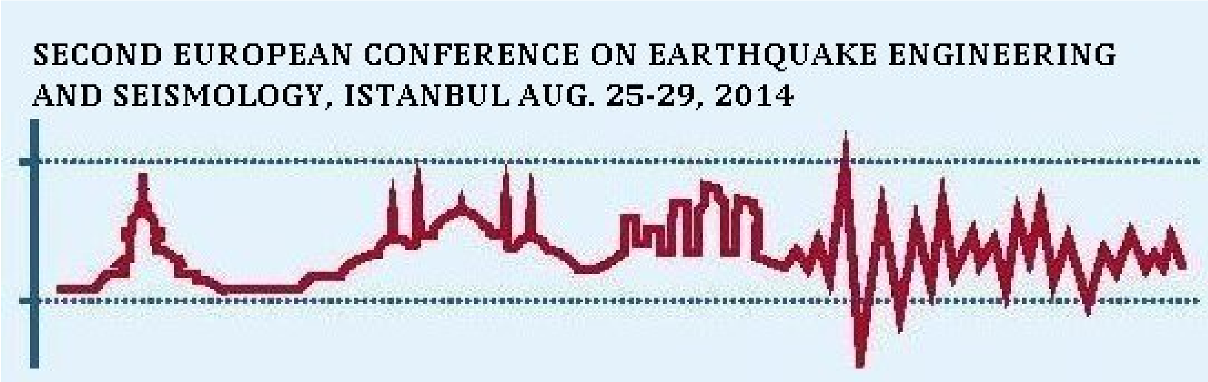


PERFORMANCE AND OVERVIEW OF THE NEW 6 DOF SHAKİNG TABLE OF C.G.S-ALGERIA

Hakim BECHTOULA[1], Abdelhalim AIROUCHE[2], Hassane AKNOUCHE[3], Youcef MEHANI[4], Abderrahmane KIBBOUA[5], Mustapha REMKI[6], Fouad KEHILA[7]

ABSTRACT

The new facilities at the laboratory of the National Earthquake Engineering Applied Research Center, CGS, Algeria, will provides some unique testing facilities within the south part of the Mediterranean Sea for large scale, multi-axis, structural dynamics testing. The laboratory is located at Algiers ant it is composed of a six degree of freedom shaking table of 6.1x6.1m, a reaction wall of 13x15m and a strong floor of 13x32m. The laboratory is equipped with an advanced hydraulic distribution system, a series of high performance actuators, 128-channel data acquisition system and two high-capacity bridge cranes of 10 and 32t. The shaking table is capable of simulating earthquake events and other ground vibration with displacements of ±150 mm and ±250mm in the horizontal directions and ±100mm in the vertical direction. Accelerations of ±1.0 g for horizontal directions and ±0.8 g for vertical direction are possible with maximum test specimens of 60tons.

1. INTRODUCTION

The laboratory facilities are specifically designed in order to test civil engineering structures and components up to collapse or ultimate limit states. Its primary mission is to study and check the seismic performance of the civil engineering structures (Airouche et al., 2008) and other industrial equipments.

The research activities of the laboratory will include:

- The development of experimental research in the field of earthquake engineering.
- Dynamic qualification test of industrial equipment.
- Conduct a collaborative research project with national and international institutions.

Ultimately, the goal of the laboratory is to improve our understanding (Stojadinovic et al., 2004; Van Den Einde et al., 2004) of earthquakes and their effects in order to make a significant contribution to the important issue of seismic safety in Algeria and around the world.

[1] Dr, Head of Dept. at National Earthquake Engineering Research Center- CGS, Algiers, bechhakim@gmail.com
[2] MSc, National Earthquake Engineering Research Center- CGS, Algiers, airouche@yahoo.fr
[3] MSc, National Earthquake Engineering Research Center- CGS, Algiers, haknouche_70@yahoo.fr
[4] Dr, National Earthquake Engineering Research Center- CGS, Algiers, mehani_youcef@yahoo.com
[5] Dr, National Earthquake Engineering Research Center- CGS, Algiers, a_kibboua@yahoo.com
[6] MSc, National Earthquake Engineering Research Center- CGS, Algiers, musremki@gmail.com
[7] MSc, National Earthquake Engineering Research Center- CGS, Algiers, fouad.kehila@gmail.com

2. LABORATORY FACILITIES

The Laboratory is located at SEBALLA 10 Km west of Algiers. The main testing equipments of this laboratory are: the 32×13m strong reaction floor, 15m high by 13m wide reaction wall, 6.1×6.1m shaking table with 6 DOF, an advanced hydraulic distribution system, a series of high performance actuators, two high-capacity bridge cranes and 128-channel data acquisition system.

Fig.1 shows the main external view of the laboratory whereas; Fig.2 illustrates the configuration of the internal space of the laboratory.

Figure 1. Global views of the laboratory

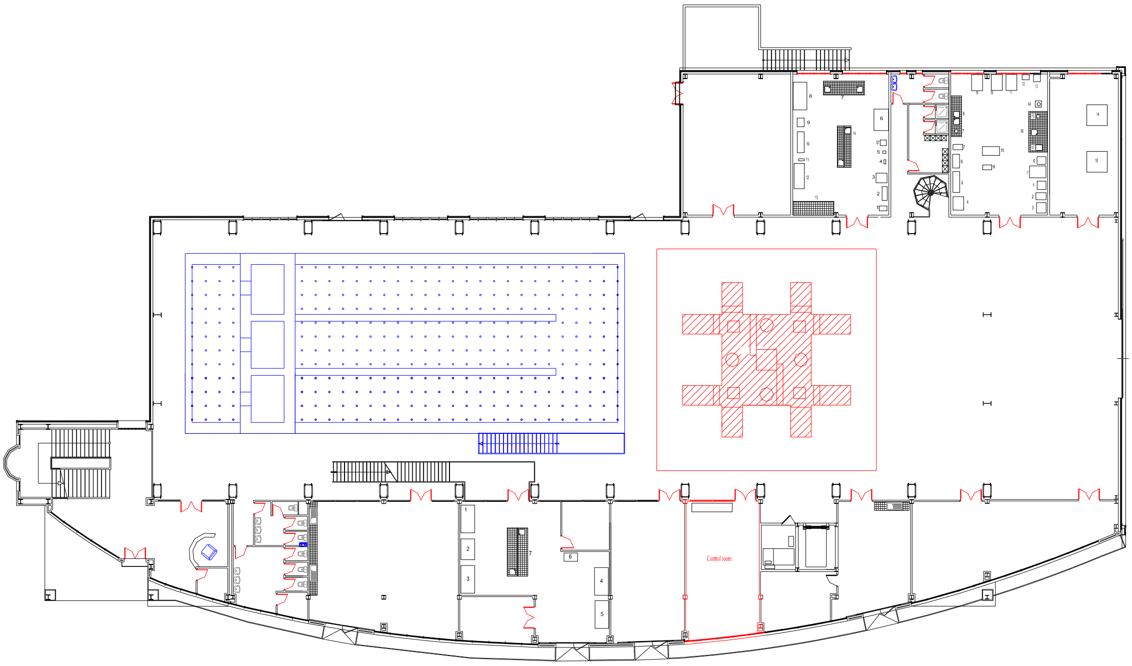
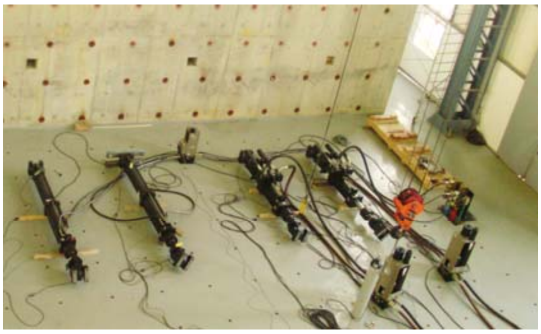


Figure 2. Ground floor level of the laboratory

3. PSEUDO-DYNAMIC TESTING FACILITY

The pseudo-dynamic testing facility of the laboratory, shown in Fig.3, will offer the possibility to perform a seismic tests on a full or reduced scale specimens, by using various experimental methods, such as traditional quasi-static tests, cyclic loading tests and pseudodynamic tests with substructuring techniques, as well techniques for modal assessment and system identification. Here after, a brief description of the components of the pseudo-dynamic testing facility are introduced.

(a) View of the 15m high reaction wall



(b) Static and dynamic actuators

Figure 3. Pseudo-dynamic testing facility

3.1. Strong Floor

The strong floor consists of a 1.0m thick post-tensioned reinforced concrete slab with a testing area of 13 × 32 square meter. The tie-down holes for fixing specimens are spaced each 1 m x 1 m having a capacity of 500 kN as axial force.

3.2. Reaction Wall

The reaction wall consists of a 15 m high by 13 m wide post-tensioned reinforced concrete wall. The fixing holes are spaced each 1 m from each other. The maximum load capacities of reaction wall is 120 MN.m bending moment and 12 MN base shear force. The specified concrete compressive strength for the reaction wall and strong floor is 40 MPa.

3.3. Hydraulic Actuators

There are 04 hydraulic double acting (push and pull) actuators, 2 for dynamic and 2 for static loadings. The capacities of these actuators are listed in Table 1.

Table 1. Actuator capacities

Actuator MTS model	Quantity	Stroke (mm)	Force (kN)	Servovalve (LPM)	Rating
244.41S	02	508	±550	1500	Dynamic
244.41	02	1016	±550	57	Static

3.4. Controller

MTS FlexTest^{TM}GT Controller: The FlexTest^{TM}GT Controller System is powerful and flexible digital controller for general testing application and includes specific application software for Civil Engineering applications. The current configuration allows up to 4 actuators and 4 independent test stations to run simultaneously. This means that any of the four actuators may be assigned to either controller and operated separately or together.

4. SHAKING TABLE FACILITY

The CGS shaking table consists of 6.1m x6.1m steel platform of 40 tons weight which has six degrees of freedom, 6 DOF, controlled by twelve actuators. Its primary function is to replicate in the laboratory a real earthquake motion inputs, an artificial ground motions and a wide range of vibration signals to simulate induced vibration, to a specimen having a maximal weight of 60tons. The system is capable of simulating earthquake events and other ground vibration with displacements of ±150 mm and ±250mm in the horizontal directions and ±100mm in the vertical direction. Accelerations of ±1.0 g for horizontal directions and ±0.8 g for vertical direction are possible with maximum test specimens of 60tons. Fig.4 shows the shaking table components and the platen before installation.

The shaking table platform, or platen, represents a structural steel box of variable depth up to 2.2m. The platen was designed to be very stiff and that the first mode frequency will be above the desired operating frequency range of the system.

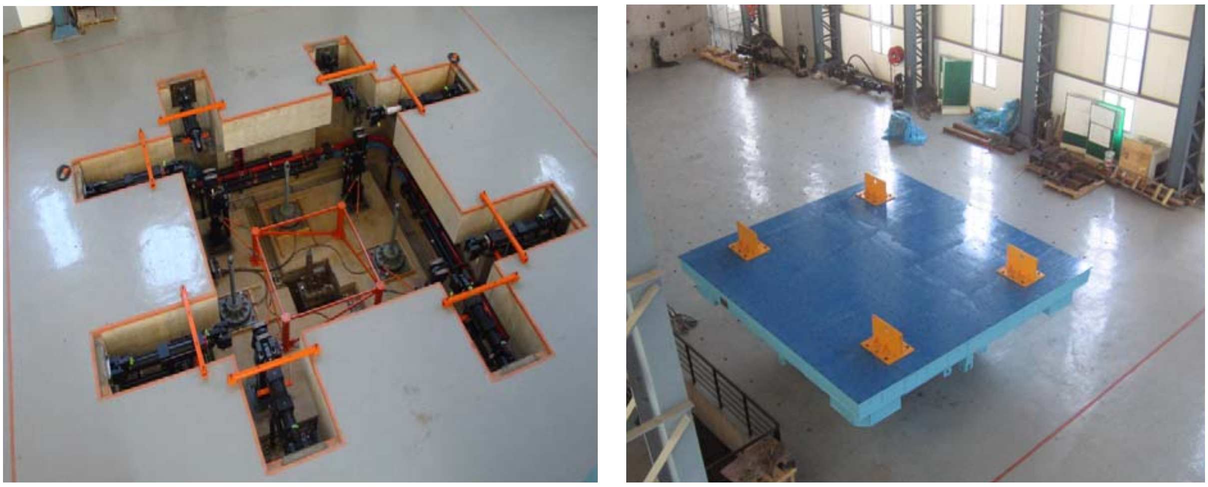


Figure 4. CGS Shaking Table components and platen

4.1. Technical parameters

The main specifications of the shaking table are summarized in Table 2.

Table 2. Specifications of the shaking table

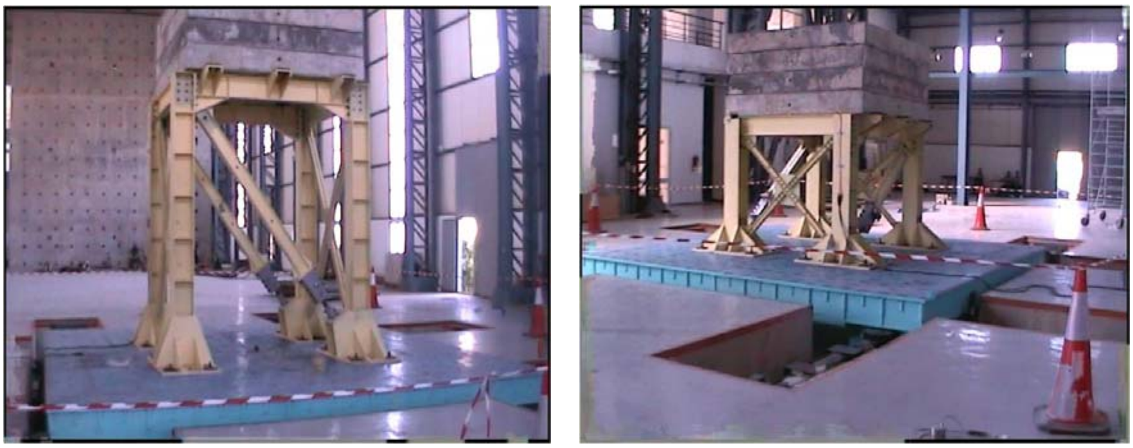
DOF	06		
Table Size (m)	6.1 × 6.1		
Specimen Mass (Ton)	60		
Shaking Direction	X-Horizontal	Y-Horizontal	Z-Vertical
Acceleration (g)	±1.0	±1.0	±0.8
Velocity (m/sec)	±1.1	±1.1	±1.0
Displacement (m)	±0.15	±0.25	±0.10
OTM (Ton-m)	180		
OCLM (Ton-m)	90		
Freq. Range (Hz)	0.1-50		

4.2. Performance curves of the shaking table

To check experimentally the performance of the shaking table, 4 specimens were constructed and tested. Figure 5 shows the 4 specimens mounted on the platen during the testing. The 60ton rigid specimen was constructed with 12 reinforced concrete blocks of 2.5x2.5x0.3m. The 20tons, 5HZ and

10HZ, elastic specimens were made of steel as illustrated in Fig.5 (c) and Fig.5 (d), respectively. A 20tons mass made of four concrete blocks was anchored to a steel beams that acted as horizontal diaphragm. Additional damping was provided using the two viscous dampers type ALGA-FD100, see Fig.5 (e). The damping system was installed in the tested direction of the specimen. The damping device was linear with a damping constant equal to 100N.Sec/m. Each damper was designed for a maximum stroke of ±50mm, a peak force of 100KN and a peak velocity of 800mm/sec.

(a) Bare table (b) 60tons rigid specimen

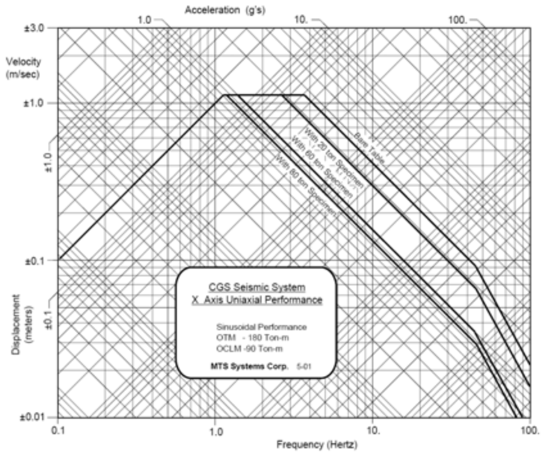


(c) 20tons elastic 5 HZ specimen (d) 20tons elastic 10 HR specimen

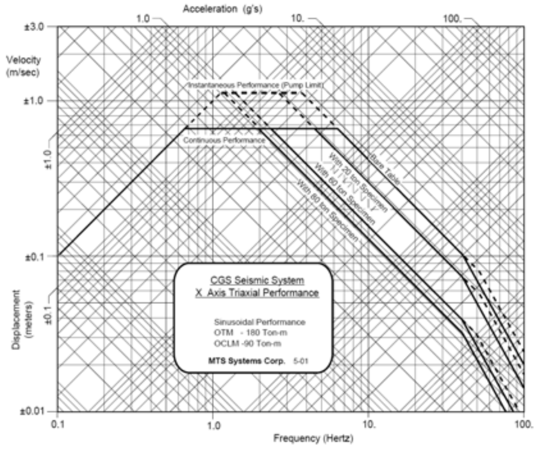
(e) Fluid dampers (type ALGA-FD100) used in the 20tons specimen

Figure 5. Configuration of the tested specimens

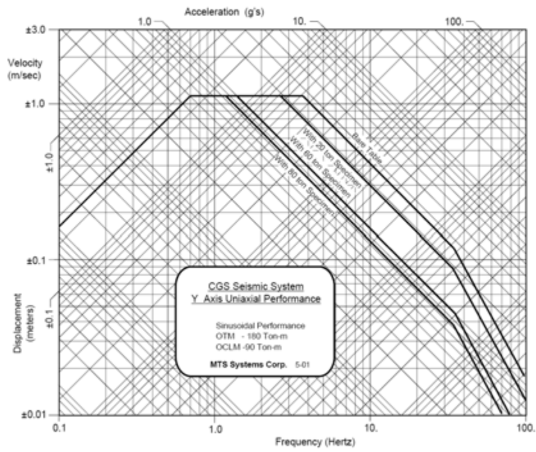
The theoretical performance (uniaxial and triaxial) curves of the shaking table are shown in Fig.6 for X, Y and Z axis, respectively. The performance curves are those for the bare table, 60tons rigid specimen and the 20tons elastic specimens of 5HZ and 10HZ.



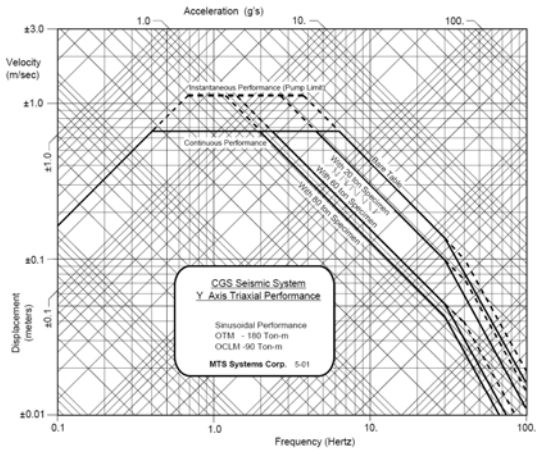
(a) X axis uniaxial performance



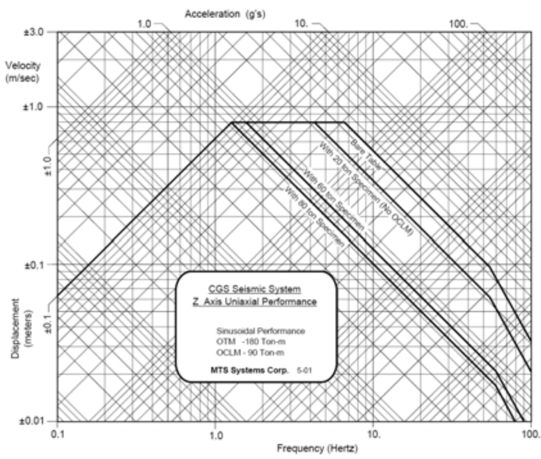
(b) X axis triaxial performance



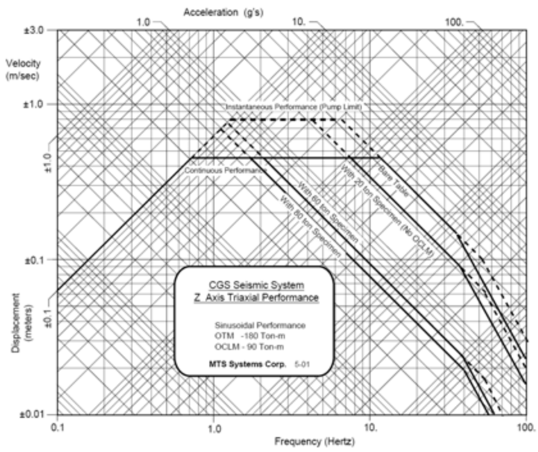
(c) Y axis uniaxial performance



(d) Y axis triaxial performance



(e) Z axis uniaxial performance



(f) Z axis triaxial performance

Figure 6**.** Performance envelopes of the shaking table

From control point of view, the shaking table and the test specimen must be viewed as one complete system whose frequency response will change with each specimen (Adam, 1997). The complex dynamics of the shaking table systems arises from multiples linear and nonlinear dynamic interactions between the various components of the shaking table (mechanical, hydraulic and electronic) and the test specimen (Ozcelik et al., 2008a).

In the literature, a limited number of studies focusing on modelling the complete shaking table systems and acceleration tracking performance of servo-hydraulic shaking tables especially for a 6 DOF ones can be found (Rinawi and Clough, 1991; Clark, 1992; Matthew, 1997; Williams et al., 2001; Shortreed et al., 2001; Crewe and Severn, 2001; Trombetti and Conte, 2002; Twitchell et al., 2003; Thoen and Laplace, 2004; Ozcelik et al., 2008b; Plummer, 2010; Shen et al., 2011; Gu and Ozcelik, 2011; Ceresa et al., 2012).

To check the performance curve of the shaking table, a testing program was set. The loading input signals, were of three types: white noise, sinusoidal and earthquake. The series of tests are intended to determine the experimental uni-axial sinusoidal performances curves and to evaluate the accuracy and fidelity in signal reproduction in order to check the performance of the shaking table.

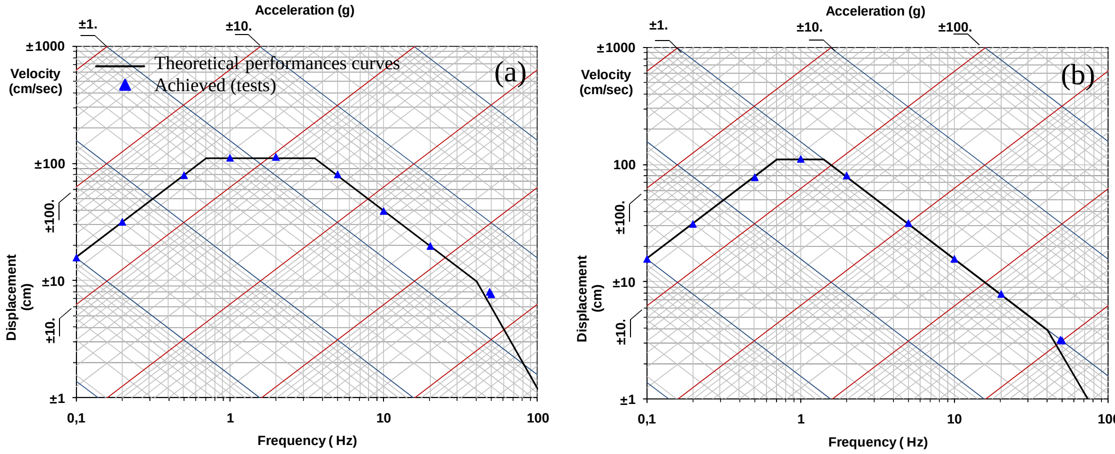
Uni-axial sinusoidal performance tests for the longitudinal, lateral and vertical axes were measured for various frequencies with target amplitude of single frequency and loadings conditions and compared with the theoretical performances curves. Table 3 summarizes the frequencies and the target amplitudes of single-frequency sine wave motion used for the testing for bare table and 60tons loaded table condition in the three directions.

Table 3: Frequencies and test amplitude in three directions - Bare table/60tons rigid specimen

Freq (Hz)	Longitudinal Direction		Lateral Direction		Vertical Direction	
	Bare table	60tons	Bare table	60tons	Bare table	60tons
0.1	±250mm	±250mm	±150mm	±150mm	±100mm	±100mm
0.2	±250mm	±250mm	±150mm	±150mm	±100mm	±100mm
0.5	±250mm	±250mm	±150mm	±150mm	±100mm	±100mm
1.0	±1.10m/s	±1.10m/s	±1.10m/s	±150mm	±0.8m/s	±100mm
2.0	±1.10m/s	±1.00g	±1.10m/s	±1.00g	±0.8m/s	±0.80g
5.0	±2.50g	±1.00g	±2.50g	±1.00g	±3.20g	±0.80g
10.0	±2.50g	±1.00g	±2.50g	±1.00g	±3.20g	±0.80g
20.0	±2.50g	±1.00g	±2.50g	±1.00g	±3.20g	±0.80g
49.0	±2.50g	±1.00g	±2.50g	±1.00g	±3.20g	±0.80g
50.0	±2.50g	±1.00g	±2.50g	±1.00g	±3.20g	±0.80g

The adequacy of performance by comparing amplitudes of input and response at various frequencies of sine wave motion yields to an amplitude spectra envelope of the shaking table response. This comparison helps in defining the accuracy of the shaking table control settings and shaking table frequency performances limitations. The frequencies and amplitudes of waveform were controlled using the MTS 469D digital controller in acceleration, velocity or displacement control. The adaptive control techniques APC (Amplitude Phase Control) and AHC (Adaptive Harmonic Cancellation) were used for the control of these motions. In displacement control, the APC technique was used. In acceleration and velocity control the AHC and APC techniques were used simultaneously. During the tests, the digitized data were recorded by the MTS 469D seismic controller software.

Fig.7 (a) and Fig.7 (b) illustrate an example of the expected and the target performance curves for the bare table and 60tons rigid specimen, in the longitudinal direction. The triangle shapes represent the achieved performance corresponding to the frequencies listed above in Tables 3.



(a) Bare table (b) 60tons rigid specimen

Figure 7. Comparison between the theoretical and achieved performance envelopes curves -Longitudinal direction-

It can be observed from Fig.7 that the achieved and the target performance envelope are in good agreement for all frequencies of operation. The error in peak value between achieved and target signal did not exceed in the worst case 1% in displacement control and 2% in acceleration control. This result indicates that the CGS shaking table is performing to its design specifications criteria. Thus dynamic testing facility can be used reliably for the type of experiments that it was designed for.

4.3. Controller and software

MTS 469D Digital Control system commands the shaking table's movement. The controller provides for closed loop control of motion in translation and rotation about the 3 principal axes. The controller is designed so that each of these 6 degrees of freedom can be programmed individually and run concurrently. Earthquake acceleration records are used in programming the command signal to the shaking table.

STEX3 supplements the real time MTS 469D Digital Controller by providing additional table programming capabilities. Tests can be programmed for data acquisition only, system frequency response measurement, and the execution of time history and compensated test waveforms. The STEX3 software is designed to provide advanced capabilities in the following areas:

- Set up and configuration of seismic tests
- Execution of tests and acquisition of system and specimen data
- Synthesis of earthquakes from Power Spectra Density, PSD, and response spectra
- Analysis and processing of acquired data
- Modeling of the system response
- Execution of iterative, compensated testing for high accuracy results

5. OTHER FACILITIES

5.1. Hydraulic power supply

The hydraulic power supplies the laboratory equipment consists of 6 high pressure pumps that can deliver a total of 4200 liters per minute at 20.5 MPa and (8× 45 liters) accumulators distributed in the pit for peak demands. Fig.8 shows the actual hydraulic power supply composed of the hydraulic pumps, the oil tank, oil cooling system and the two towers for cooling water.

(a) Hydraulic pumps

(b) Oil tank and oil cooling system

(c) Towers of the cooling water

Figure 8. View of the hydraulic power supply and the cooling systems

5.2. Data acquisition

The data acquisition system consists of 128 channels of Conditioned inputs (DC conditioner), expandable. The system is portable and can be easily moved with the STEX computer to the structural area during testing. Maximum sampling rate per channel simultaneously is 2000 data samples per second. The main features of the acquisition system are:

- Signal input panel for easy hookup
- Programmable differential amplifier
- Programmable anti – aliasing filter
- Programmable excitation
- Auto zero and balance
- 16 bit conversion accuracy
- Data storage for up to 512 kB per channel

5.3. Bridge Cranes

Two overhead bridge cranes span the laboratory. One crane has 32 ton capacity and the other has 10 tons capacity. The cranes have a clear height of 16.5m and travel in the longitudinal and transverse directions. They are remotely controlled and can operate in unison or independently of each other.

5.4. Fabrication and Staging Area

One thousand two hundred square meters (1200m^2) fabrication, staging, and storage area is adjacent to the building. This area will be used for fabricating the specimens that will be tested either on the shaking table or on the strong floor and the reaction wall.

6. CONCLUSIONS

In this paper, the new facilities of the National Earthquake Engineering Applied Research Center, CGS, Algeria, located at Sebala, Algiers, were presented. The six degree of freedom shaking table of 6.1x6.1m, and the huge reaction wall of 13x15m and a strong floor of 13x32m, will provides some unique testing facilities within the south part of the Mediterranean Sea for large scale, multi-axis, structural dynamics testing. The shaking table is capable of simulating earthquake events and other ground vibration with displacements of ±150 mm and ±250mm in the horizontal directions and ±100mm in the vertical direction. Accelerations of ±1.0 g for horizontal directions and ±0.8 g for vertical direction are possible with maximum test specimens of 60tons. Performances of the shaking table were checked using 4 specimens. It was observed that the achieved and the target performance envelope are in good agreement for all frequencies of operation. The error in peak value between achieved and target signal did not exceed in the worst case 1% in displacement control and 2% in acceleration control. This result indicates that the CGS shaking table is performing to its design specifications criteria. Thus dynamic testing facility can be used reliably for the type of experiments that it was designed for.

REFERENCES

Adam C (1997) Standardisation of Shaking Tables, Laboratorio Nacional de Engenharia Civil, Lisboa-Portugal

Airouche A, Casarotti C, Thoen B K, Dacarro F, and Pavese A (2008) “Numerical modeling and experimental identification of the EucentreTREES Lab shake table”, *Proceedings of the 14th World Conference on Earthquake Engineering, Beijing, China* Paper No. 0220

Ceresa P, Brezzi F, Calvi GM, Pinho R (2012) “Analytical modelling of a large-Scale dynamic testing facility”, *Earthq Eng and Struct Dyn* 41(2):55-277

Clark A (1992) “Dynamic Characteristics of large multiple degree of freedom shaking tables”, *Proceeding 10th World Conference on Earthquake Engineering*, Madrid, Spain, 2823-2828

Crewe AJ, Severn RT (2001) “The European collaborative programme on evaluating the performance of shaking tables”, *Philosophical Transactions: Mathematical, Physical and Engineering Sciences*, Vol 359, N°1786, Dynamic Testing of Structures, 1671-1696

Gu Q, Ozcelik O (2011) “Integrating OpenSees with Other Software - with application to coupling problems in civil engineering”, *Struct Eng and Mechanics*, 40(1):85-103

Matthew JM (1997) Analysis, Design and Construction of a Shaking Table Facility, PhD Thesis, Rice, University, Huston, Texas

Ozcelik O, Luco J, Conte J, Trombetti T, Restepo L (2008a) “Experimental characterisation, modelling and identification of the NEES-UCSD shake table and mechanical system”, *Earthq Eng Struct Dyn*, 37(2):243-264

Ozcelik O, Luco JE, Conte JP (2008b) “Identification of the mechanical subsystem of the NEES-UCSD shake table by a least-squares approach”, *J of Eng Mechanics*, 134(1):23-34

Plummer AR (2010) “A general coordinate transformation framework formulation axis motion control with application in the testing industry”, *Control Engineering Practice*, 18(6):598-607

Rinawi AM, Clough RW (1991) Shaking table-structure interaction, Earthquake Engineering Research Center, University of California at Berkeley, CA, EERC Report No. 91/13

Shen G, Zheng ST, Ye ZM, Huang QT, Cong DC, Han JW (2011) “Adaptive inverse control of time waveform replication for electrohydraulic shaking table”, *J of Vibration and Control*, 17(11):1611-1633

Shortreed JS, Seible F, Filiatrault A, Benzoni G (2001) “Characterization and testing of the caltrans seismic response modification device test system”, *Philosophical Transactions of the Royal Society of London* Series 359:1829-1850

Stojadinovic B, Moehle J P, Mahin S A, Mosalam K, Canny J F (2004) “NEES equipment site at the university of california, Berkeley”, *Proceedings of the 13th World Conference on Earthquake Engineering,. Vancouver, BC, Canada* Paper No. 1540

Thoen BK, Laplace PN (2004) “Offline tuning of shaking tables”, *Proceedings 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada*, August 1-6, Paper No. 960

Trombetti TL, Conte JP (2002) “Shaking table dynamics: results from a test analysis comparison study”, *J of Earthq Eng*, 6(4):513-551

Twitchell BS, Symans MD (2003) “Analytical modelling, system identification, and Tracking performance of uniaxial seismic simulators”, *J of Eng Mechanics*, 129(12):1485-1488

Van den einde L, Restrepo J, Conte J J, Luco E, Seible F, Filiatrault A, Clark A, Johnson A, Gram M, Kusner D, & Thoen B (2004) "Development of the George E. Brown Jr. network for earthquake engineering simulation (NEES) large high performance outdoor shake table at the University of California, San Diego", *Proceedings of the 13th World Conference on Earthquake Engineering, Vancouver, BC, Canada* Paper No. 3281

Williams DM, Williams MS, Blakeborough A (2001) "Numerical modelling of a servohydraulic testing system for structures", *J of Eng Mechanics*, 127(8):816-827