Dynamic analyses of structures in shaking tables
Characterization of the Instituto Superior Técnico Shaking Table

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Civil Engineering

Jury

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1. Introduction

Dynamic testing in small-scale models always performed a very important role in the understanding of dynamic loads in structures, therefore it is important to understand many of the concepts involved in experimental analysis in structures, namely in the testing of small-scale models.

It is in the context of dynamic testing of structures, that the Departamento de Engenharia Civil of Instituto Superior Técnico developed their shaking table that in this paper will be the main subject of study.

It is a fact that since the date of inauguration, the shaking table was never tested or analyzed for its performance for that, the main objective of this work is to perform this evaluation, to introduce improvements in the system and to suggest future interventions in the table. The shaking table is analyzed for their frequencies and movement amplitudes that are obtained in accordance with the mass that is excited in the platform.

A complete understanding of the shaking table capacities, will allow a more accurate performance of the dynamic testing in small-scale models.

In the last chapter of this work, is executed the design and dynamic testing, of a small-scale steel framed structure when it is excited with the shaking table of Instituto Superior Técnico.

2. Characterization of the shaking table of Instituto Superior Técnico

The shaking table developed by the Departamento de Engenharia Civil of Instituto Superior Técnico, launched on July 29, 2006 is for the first time being tested and analyzed for its capacity and performance. Next it will be described all essential aspects that lead to its functionality and it will be provided an analysis of its performance in terms of the ability of generating shaking frequencies on mass bodies placed on the platform.

2.1. Description of the shaking table of IST

The test platform is a welded steel structure, consisting in commercial profiles with U, L and H cross-sections, arranged in order to produce a rigid platelike rectangular structure. The rectangle was designed to be a diaphragm as rigid as possible and measures 3.85x2.30m. The entire steel structure is covered by three screwed metal plates and weights 1230kg. Its surface has a regular mesh of holes spaced by multiples of 36cm for M24 class bolts. Those holes allow the fixation of the physical models.
2. The maximum amount of weight to be placed in the platform is restricted by the ability of loading of the four bearings on which the platform is placed on. Each of these support systems have the capacity to support statically 1700kg, and given that the table has four equal bearing systems, the maximum weight that the physical model can have mustn’t exceed in any way the 6800kg (6.8 ton). This same weight capacity can also be influenced by the performance of the hydraulic actuator, it may be that the actuator can’t move this amount of mass efficiently.

2.2. Support system of the shaking table

In the case of the shaking table of IST, this was installed on an isolated slab from the remaining slab of the Laboratory through four tears. Those tears are addressed with technical rails. The slab rests on four pillars whose foundation is common to the rest of the building. Above the slab are placed the four cylindrical supports (bearings) above mentioned, aligned two by two and fixed to the shaking table. The bearings enables the platform to slide on the slab smoothly since the linear ball bearings are bushings with recirculating ball tracks which provide low friction movement and the possibility of unlimited stroke.

As the performance of the shaking table relies heavily on the system where it is supported, it was developed a small numerical model in SAP2000, where it was determined the resonant frequency of the support slab, in the direction of excitation of the hydraulic actuator. The model consisted in four pillars fully supported in the base and a slab where is placed a static mass that simulates the weight of seismic platform. The frequency obtained from that model was:

$$f_1 \approx 15 \text{Hz}$$
2.3. Actuator system

The actuator system is powered by a hydraulic pumping centre, consisting of an electric pump that removes oil from a tank and delivers it to a pressure system that supplies it to the actuator. Given the high pressures and temperatures that occur in the system, the pump is equipped with a water cooler system. The pump works with an electric 37kW motor that impels a maximum flow of 90 L/min at a maximum pressure of 207bar. The supply tank is capable of storing about 270 litres of oil that when pumped at the maximum pressure brings the actuator to put into effect around 250kN of force.

The hydraulic actuator is attached to the platform by a screwed metal plate. The actuator is aligned with the center of gravity (CG) of the platform in order to minimize the disruption (vibration) caused by the effects of mass eccentricity in relation to the axis of the actuator. The control of impulses is accomplished through a servo-valve which calculates the flow to be provided to the actuator so that it meets the desired momentum. This unit is extremely sensitive and requires constant maintenance; any impurity in the circulating oil in the pumping system can damage the unit, or even influence its performance. The actuator can generate around 250kN of force and has a maximum stroke range of ± 200mm.

2.4. Control system

The control module provides complete control and monitoring over the actuator system. It is a digital system that processes all the information related to the system in a digital format. The module consists of several panels where each plays a specific function of control. This module also allows the connection to a computer to perform all kinds of control activities over the actuator, overlapping if necessary, the modules of the console. This extends the scope of possibilities and parameters to consider.

Data recording systems as transducers can be mounted in physical models to be tested and connected to the console. The console provides up to six different data input channels.

The many control panels allows real-time control over the seismic actuator of the platform, as real-time readings through a small digital display. Parameters such as frequency, stroke, load action, among others, may be regulated.

The major limitation at the moment is to be restricted to the reproductive dynamic functions generated by one of the control panels (functions like the sinus, teeth saw and square); there by not existing yet the possibility of introducing accelerograms in the system.

2.5. Performance of the shaking table

The performance of any shaking table depends on the nature of the model that is excited. This is affected by the mass, center of gravity and flexibility of the model. From the
standpoint of control, the shaking table and the physical model should be seen as a whole, whose frequency response will change from model to model.

The main objective of this assessment is to determine the frequencies, amplitudes, speed and accelerations that can be produced by the system actuator. To do so, by generating a sinus function, a wide range of frequencies was covered (entered manually in the control system) and for which the detail stroke amplitudes achieved by the actuator system were registered. This procedure was conducted with the shaking table working without any load (the actuator only interacts with the mass of the platform, which is 1230kg) and with the placing of two additional levels of mass (1304 and 2608 kg). Through this analysis it will be known the extent to which the system can produce movement in accordance with the mass placed on the platform and obtain the performance graphics that define the range of values upon which the system actuator produces reliable movements.

2.5.1. Experimental procedure

To analyze the performance of the shaking table, test of all frequencies that could be played with efficiency, and readings of the resulting performed amplitudes were made. It was establish a plan to "sweep" all the frequencies. This plan consisted in imposing values in the control system that began in 0.1 Hz from which increments of 0.1 Hz were made until it reached 4.0 Hz. For the higher frequencies (higher than 4.0 Hz) increments of 0.5 Hz were made. The whole procedure stopped when it were reached frequencies for which the actuator response had low range (below 5mm). This allowed covering a large number of frequencies with some discrimination, obtaining the maximum amplitudes that the system could play with the harmonic function.

The function chosen to be generated was a sinus function. This would lead to a soft response of the system actuator with continued effort. The flow of oil pumped to the actuator would be in constant movement, providing the best performance of the shaking table. This also permits to have a default response of the amplitudes achieved by the system actuator according to the frequency generated.

![Image of the shaking table for 2608kg.](image-url)
2.5.2. Analysis and discussion of the experimental results

The experimental results are based on certain assumptions, some of them already mentioned, which are to be noted:

- These values presented correspond to the maximum response that the shaking table produced depending on the levels of weight put on. Never was intended to reach a response equal to the excitement imposed in the control system (in terms of amplitude). Instead, it was registered the maximum amplitude occurred for a given frequency, therefore the graphics presented in Figure 2.3 delimit the range, speed and acceleration that the platform can produce for a given frequency.

- Those same values concern to the maximum response in frequency to the generated sinus wave. Similar results (but slightly by excess) can be obtained for the response to other functions that the control system can generate.

- The range of frequencies studied corresponds to the maximum response in terms of amplitude that the system produced stably.

- Better discretization of masses did not take place given the complexity of the connection and shortage of elements capable of being put on the most suitable conditions on the shaking table. When it is said that the shaking table is acting without any load, it means that it only interacts with the weight of the platform itself that is 1230kg.

- The recorded values (amplitudes) contain an error margin in the order of the tenth of a millimetre. This margin corresponds to the difference of values that may occur between the time of reading in the control system and the time to register them.

- The readings obtained through the control system were the frequency (the imposed signal) and the amplitude performed by the shaking table (the "output" of the system). The speed and acceleration values presented in Figure 2.3 are respectively the 1'st and 2'nd derivative form of the characteristic equation generated by the shaking table (sinus form).

- The acceleration presented is defined as "G force" for better understanding of the values involved. This means that the acceleration achieved (in m/s²) is divided by the acceleration of gravity (1G=9.8m/s²).

Taking into account all these mentioned aspects and by analysing the performance graphics obtained and presented in Figure 2.3, these main conclusions are drawn for each of the tested weight levels:

- **Performance of the shaking table without any load**

As expected, the first idea to draw is that the range of movement amplitudes achieved by the hydraulic actuator of the shaking table is increasingly smaller as the frequency increases; this is easily explained by the need for greater flow pumped as the frequency increases (the
flow capacity can’t grow indefinitely). Thus the amplitudes decrease as the frequency generated increases.

The speed achieved by the hydraulic actuator has remained constant. This happens because, as has been noted, when the generated frequency increases, the amplitude achieved decreases, which means that the system does not suffer major fluctuations in terms of speed.

In other hand the acceleration varies with the square of the angular frequency, so increasing the frequency of the system certainly leads to the increasing of the acceleration.

Small fluctuations presented around 14Hz, are due to the fact that the excitation produced by shaking table is unstable to this order of values. Therefore results above the level of 14Hz are unreliable. This effect may result from the excitation of the vibration mode of the slab that supports the shaking table. As has been seen, through a simplified model, the fundamental resonant frequency of 15Hz was identified for the support system of the shaking table.

- Performance of the shaking table with a load of 1304kg

Noting the performance graphics presented in the Figure 2.3, for this level of mass is easy to draw the same conclusions explained in the previous paragraphs. The increase in mass held did not affect much the shaking table performance, it can faithfully reproduce the studied frequencies, reaching similar amplitudes to those obtained when the actuator acted without any kind of load.

- Performance of the shaking table with a load of 2608kg

The behaviour of the shaking table is similar to previous situations. What can be observed from different is that the maximum frequency and magnitude achieved by the hydraulic actuator correspond to values around 8.0 Hz, above this it could not generate any kind of harmonic frequency. The forces of inertia resulting from the movement of the mass were too high and the actuator worked in great effort, therefore the interruption of the tests was advisable.

Overlapping the performance graphics of the many mass levels tested (Figure 2.3) it is easy to find out that the performance of the shaking table is similar to the levels of mass that were tested. Thus the flow of oil pumped into the hydraulic actuator is sufficient to handle any amount of weight between the tested ones, not compromising differences in the shaking table performance.

The need to move higher values of mass would have to be reassessed as also the desire to test out higher frequencies. Possibly the flow of oil pumped into the hydraulic actuator is not enough to reproduce the desired movements. Also the support system of the actuator would have to be reassessed, since it is already in a big effort when it is moving 2608kg for a frequency of 8.0 Hz.
Next is presented the overlapping of the different performance graphics obtained for the many mass levels tested.

**Figure 2.3** - Overlapping of the performance graphics obtained for the many levels of mass analyzed.
3. Design and dynamic analysis of a steel framed structure

In this last chapter it will be approached the design and dynamic analysis of a steel framed structure with two stores high on the shaking table, idealized to test the shaking table and explore some concepts of the dynamic behaviour of structures.

3.1. Design of the steel framed structure- General design

The design of the steel framed structure was thought in response to some issues, namely the shaking table performance. The definition of the structural dimensions were constrained by the defined structural mesh where the shaking table has some stiffness (it wasn’t advisable to download a powerful structure on a plate that doesn’t have any stiffness elements under it). This also permits, as intended, a fully supported connection at the base of the steel framed structure.

The height of the steel framed structure and the number of floors designed (degrees of freedom), were issues constrained by the choice of commercial profiles for the construction of the structure. It was pretended to obtain one structure that could had a good balance in terms of flexibility and stiffness in order for the shaking table be able to excite the structure within a range of frequencies which could cover the vibration modes of the steel framed structure.

The mass placed on the floors of the model aims to simulate the mass of a scaled prototype (scale of 1 / 3), whose slab is 15cm thick. In addition to the weight of the slab itself, it was considered the contribution of a mass portion equivalent to a distributed live load on the slab of 2kN/m² ($\psi = 0.4$). According to this reasoning the weight to put on each of the floors of the model should be:

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>At the prototype:</th>
<th>At the model:</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4.80 m</td>
<td>Scale factor</td>
</tr>
<tr>
<td>B</td>
<td>3.84 m</td>
<td>Total Weight</td>
</tr>
<tr>
<td>Thick</td>
<td>e 0.15 m</td>
<td>Dead Load</td>
</tr>
<tr>
<td>Live Load</td>
<td>sc 2.00 kN/m²</td>
<td>Density</td>
</tr>
<tr>
<td>Total Load</td>
<td>M 83.87 kN</td>
<td>Dead Load</td>
</tr>
</tbody>
</table>

Table 3.1 - Summary table of the weight calculated to put on each floor of the model

Despite several modules of mass calculated and built, it were only used the mass modules that weigh about 4.86kN per floor. This situation occurred because the build structure has a very high flexibility and we couldn’t run the risk of causing the collapse of the structure by placing the other mass elements on each floor. On the other hand, there is also another limitation related to the data record systems that limit the reading capacity of the acceleration to
values of ± 1G (the placement of additional mass elements would result in higher accelerations on each floor).

3.2. Analytical approach

3.2.1. Determination of the mass and stiffness matrix

According to the above, it was determined analytically the mass and stiffness matrix of the steel framed structure.

The calculation of the stiffness matrix of the structure is made using the Displacement Method. So for \( q_{\nu j} = 0 \) and \( q_j = 1.0 \), we obtain the following condensed stiffness matrix for the structure:

\[
\begin{bmatrix}
  1033.23 & -476.47 \\
  -476.47 & 405.43
\end{bmatrix}
\]

Table 3.2 - Condensed stiffness matrix for the steel framed structure.

As for the mass matrix of the structure, this is also a 6x6 matrix; however it is possible to condense the matrix just as the stiffness matrix. It is easy to see that the mass matrix is a diagonal matrix, where the mass is only concentrated in the two horizontal freedom degrees of the structure. This is explained as to, the application of a unitary mass acceleration in one of the horizontal degrees of freedom, does not generate mass forces in any of the other degrees of freedom.

\[
\begin{bmatrix}
  0.50 & 0.00 \\
  0.00 & 0.50
\end{bmatrix}
\]

Table 3.3 - Condensed mass matrix for the steel framed structure.

3.2.2. Frequencies and vibration modes

The analytical determination of the frequencies is held by the following equation:

\[
\det\left( K - p^2 \cdot M \right) = 0 \quad [3.1]
\]

therefore, by solving the determinant, it was obtained the following fundamental frequencies that correspond to frequencies of the first and second vibration mode respectively:

\[
\begin{array}{ccc}
p_1 & 17.32 & \text{rad. s}^{-1} \\
p_2 & 51.01 & \text{rad. s}^{-1} \\
f_1 & 2.76 & \text{Hz} \\
f_2 & 8.12 & \text{Hz}
\end{array}
\]

Table 3.4 – Fundamental frequencies obtained for the steel framed structure (analytical approach)
For each frequency there is a vibration configuration associated, therefore the deformed shape of each configuration is an implicit characteristic of each fundamental frequency for that the next configuration for the vibration modes is presented:

<table>
<thead>
<tr>
<th>Mode</th>
<th>v_1</th>
<th>v_11</th>
<th>1.00</th>
<th>v_12</th>
<th>1.86</th>
</tr>
</thead>
</table>

| Mode | v_2 | v_21 | 1.00 | v_22 | -0.54 |

Table 3.5 – Configuration of the vibration modes of the steel framed structure (analytical approach)

Analyzing the values obtained it is easy to see how the 1st vibration mode results from the entire movement of the two floors in the same direction as the 2nd mode results of the oppose movement of the floors.

3.3. Experimental analyses of the steel framed structure

3.3.1. Frequencies and vibration modes

The experimental analysis of the steel framed structure is based on the interpretation of its response under free and forced regime when subjected to a harmonic excitement.

The response of the structure was obtained by the placement of two accelerometers in each degree of freedom of the steel framed structure under study. Through the reading of the power spectral density functions (these functions relate the response in acceleration with the excitement forced in the structure) given by the accelerometers, it was possible to identify with accuracy the following fundamental frequencies for the two vibration modes of the structure, under the direction of excitement:

<table>
<thead>
<tr>
<th>Frequency [Hz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Mode</td>
</tr>
<tr>
<td>2nd Mode</td>
</tr>
</tbody>
</table>

Table 3.6 – Fundamental Frequencies obtained for the steel framed structure (experimental approach)

Knowing now the frequencies of the 1st and 2nd vibration modes, according to the direction of excitement, it can now be performed some tests in forced regime, where the characteristics for the excitement applied, match with the frequency characteristics of 1st and 2nd vibration modes. This type of testing will permit the knowledge of the vibration modes configuration. According with the mentioned the following modal configuration was obtained for the 1st mode:

<table>
<thead>
<tr>
<th>v_1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Floor</td>
</tr>
<tr>
<td>2nd Floor</td>
</tr>
</tbody>
</table>

Table 3.7 – Modal configuration for the 1st vibration mode.
As for the excitement of the second mode, it was not possible to obtain stable readings in the accelerometer. The acceleration obtained at the 1’st floor was much higher than the reading capacity of the accelerometer. In fact, the functions obtained appear “cut” (for acceleration values higher than ±1G the accelerometer isn’t able to make records, for that the response functions appear cut), despite the low amplitudes tested.

### 3.3.2. Damping

The determination of the damping coefficient of the structure is performed using its response under free-vibration test. For that the steel framed structure response over time was registered, after having been subjected to two initial basis excitements that correspond to the application of movements with the characteristics of the first and second vibration modes (movements with a frequency of 2.6 and 7.2 Hz).

The modal damping coefficient differs according to its structural response, may this be predominant for the first or second vibration mode. Thus the most certain way to obtain accurate values for the modal damping coefficients, is to examine the response of the first vibration mode obtained in the accelerometer put in the 2’nd floor of the structure when it is excited with the characteristic frequency of the first mode (2.6 Hz) and examine the response of the second vibration mode obtained in the accelerometer put in the 1’st floor of the structure when it is excited with the characteristic frequency of the second mode (7.2 Hz).

Through an analysis of the values obtained by the Logarithmic Decrement Method, the following values for the modal damping of the structure for the 1’st and 2’nd floors respectively were obtained:

<table>
<thead>
<tr>
<th></th>
<th>(q_i/q_j)</th>
<th>(\ln(q_i/q_j))</th>
<th>(j)</th>
<th>(\ln(q_i/q_j)/j)</th>
<th>(\xi)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1’st</td>
<td>1.1709</td>
<td>0.1578</td>
<td>24</td>
<td>0.0066</td>
<td>0.1046</td>
<td>%</td>
</tr>
<tr>
<td>2’nd</td>
<td>1.4306</td>
<td>0.3581</td>
<td>34</td>
<td>0.0105</td>
<td>0.1676</td>
<td>%</td>
</tr>
</tbody>
</table>

**Table 3.8 - Modal damping coefficients obtained in accordance with the records taken from the 1’st and 2’nd vibration modes.**

In practice however a single value to this factor is admitted, since the material used is the same for the both floors. This value will be useful to calibrate the numerical model of the structure, for that the value adopted will be \(\xi = 0,1\%\).
3.3.3. Transfer function

The experimental determination of this function, characteristic for each of the degrees of freedom, was held by exciting the structure with a broad spectrum of frequencies between 0.5 and 10.0 Hz. For each frequency generated a record was made at each floor by the accelerometers. Knew the accelerations at each floor according to the acceleration generated at the base, we were able to get several points that allow tracing a similar function to the transfer function $\beta_2$ (for systems of one degree of freedom).

![Transfer function graph](image)

**Figure 3.1** – General appearance of the transfer function between the base acceleration and the acceleration obtained at each floor

From the tests realized it is important to point out that the peak value for the 1'st floor (7.2 Hz) was estimated. In fact the accelerations obtained on this floor are much greater than $\pm 1G$. Despite the low amplitude tested, the accelerometers are limited to hold records below $\pm 1G$, for that the functions obtained are again "cut".

The resonance effect is a phenomenon that is matched by a high value of dynamic amplification for excitement frequencies near the fundamental frequencies of the structure.
According with this definition is easy to see, by analysing the graph of Figure 3.1, that the peak values presented are located approximately near by the fundamental frequencies that have been previously determined, which are:

\[ f_1 \equiv 2,6 \text{Hz} \text{ and } f_2 \equiv 7,2 \text{Hz} \]

3.4. Comparative analysis of the experimental physical model with the numerical model of the steel framed structure

At this stage it is intended to assess the accuracy of the values obtained from the experimental tests, the results to be drawn from the numerical model will get a comparative basis from which further conclusions will be made for some of the values obtained in the experimental tests.

3.4.1. Frequencies, vibration modes and transfer function

Done the modal analysis to the calibrated numerical model of the steel framed structure under study, the following fundamental frequencies in the direction of the excitement were obtained:

\[ f_1 \equiv 2,63 \text{Hz} \text{ and } f_2 \equiv 6,84 \text{Hz} \]

As it can be seen the frequencies obtained are very similar to those determined through the experimental tests:

\[ f_1 \equiv 2,59 \text{Hz} \text{ and } f_2 \equiv 7,22 \text{Hz} \]

The main difference verified is in the second vibration mode, where the difference in values is more significant. This may be related to the simulation of the stiffness of the floor, because it is difficult to evaluate the stiffness of the welded steel frames between the first and second floor. In other hand, this difference in values can also result from mass values for the slabs slightly different from those calculated (it was only experimentally measured two kind of slab elements, admitting them that the others had the same weight). For this difference in values obtained for the frequencies, it was thought that further investigation wasn’t needed in order to obtain more similar values.

The determination of the vibration modes was performed similarly to the experimental approach. The structure was excited up with the fundamental characteristics of their frequencies and with the same movement amplitudes used in the seismic tests performed in the shaking table. According with this the following values were obtained:

<table>
<thead>
<tr>
<th></th>
<th>( v_1 )</th>
<th></th>
<th>( v_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1’st Mode</td>
<td>1</td>
<td>2’nd Mode</td>
<td>1</td>
</tr>
<tr>
<td>1’st Floor</td>
<td></td>
<td>1’st Floor</td>
<td></td>
</tr>
<tr>
<td>2’nd Floor</td>
<td>1.756</td>
<td>2’nd Floor</td>
<td>-0.604</td>
</tr>
</tbody>
</table>

Table 3.9 – Configuration of the vibration modes obtained by the numerical model
There exists some difference between the values obtained experimentally for the configuration of 1’st vibration mode and the presented for the numerical model, however their order of magnitude is the same. This difference may be related to the irregular response read in the registered values removed from the accelerometer. Another reason related to this difference of values found could be related to the synchronization of the readings recorded among the accelerometers of the 1’st and 2’nd floor, however the fluctuations found are not sufficient to cause the this verified difference that is in the order of 10%.

There is no way to compare the configuration of 2’nd vibration mode, but it was experimentally observed, that the second floor was virtually static while the 1’st floor considerably vibrated, therefore it can be said that the values obtained by the numerical model are a reasonable approach for the configuration of the 2’nd vibration mode of the steel framed structure.

As for the transfer function between the acceleration generated at the base of the structure and the acceleration obtained at each floor it was drawn the following graphics:

![Transfer function for the 1’st floor](image)

**Figure 3.2** – Transfer function between the base acceleration and the acceleration obtained in the 1’st floor according with the numerical and experimental model.
Figure 3.3 – Transfer function between the base acceleration and the acceleration obtained in the 2’nd floor according with the numerical and experimental model.

As it can be seen in Figures 3.2 and 3.3, for frequencies close to the fundamental frequencies of the steel framed structure, the response from the numerical model is less than that obtained in experimental model. The most likely reason for this difference has to be with the fact that it isn’t known specifically if the seismic signal produced on the shaking table was performed in the most adequate conditions. As there was no way of knowing whether the signal generated in the control system was actually being played in the most perfect conditions for the shaking table, it is not known for sure if the accelerations were being produced in perfect conditions. In addition the responses registered by the accelerometers put in the structure weren’t stationary answers, it can be concluded again that the generated actions may not correspond to a perfect harmonic function.

Another fact involved in these differences in the responses is related to the low range that it had to be generated to achieve some kind of readings in the accelerometers placed in each floor level (it is to remember that these accelerometers are limited to record answers below ± 1G). It is to be expected that the reproduction of amplitudes with this order of magnitude (in the order of millimetres) isn’t made in the most perfect conditions.
The translation found in the transfer function withdrawal from the numerical model for the second vibration mode, results of course from the difference between the frequencies themselves checked for the numerical and the experimental model.

Another thing that it can be concluded from this analysis is that the relationship between the base and the 1'st floor acceleration is in the same order of magnitude when excited the 1'st or the 2'nd vibration mode, and that the 2'nd floor has higher levels of acceleration when excited the 1'st vibration mode (about 80-100 times the base acceleration).

The graphics presented above also serve as basis information for the conduct of future experimental tests in the steel framed structure on the shaking table, although some error is associated with these values, an order of magnitude for the acceleration produced at each floor can be read.

4. Conclusions and suggestions for future developments

The performance analysis made to the shaking table of DECivil-IST has as main objective, identify the range of frequencies and movement amplitudes that the shaking table could produce according to different values of excited mass. It was possible to identify the performance values which delimit the same breeding and it was found that the addition of mass little influenced their performance, however it is important to note that the reproduction of the harmonic movements is contestable. Tests conducted to determine the performance graphics represent the maximum range achieved by the hydraulic actuator for a certain frequency. A forthcoming experiment is needed to evaluate the ability to reproduce accurate signals generated by the control system that is, examine the extent to which the platform can reproduce the seismic signal generated by the control system according with the different mass values excited.

The design of a communication platform as a data acquisition platform must be developed, with the installation of equipment for registration (such as accelerometers and the displacement transducers) with increased capacity for registration (especially the accelerometers in order to achieve record accelerations exceeding ± 1G). They must also communicate and record values in parallel, this is essential to advance to the next step, which is the determination of the transfer function between the signal imposed in the control system and the seismic signal produced in the platform. It is necessary to evaluate the relationship between these signals.

It is true that there is a difference between the sign placed in the control system and reproduction of that signal. According to the authors Trombetti and Conte [16] the reproduction of any seismic signal by the shaking table is influenced by: the dynamic characteristics of each constituent system of the shaking table (control system, servo-valve, actuator and the support
system), by the dynamic characteristics of the excited model in the shaking table and by its dynamic interaction.

During the tests carried out to obtain the performance graphics of the shaking table, we were faced with some resonance frequencies for the system, involving the actuator and the building of DECivil-IST. These effects have been noted between the frequencies of 2.8-3.0Hz and 9.2-9.4Hz. Possibly it are intervals where the reproduction of any seismic signal will be more affected (the determination of the transfer function between the imposed signal by the control system and the signal produced will present its highest difference for these values). If future tests to be carried out arrive at frequencies close to 15Hz, it is possible to be noted another characteristic resonance frequency of the support system of the shaking table.

The analysis of the steel framed structure presented in Chapter 5 of this thesis is very influenced by the conclusions drawn previously. If the signal produced on the basis of the structure doesn’t correspond to a perfect harmonic, the response at the level of each degree of freedom will not be regular, and that was noted in tests carried out. The dynamic analysis is therefore compromised by the generation of these harmonic functions at the base, and the difference of responses found for the accelerations obtained by the numerical and the experimental model during the construction of the transfer function is justified by the not accurate reproduction of these functions (this difference is more pronounced in the resonance frequencies of the steel framed structure).

The steel framed structure in study was built in the thinking of future interventions and testing. For the tests carried out in Chapter 5 it was found that the structure had a low damping ratio, so a suggestion for the conduct of future dynamic tests in this structure goes through the providence of inertial dampers to the structure, and evaluate the structure response under the dynamic influence of the dampers. It would also be interesting to evaluate the influence of a braced reinforcement in the structure.

Despite the constraints found in the dynamic analysis of the steel framed structure, the results obtained for the damping coefficient, the configuration of its modes of vibration and the transfer function of the acceleration produced at each of the degrees of freedom are a good approximation of its dynamic characteristics, as witnessed by comparison with the numerical model performed.
5. References


[8] Edited by Crewe, Adam; “Standardisation of shaking tables; Pre-normative research in support of Eurocode 8”.


[12] Ballio, Giulio; Calado, Luís; “Steel bent sections under cyclic loads, experimental and numerical approaches”, publication of the magazine “Costruzioni Metalliche”, 1986.

