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Large scale seismic tests performed on the table Azalee of CEA - Reproductibility of seismic motions

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Abstract

After a presentation of the AZALEE shaking table and of its control command, this paper presents results of tests performed on the table, loaded with three different heavy and large mockups. It shows the procedure to obtain a good reproduction of seismic excitations at low level and high level acceleration.
The first mock-up is a reduced scale mock-up of a 8 floors building. The mass of this mock-up is 90 tons. The maximum acceleration is 0.5 g.
The second mock-up represents 3 rows of fast breader reactor fuel assemblies. The mass with the inside water is about 50 tons. The maximum acceleration applied at the table is 1.5 g.
The last example is a tank, full of water, with a mass of 40 tons. The excitation is increased up to 1.6 g.
For all these tests, the paper presents comparison between the required acceleration and the measured acceleration on the table. Some comparisons are also performed between the measured accelerations at the base and on the top of the specimen.

1.Introduction

To verify the performances of the Azalee table, the EMSI laboratory of the CEA, has performed tests on different mock-ups. The objectives of these tests were to verify :

- the maximum acceration and velocity of the table loaded with large mock-ups,
- the control of the rocking motion of the table,
- the good reproduction of seismic motions when :
  - the mock-up is very heavy (> 50 tons),
  - the mock-up is the very heigh (> 5 m),
- and to determine the minimuim level of the preliminary test, to measure transfert functions of the table.

Many equipments do not authorize preliminary tests for the determination of transfer functions of the setup, for example for concrete specimens. In these cases, it is necessary :

- to qualify the table and to measure the transfer functions be making preliminary tests on equivalent masses, representative the most possible of specimens (mass, frequency and position of the gravity center),
- or to realize preliminary tests at a very low level excitation.

2. Characteristics of AZALEE shaking table

2.1. Shaking table

The Azalee shaking table (figure #1) is a biaxial horizontal-horizontal table which can performed tests on large specimens up to 100 tons. This set-up has 4 actuators (1000 kN each) fixed along each side. The other degrees of freedom are locked by means of 4 vertical beams with suivels bolted under the table. Each actuator is equipped with 3 servo-valves allowing a maximum oil flow of 2200 l/mn.
The size of the table in aluminium is 6 m X 6 m and the empty mass is 25 tons. The first eighen frequency of the table is located at 80 Hz.

2.2. Control divice

The table is controlled by electronic controllers which move Azalee along 6 degrees of freedom. These controllers (MTS 469) allow to obtain for each actuator a transfert function flat up to 150 Hz. Generaly, the control of an actuator is obtained by the control of one variable (figure #2). However, one of these control variables (whether it is displacement, velocity, or acceleration) cannot provide flat performance in the broad frequency range of a typical seismic test system. Therefore, AZALEE table utilizes all three of these control variables in seismic systems through application of the three-variable control concept (TVC). The TVC concept provides simultaneous control of displacement, velocity, and acceleration variables (figure #3). It combines the command and feedback signals of all three control variables to provide the needed system performance, emphasizing displacement at low-range frequencies, velocity at middle-range frequencies, and acceleration at high-range frequencies. This tailors the frequency stability characteristics of the seismic system to achieve the best performance. There are three components which contain circuitry that is critical to the implementation of MTS TVC : the reference generator, velocity conditioner and servo stability modules. In general, these components complete the following tasks :

- reference generator circuitry derives the three control (or referenece) signals needed for TVC from one command signal,
- velocity conditioner circuitry derives the velocity feedback signal from acceleration and displacement feddback signals,
- servo stability module circuitry sums the reference and feedback signals to create three control variables errors, and then sums these errors to form the composite error signal that drives the actuator (figure #4).

The remaining seismic control concepts are methods of compensation and stabilization techniques that improve the fidelity of system performance. The techniques used are :

- geometric cross coupling compensation,
- overturning moment compensation,
- off center load compensation,
- load dynamics compensation ,
- force balance compensation,
- differential pressure stabilization,

- velocity lead terms,
- acceleration lead terms,
- servo-valve linearization.

A computer is coupled to the electronic to perform tests. This computer allows :

- to calculate synthetic accelerograms from required response spectra (RRS),
- to generate input signals in the MTS controllers, calculated from a synthetic accelerogram or from a recorded earthquake which take into account transfert functions of the table and of the controllers measured during a preliminary test in open loop,
- to modifie the driver signals in order to have signals in good agreement with the maximum performances of the table (low or high pass filters, correction of the velocity and acceleration to obtain displacement, velocity and acceleration equal to zero at the end of the excitation.
- to perform sine sweep or random excitation in close loop control.

3. Tests performed and principal resultats

Tests were performed on three differents mockups :

- to verify the good reproductibility of accelerograms in cases of heavy mockups,
- to show that the table does not present any parasite rocking motion,
- to determine the maximum performances of the table loaded with heavy and slender mockups,
- to determine the minimum acceleration to perform the preliminary test for concrete mockup.

3.1. SYMPHONY mockup

Tests were performed on a slender mockup which corresponds to three fuel assemblies rows of a fast breader reactor core, scale one. The mockup consists in (figures # 5 and 6) :

- a tank (5.230 m height and 6.3 m length) with a empty mass of 22000 kg,
- 3 raws of 24 fuel assemblies (total mass 4920 kg) with a eighen frequency resonance located at 2.9 Hz,
- 11 steel beams (lateral neutronic protection) at each extremity of the raws (mass 3700 kg) with a eighen frequency at 4.1 Hz.

The mockup, full of water, has a total mass of 42700 kg, and is submitted to a serie of increasing level earthquakes.

3.1.1. Test at 0.65 g

This test shows the good reproductibility of an accelerogram after a small number of iterative corrections (maximum 2). The figure # 7 presents the Required Response Spectrum (RRS) and the Test Response Spectrum (TRS) measured on the table.
The figure # 8 presents the acceleration measured on the table and the required acceleration. The two signals are in good agreement.

3.1.2. Test at 1 g

The aim of this test is to show, by the comparison between spectra measured at the bottom and at the top of the mockp. The figure # 9 shows the TRS measured on the table and the response spectrum measured on the top of the mockup. There is not rocking motion of the table during the excitation.

3..2. CASSBA mockup - Test on a concrete mockup

In the framework of CASSBA and CAMUS research and development programs to study the seismic behavior of structures with reinforced concrete wall, tests were performed on concrete mockups. A first serie of tests were performed (CASSBA program) on a mockup, which represents a 8 floor building, scale 1/3. The mass of the mockup was 87000 kg. The transfert functions were obtained during a very low level excitation to do not damage the mockup. The figure # 10 shows the TRS and RRS obtained during a first test at 0.05 g without correction of transfert functions.

3.3 Tests on a tank full with water

New tests will be performed in the next months another concrete mockups scale 1/3. These mockups will consist in 2 walls and 6 floors with additionnel concrete masses. The total mass of a mockup will be 39000 kg and the principal dimensions will be :

- height = 5.1 m,
- width = 1.7 m,
- length = 1.7 m,
- gravity center position = 2.5 m.

The mockup is defined for an acceleration level of 0.8 g in taken into account the similitude law. To prepare tests and to verify the program faisability, preliminary tests were performed on an equivalent mockup. This mockup consists in a tank, full of water, and closed by a lid. The weigh is 40000 kg and the gravity center is located at 2.3 m height (figure # 11). The dimensions of the tank are :

- height = 3.9 m,
- length = 3.8 m,
- Width = 2.4 m.

The tank is submitted to a serie of increasing level seismic excitations and differents accelerograms up to the maximum performances of the table. Tests were stopped at 1.6 g. The calibration of the table was realized in the same conditions as for the concrete mockup. The transfer functions (mockup bolted on the table) were measured in a first step with a random excitation with a maximum table acceleration at 0.05 g. The figure # 12 shows the acceleration of the test to 0.4 g without iterative correction of transfer functions.

The figure # 13 shows a zoom presenting the comparison (between 0 s and 11 seconds time) between the acceleration measured on the table and the reference acceleration (EDF spectrum) for a test at 1.25 g. One can notice that the acceleration of the table at 0.4 g and 1.25 g are similar and that the measured signal can be superposed to the required acceleration.

The figure # 14 shows TRS and RRS for an other spectrum (NICE spectrum). We observe also a very good agreement between the two spectra.

4. Conclusion

All tests performed on the AZALEE table with specimens, in the range 10 tons to 90 tons, show a very good reproduction of the required acceleration. No pitch and rocking motion on the table are observed during tests, but it is necessary to adjust gains of the electronic controller loops in function of the specimen mass. In some cases, it is necessary to perform preliminary tests on a equivalent mockup. These results show that the three-variable controllers added to a control computer for the correction of the transfert function allows :

- to reproduce perfectly temporal signals and therefore the required response spectrum, even at the maximum performances of the table,
- to realize tests with preliminary tests at very low level acceleration.

This procedure was used for test on a 90 tons concrete mockup (maximum acceleration 0.5 g), and will be used again for the new tests on the 40 tons mockup for acceleration up to 1.25 g).

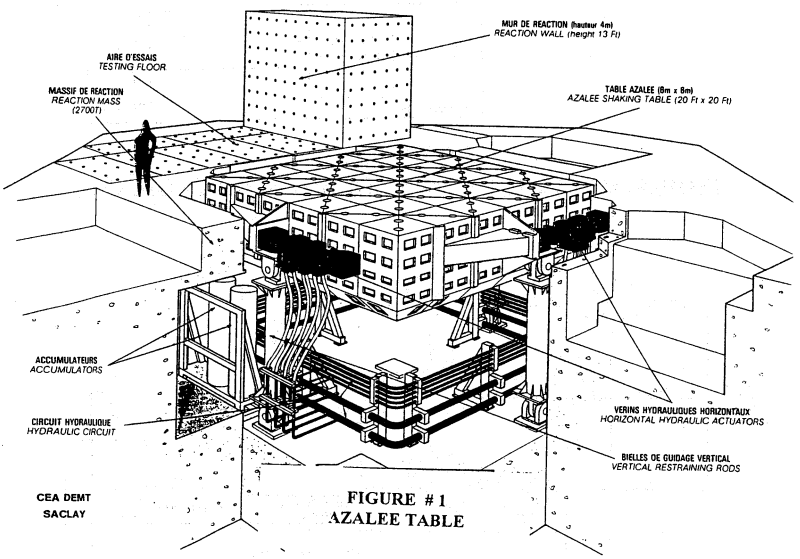


FIGURE # 1
AZALEE TABLE

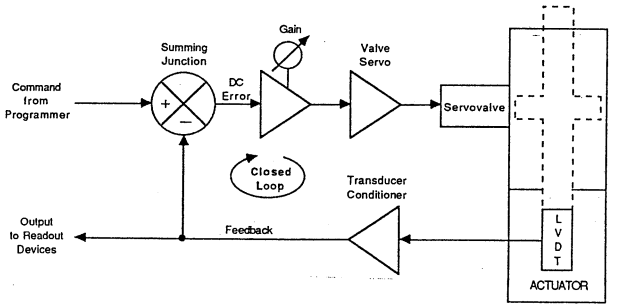


FIGURE # 2
BASIC CLOSED-LOOP CONTROL

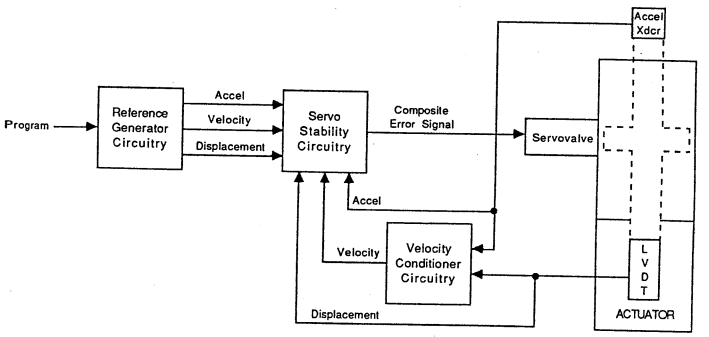


FIGURE # 3
THREE-VARIABLE CONTROL BLOCK DIAGRAM

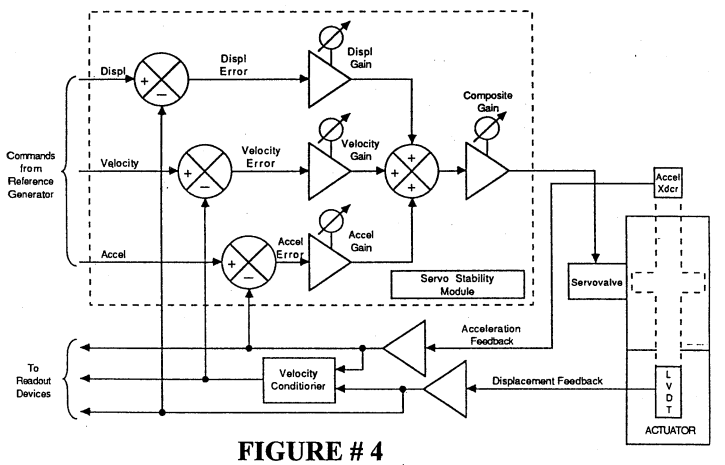
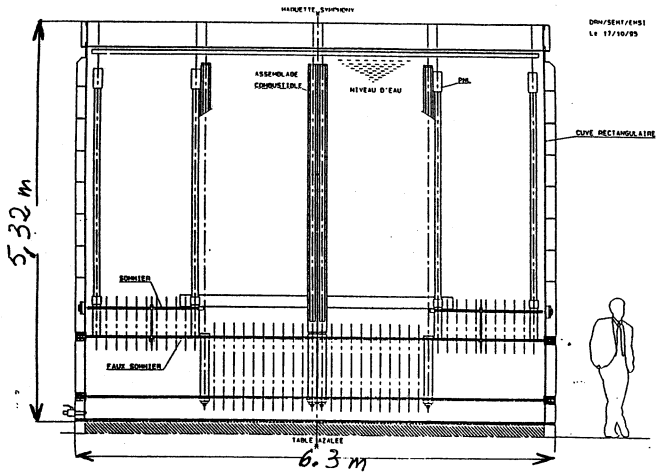


FIGURE # 4
SERVO STABILITY MODULE FUNCTIONAL

FIGURE # 5
SYMPHONY MOCKUP



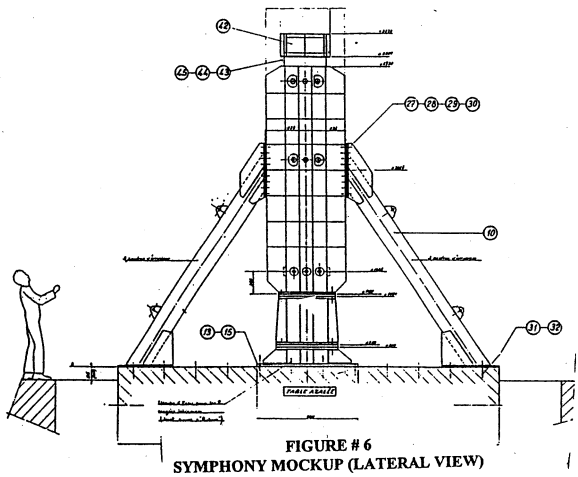


FIGURE # 6
SYMPHONY MOCKUP (LATERAL VIEW)

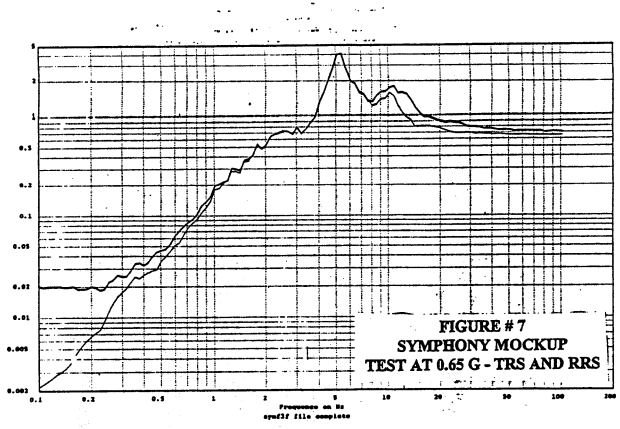


FIGURE # 7
SYMPHONY MOCKUP
TEST AT 0.65 G - TRS AND RRS

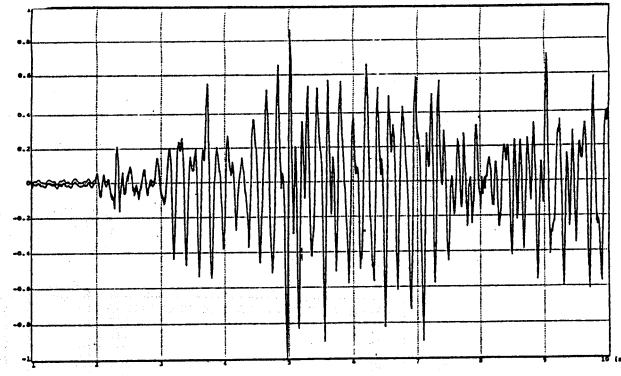


FIGURE # 8
SYMPHONY MOCKUP - TEST AT 0.65 G -
COMPARISON BETWEEN ACCELERATIONS

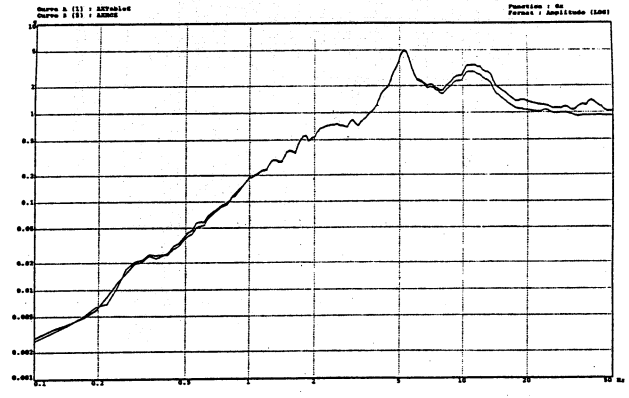


FIGURE # 9
SYMPHONY MOCHUP - TEST AT 1 G

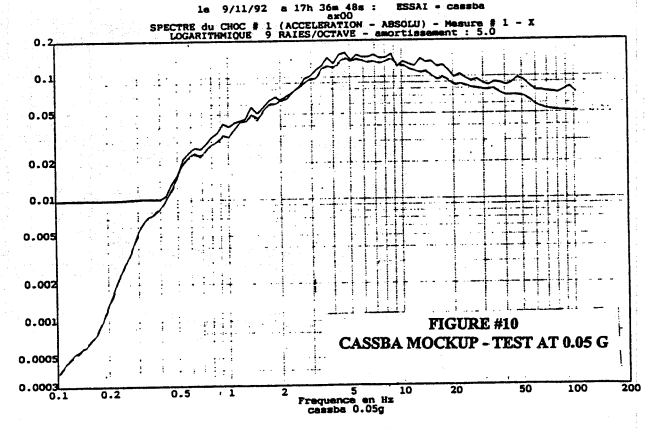


FIGURE #10
CASSBA MOCKUP - TEST AT 0.05 G

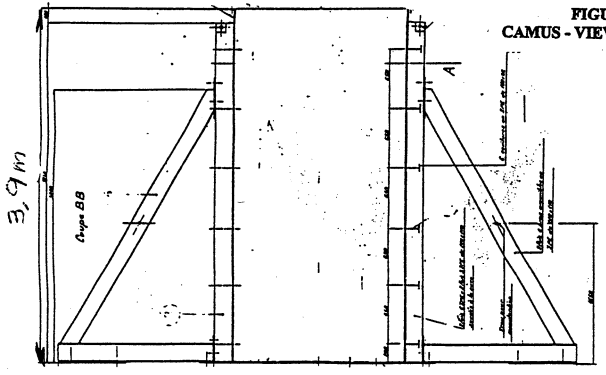


FIGURE # 11
CAMUS - VIEW OF THE TANK

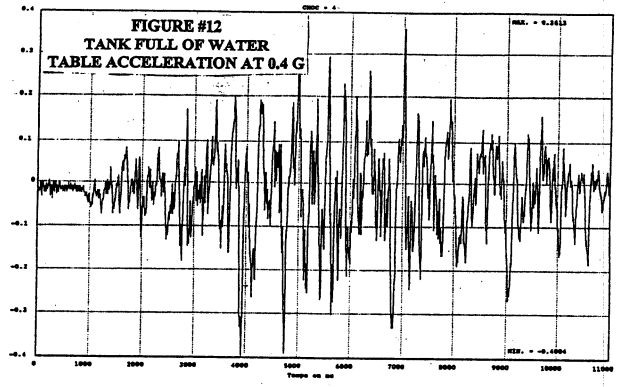


FIGURE #12
TANK FULL OF WATER
TABLE ACCELERATION AT 0.4 G

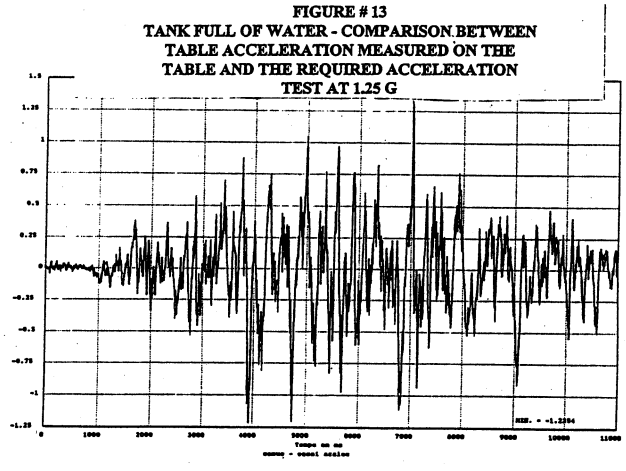


FIGURE # 13
TANK FULL OF WATER - COMPARISON BETWEEN
TABLE ACCELERATION MEASURED ON THE
TABLE AND THE REQUIRED ACCELERATION
TEST AT 1.25 G

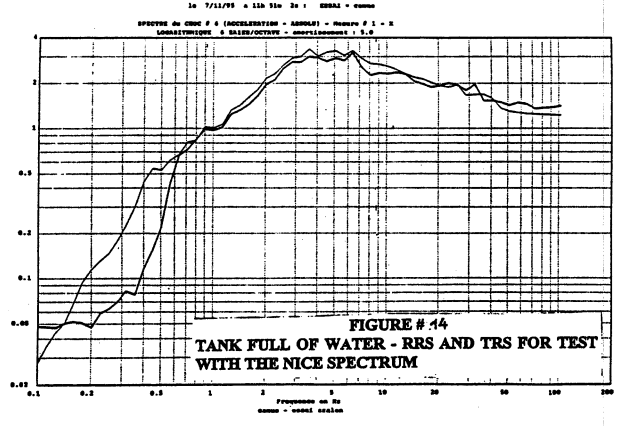


FIGURE # 14
TANK FULL OF WATER - RRS AND TRS FOR TEST
WITH THE NICE SPECTRUM