximum elongation at R_m A_{gt} (%)**
Inferior limit	Inferior limit	Inferior limit
500	1,08	5

R_m : Tensile strength

Table 4 presents the bars' diameters and areas used to build-up the specimen.

Table 4 Reinforcement characteristics

Bar	DX3	HA4	HA6	HA8	HA10
Diameter (mm)	3	4	6	8	10
Area (cm²)	0.07	0.13	0.28	0.50	0.78

The distance between the surface of the concrete and the centre of the reinforcement bar is about 0.015 m.

1.3. Transfer of the specimen

A specific "handling beam" was designed and realised for the transfer of SMART specimen from the fabrication area to AZALEE shaking table. Figure 5 shows the bare specimen during the transfer.

Figure 5 SMART specimens’ transfer

2. AZALEE SHAKING TABLE

The seismic tests are performed on AZALEE shaking table at the Seismic Mechanic Study Laboratory of CEA Saclay (France) (Figure 6).

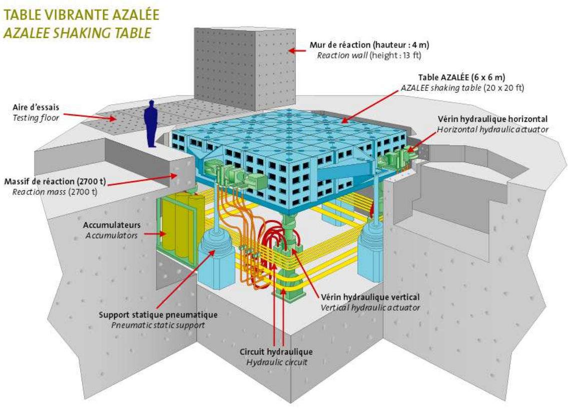


Figure 6 AZALEE shaking table

AZALEE is a 6 m x 6 m aluminium shaking table, with 6 degrees of freedom and a maximum payload of 100 Tons. Eight hydraulic jacks (4 for horizontal excitations and 4 for vertical excitations) are connected to the table. Four static pneumatic supports under the table uphold part of 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.

3. TESTS PROGRAM

1.3. Scaling factor

The specimen is a reproduction of a typical nuclear building at a scale of ¼. In order to keep the same acceleration (gravity load can not be changed) as well as the same material properties, the scaling of ¼ of the structure’s dimension implies to scale the mass by $^{1}/_{16}$ and the time by ½. Table 6 summarizes the scaling values already applied to the different parameters.

Table 6 Scaling factor of parameters

	Scaling factor		**Scaling factor**
Length	4 (= λ)	**Stress**	1
Mass	16 (= λ^2)	**Frequency**	0.5
Time	2 (= $\lambda^{1/2}$)	**Force**	16
Acceleration	1	**Steel reinforcement area**	16

1.4. Seismic inputs

Bi-axial horizontal seismic tests, with a pga ranging from 0.05 g up to 1 g, will be performed.
One set of two synthetics accelerograms has been derived from the following design response spectra (Figure 6).

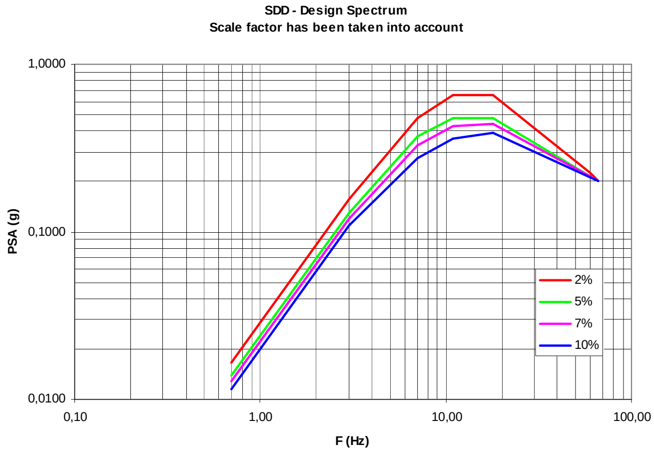


Figure 6 Design Response Spectra

Moreover, a set of 3 real accelerograms have been chosen in order to 'slighlty' damage artificially the specimen. In order to respect the scaling factor of the specimen, the time of the accelerograms has been divided by two.

The following tests sequence will be realised as follows :

- 3 seismic tests with 3 different set of real accelerograms, at 0.05 g pga level,
- 10 seismic tests with the scaled set of synthetic accelerograms from 0.1 g up to 1 g pga level.

Each set of accelerograms consists of two different horizontal accelerograms applied respectively in each main direction of the specimen. Figure 7 shows the two synthetic accelerograms for a pga level of 0.1 g.

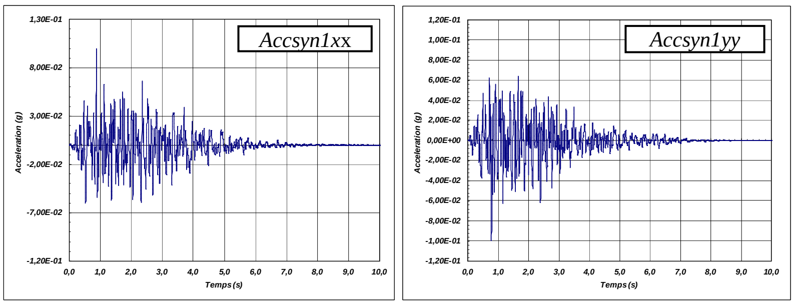


Figure 7 Synthetic accelerograms (pga level : 0.1 g)

4. DESCRIPTION OF INSTRUMENTATION

The objectives of the instrumentation defined for the tests campaign are :

- **For AZALEE shaking table** : to record the behaviour of each degree of freedom (Dx, Dy, Dz, Rx, Ry, Rz) of AZALEE in acceleration and displacement,
- **For SMART specimen** : to monitor the boundary conditions, to understand the global and the local behaviour of the specimen, to perform image analyses from high speed video recordings, realised during each test.

Table 7 summarizes the instrumentation defined for the different seismic tests.

Table 7 Instrumentation description

Location	Acceleration	Displacement	Crack Openings	Concrete Gages	Steel Gages	Total
Table	6	6	-	-	4	12
Foundation	12	4				16
Slab 1	15	13	-	-	-	28
Slab 2	21	13	-	-	-	34
Slab 3	21	13	-	-	-	34
Walls #1-2	-	13	-	12	17	43
Wall #3	-	14	3	21	15	53
Wall #4	-	10	3	9	6	28
Column	2	-	-	-	-	-
Total	77	86	6	42	42	253

Global behaviour of the specimen (acceleration / displacement) will be monitored at 7 main locations (see figure 8) :

- Points A, B, C and D : corners of the specimen at each level,
- Point E : middle of the beam at each level,
- Points F and G : center of mass of each part of the slab, at level 2 and 3.

Tri-axial accelerometers will be placed at each points. Horizontal displacements in X and Y direction will be recorded at points A, B, C and D and vertical displacement at point E between each level.

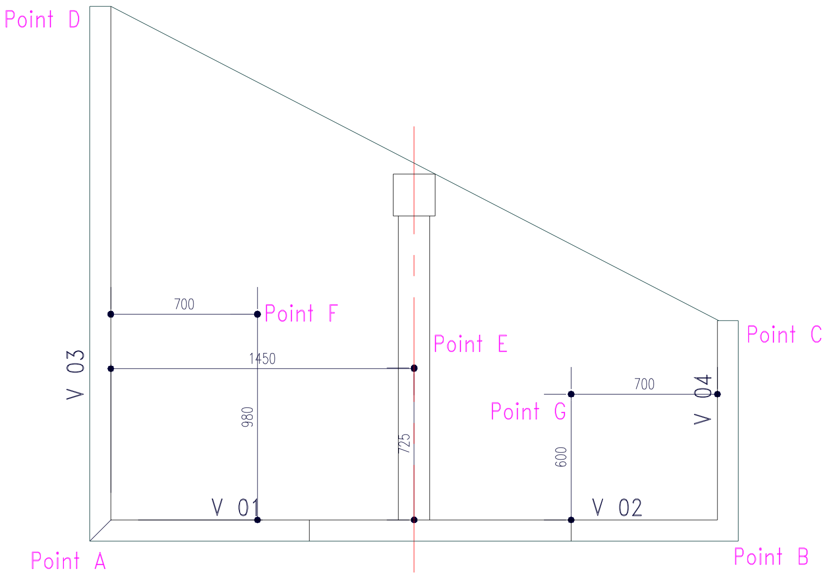


Figure 8 Instrumented points for global behaviour of the specimen

Local behaviour of the specimen will be monitored at several locations using :

- 42 steel gages on foundations', walls' and lintels' steel bars,
- 42 concrete gages at the base of walls and on lintels of the 1st level,
- 55 displacement transducers on walls and lintels,
- 6 cracks opening transducers at the base of walls #3 and #4.

Figure 9 shows some examples of the local instrumentation of the specimen.

Figure 9 Exemples of local instrumentation of SMART specimen

Each seismic tests will be recorded with 2 categories of cameras :

- 3 DV cameras for general views of the specimen,
- 2 high speed cameras for image analyses (~ 100 images/s).

5. PRELIMINARY EXPERIMENTAL RESULTS

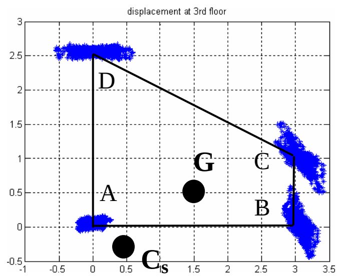
At this stage of the project, the seismic levels inputted at the table level are up to 0.2 g, which corresponds to the design level of the structure. Some preliminary results are presented below :

- **<u>Frequencies</u>** : frequencies of the specimen have been determined during the 1st seismic test (pga : 0.05 g). Table 8 summarizes the first 3 values :

Table 8 Initial natural frequencies

	f (Hz)	Type
Mode 1	6.24	Bending (Ox)
Mode 2	7.86	Bending (Oy)
Mode 3	15	Torsion

- **<u>Damping values</u>** : The structural damping value has been estimated between 1 and 2 % during the 4 first seismic tests (corresponding to low seismic levels),
- Torsional effect is clearly exhibited during each experimental campaign. Figure 10 presents the relative horizontal displacements of each corner of the structure at the 3rd floor (scaled to exhibit the structure behaviour).



G **centre of mass**
C_s **shear centre**

Figure 10 : Top floor horizontal displacement – 0.1 g seismic test

- The maximal absolute acceleration at the top floor are : (1) x-x : 0,22 g to 1 g and (2) y-y : 0,25 g to 0,86 g.

As expected, the structure exhibited the tri-dimensional behaviour expected but after undergoing through 4 seismic excitations (including one input equivalent to the design level), the structure has suffered no apparent damages (no cracks opening could be observed). In the following months, the same specimen will be tested with higher seismic motions (up to 0.8 g, at least).