LNEC EXPERIENCES AND STRATEGIES IN EARTHQUAKE SIMULATION. RECENT DEVELOPMENTS

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SUMMARY

Earthquake simulation is a growing area of testing. On the recent past, specific strategies for adapting the signals to LNEC 3D earthquake simulator were developed, being nowadays possible to test real size structures with an accurate reproduction of almost any given earthquake time history. That allows us to perform dynamic studies on the behaviour of some particularly interesting structures and to develop strategies to study some specific areas in Earthquake Engineering such as damage evolution and rehabilitation and/or retrofitting of structures. Among the series of tests already planned are also some studies on the use of steel and aluminium dissipators.

Most of the models usually tested are reinforced concrete, or masonry, structures or elements, which exhibit a degrading non-linear behaviour due to the accumulation of damage during testing. Nonetheless, given the masses involved and the relative independence of the 3 translations, from the control point of view a linear approach is taken, using an equivalent, from the mass point of view, set of inert load for obtaining an adapted drive signal to control the seismic platform.

In the present paper is presented the control method used along with a practical example and are also referred the efforts on implementing more modern control techniques, on LNEC earthquake simulators, in order to bring us closer to real time control.

INTRODUCTION

LNEC's triaxial shaking table was designed by LNEC's staff (Emilio et al., 1989) and was built during the early nineties. From the beginning it was conceived as a platform suitable to reproduce seismic actions on civil engineering structures and according to observed earthquakes. It should be stressed here that the shaking table has all rotations inhibited by a set of three torque tubes, the translational couplings are minimised by a system of linking rods connecting the actuators to the platform and the inert weight load is compensated by a passive nitrogen hydraulic system. Furthermore each one of the translations can be mechanically blocked. (Duarte et al., 1992, Duarte et al., 1994, Bairrao et al., 1995).

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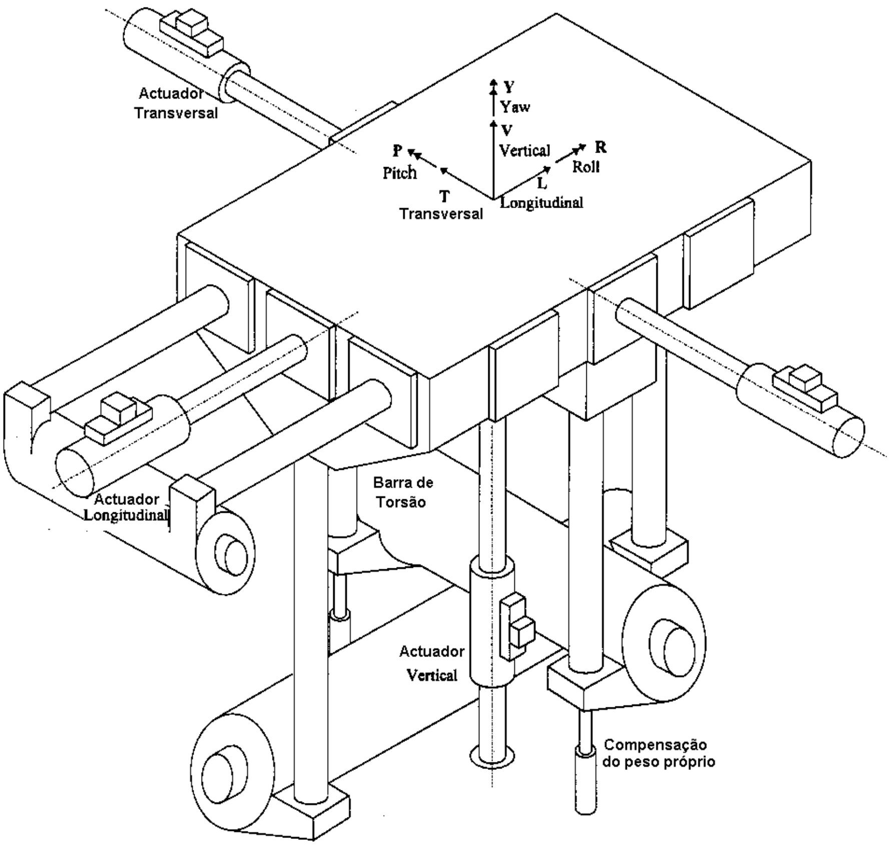


Fig. 1 – Schematic view of the LNEC's 3 DOF seismic platform.

The digital control was supplied and installed by INSTRON. The control and signal adapting are installed on two personal computers communicating with each other by a TCP/IP based local area network.

After characterisation (Costa et al., 1996), the shaking table start to operate normally in the beginning of 1997 performing dynamic tests on structures presenting non-linear behaviour.

LNEC'S 3 DOF SEISMIC PLATFORM CONTROL

The actuators servo-valve control is done with an RSPLUS, INSTRON, program installed on a personal computer with the WINDOWS 3.11 operative system. To obtain a drive signal that reproduces a given time history on the shacking table, an iterative process is implemented using SPIDAR, a general-purpose software package for data analysis and display, on another PC, running UNIX OS and communicating by TCP/IP with the control program.

Standard procedure for obtaining the control drive signals involves a MATHLAB signal pre-processing of the target file which typically includes the:

Data verification: the data is plotted and visually inspected, bad data should be removed and signal demands verified;

Resampling: The digital control system uses a 200 samples/s scan rate, the target signal data should be resampled if needed;

Signal filtering: In order to eliminate the frequencies the rig needs not or cannot produce, typically frequencies below 0.1Hz and above 22 Hz;

Tapering: To avoid discontinuities, a rectangular cosine tapered window is applied to signals.

To have the proper signals is not but a part of the solution. Besides that, a drive signal is to be created from those of the adapted response. If the models to experiment with were inexpensive, and could then be ordered by thousands, a more conventional way of first tuning the rig would certainly be adopted using some of the models and saving the remaining to carry on the experiment. Unfortunately the models are usually expensive and so to tune the rig a set of equivalent inert load is used, giving up of geometrical and non-linear effects. Even in the case in which the model is to be submitted to actions that may originate non-linear behaviour this linear approach gives good results if the masses involved are relatively small compared to the seismic platform weight.

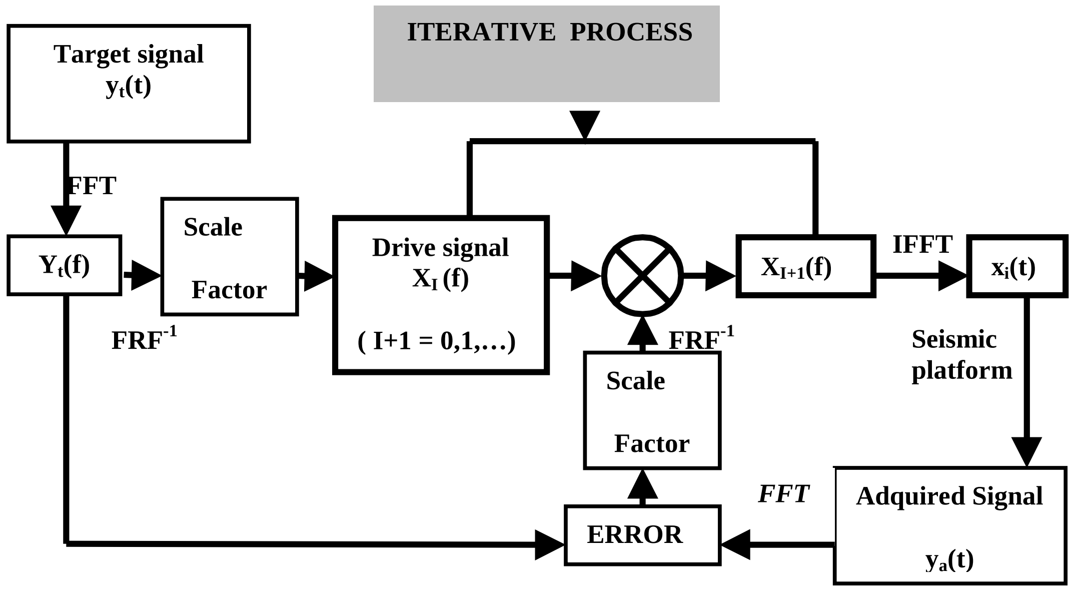


Fig. 2 – Simplified diagram of the iterative process used for adapting signals to the shaking table.

To obtain the characterisation within all the frequency working range of a general system, a long duration white noise is normally used. However, practical considerations about the loads involved and the hydraulic flows needed led to the use of a pseudo pink noise signal varying inversely with the frequency. Such a signal drastically reduces the kinetical energy involved while reducing the peak flow values demands. A corresponding control signal drive was obtained, by trial and error, for a range of typical loads

To obtain an appropriate drive signal the frequency response function (FRF) is evaluated by applying, to the loaded shaking table, a control drive that originates a movement that has a pink noise spectral shape. Writing the corresponding set of equations in the matrix notation a set of simultaneous equations is obtained by:

$$\left\langle S_{tgt} \right\rangle = \left[H \right] \left\langle S_{drv} \right\rangle$$

Where $[H]$ is the familiar transfer function matrix between output and input, S_{tgt} is the target signal and S_{drv} is the drive signal. In order to perform the characterisation there must be at least as many response transducers as actuators. If this is not the case then there is insufficient information to solve the system and a drive signal can not be obtained. If the number of response transducers and actuators is the same, then $[H]$ is a square matrix and it can be directly inverted. Usually there are, as in the example used in this paper, more response transducers than actuators and the matrix $[H]$ is non-square. It can be proved, using standard linear regression techniques, that the following set of simultaneous equations:

$$\left\langle S_{drv} \right\rangle = \left[(H^T H)^{-1} H^T \right] \left\langle S_{tgt} \right\rangle$$

can be used to obtain the inverse matrix of $[H]$. Given the fact that the transducers do have limited frequency working ranges, they give none, or a very little, response outside that frequency range. Low multiple coherence, low values of transfer function and high values of inverse transfer function are than produced. At those frequencies the process can not be carried out. To avoid this, multiple coherence should be high, typically greater then 0.6.

Having all the previous considerations in mind, it is now possible to begin an iterative process (Fig. 2) by obtaining a drive signal that will reproduce, on the loaded seismic platform, the target signal using:

$$\langle S_{drv} \rangle = [H^{-1}] \langle S_{tgt} \rangle$$

To avoid the over-prediction of those drive signals they must be scaled being the initial drive given by:

$$\langle S0_{drv} \rangle = a \langle S_{drv} \rangle$$

Where *a* is a positive, less then 1.0, constant. Then those drive signals are injected to the seismic platform and the corresponding response signals are measured. The response error is calculated and from it a drive error is then computed, by doing:

$$\langle eS0_{drv} \rangle = [H^{-1}] \left(\langle S_{tgt} \rangle - \langle S0 \rangle \right)$$

The new estimate for the drive signal is now obtained making:

$$\langle S1_{drv} \rangle = \langle S0_{drv} \rangle + b \langle eS0_{drv} \rangle$$

where *b* is once again a positive, less then 1.0, constant. The new drive signal is output to the seismic platform and the all process is repeated until a convenient set of response is obtained. Typically, at least, three iterations are needed, but more then six are not seldom done.

Furthermore, LNEC is investing on the implementation of a control system for its uniaxial shaking table in co-operation with its European partners. The idea is to implement on a PC, equipped with a 16-bit resolution acquisition board, new control algorithms implemented with commercial software packages, such as MATHLAB or LABVIEW. This particular approach will be pursued in the near future with a broader number of participants, thus diluting the software programming costs, and allowing the incorporation of some dedicated hardware, developed by some of the partner members, that will allow, with the same hardware, to test different approaches to real time control. It is also foreseen to use an open code source operative system.

ADAPTING A TARGET SIGNAL TO THE SEISMIC PLATFORM

An example of a current adaptation procedure in LNEC is detailed. A given artificial target signal, generated from a response spectrum with 2% damping, was used to adapt to the shaking table with a ¼ scaled model weighting 18 tone. This target signal was time scaled to comply with the similitude criteria. The signal was pre-processed and an adequate target signal (Figures 3 to 7) was passed to the control computer. All the signals units used are: mm for displacements, g for accelerations, second for time and Hz for frequencies

The characterisation process was initialised and the FRF was then computed, using both the displacement and the acceleration target components. Butterworth lowpass and highpass digital filters were applied to the displacement and the acceleration components, respectively, to adjust the acquired signals to their frequency measuring range. All the signals were tapered.

Once the iterative process started, using SPIDAR, the pertinent variables can be monitored at each step. A limited set from all the signal or error files, the correlation files, the FRF function, the Power spectra etc. can be plotted. However, to detail the present example, the successive driver and acquisition data files saved to the hard disk during the above described process were copied to another computer where the reproduction of that process was implemented using Mathcad. The adapting of the target signal took 6 iterations to accomplish. If pursued further the iterative process would have diverged due to non-linear phenomena such as mechanical shocks, the accumulation of phase errors and noise effects. These noise effects become of increasing importance just because the signal errors get smaller.

On Figure 3 are plotted together the target signal and the displacements acquired during the sixth and final iteration, the same is done for the acceleration histories on Figure 4. On Figures 5 and 6 are presented the same histories but with a time zoom.

On Figure 7 are presented the displacement (a) and acceleration (b) error histories for the iterations 0, 3 and 6.

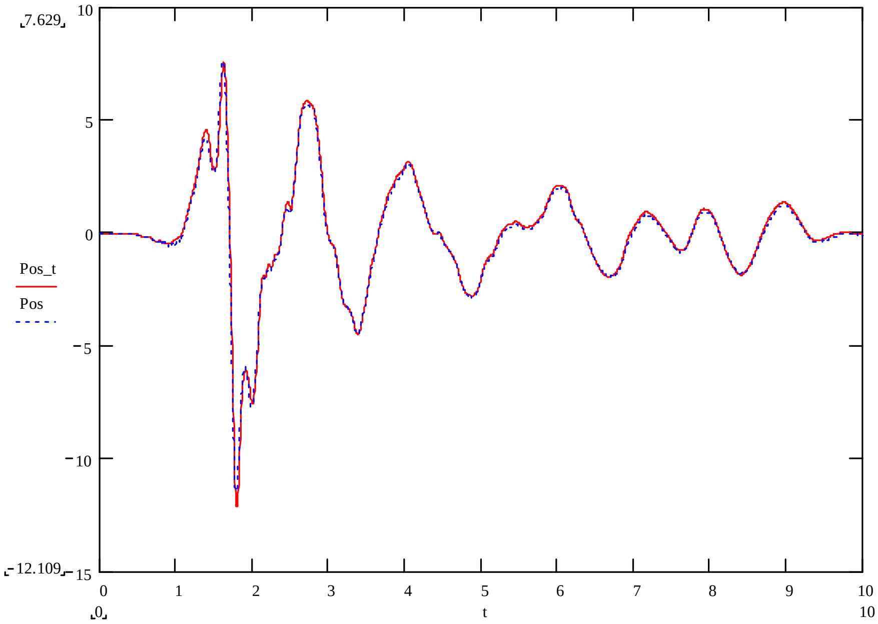


Fig.3: - Displacement histories for the target (Pos_t) and the final acquired (Pos) signals.

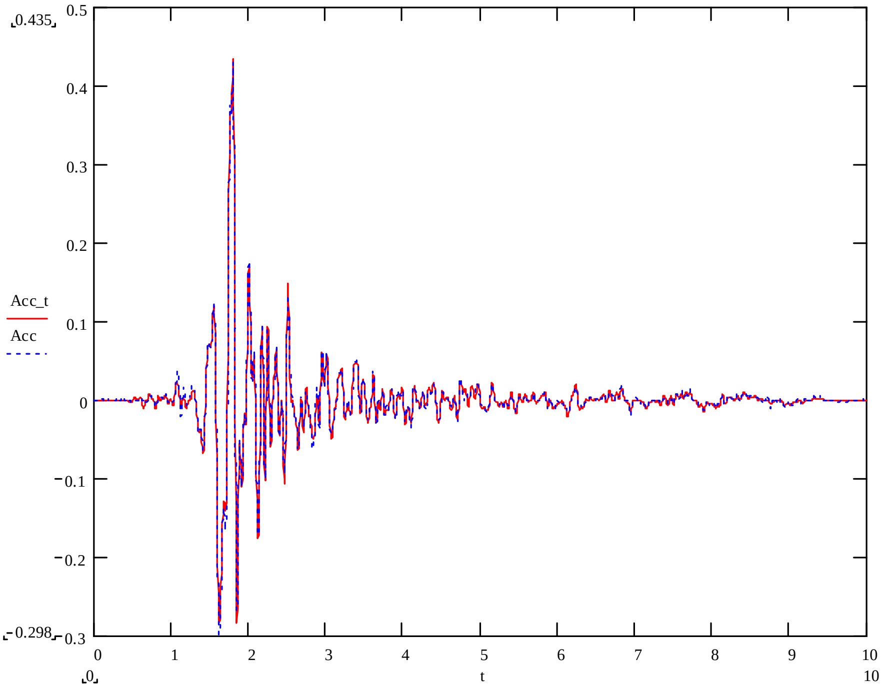


Fig.4: - Acceleration histories for the target (Acc_t) and the final acquired (Acc) signals.

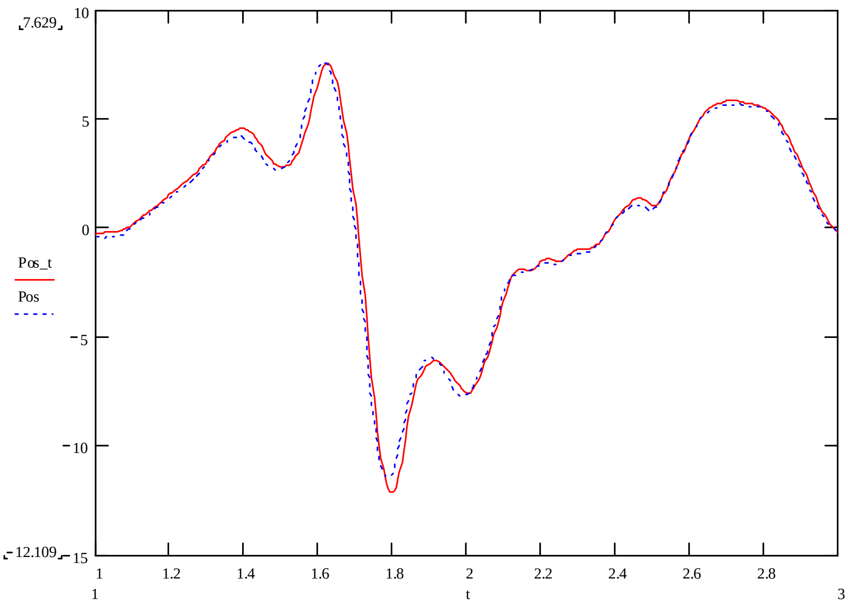


Fig.5: - Displacement histories for the target (Pos_t) and the final acquired (Pos) signals, detail.

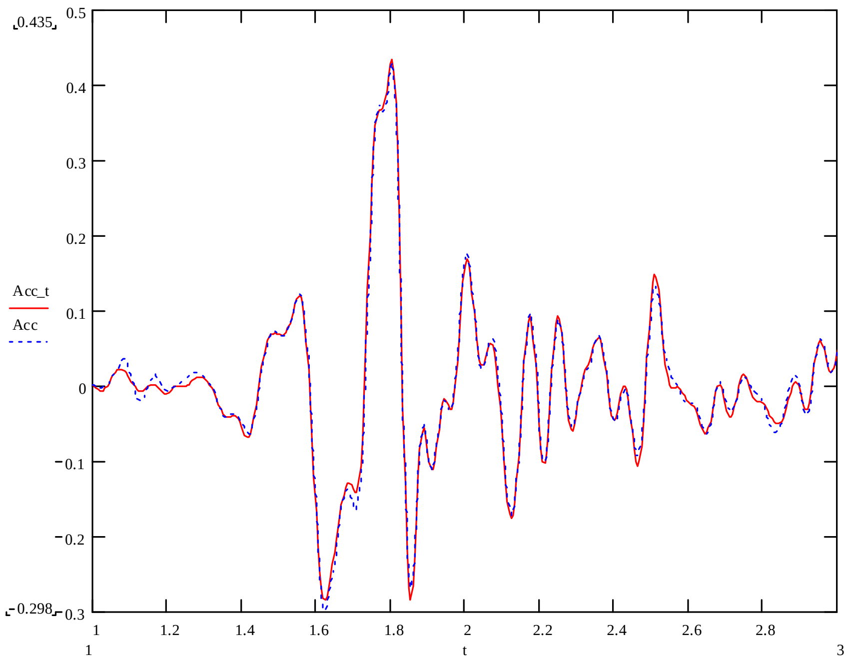
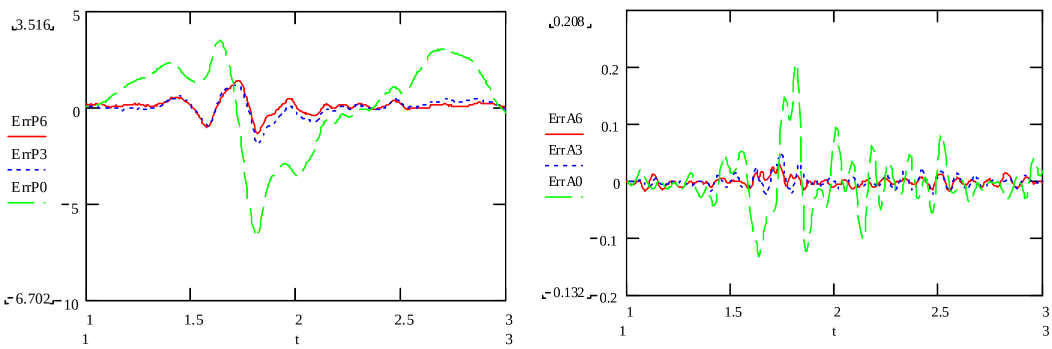


Fig. 6: - Acceleration histories for the target (Acc_t) and the final acquired (Acc) signals, detail.



(a) (b)

Fig.7: - Displacement (a) and acceleration (a) error histories, detail. Iteration 0, 3 and 6.

CONCLUSIONS

The pertinent conclusion to retain is that the present LNEC control method is able to reproduce on the seismic platform, with an acceptable precision, time histories that were measured during a real earthquake as well as artificially generated time histories. However, in order to cope with the dynamic behaviour characteristic changes of specimens during non-linear testing, special efforts are being carried on to allow future experimental activities as close as possible to real time control. But maybe even more important is the fact that the limits of this very unique 3 DOF shaking table have been clearly identified and are being mitigated by an upgrade, currently under way, to push further away the testing capability of the LNEC Earthquake Testing Division.

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