Dynamic Interaction between the Shaking Table and the Specimen during Earthquake Tests

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- **In shaking table studies or testing**, analyses are made considering a completely rigid shaking table: rigid actuators and rigid platform.

- Since quite a long time, an interaction between the shaking table and the structure has been clearly observed for massive structures.

- The optimisation of leading experimental tools as shaking tables is one of the main fields of research: control systems, hybrid tests, high-speed data transfer, sub-structuring,…

- This study must allow to experimental and numerical engineers to better take care, before tests (during the design), of the boundary conditions between the platform of the shaking table and the mock-up.

- The presentation deals with boundary conditions between the tested structures and the platform of the shaking table. Indeed, these boundary conditions are a major parameter for the design and numerical analyses of shaking table tests.
- In CEA Saclay, during the last 15 years, decreases of mockup frequencies between calculations and experimental tests of massive structures have been observed.

- For a long time it has been calculated, after tests, the global stiffness that “Azalée” shaking table should have to explain those decreases.

- Recently, it has been studied the validity domain of the rigid platform hypothesis for the “Azalée” shaking table of the CEA Saclay laboratories, one of the larger shaking tables in Europe with a quite standard design of its platform.
Azalée shaking table

- the biggest 6DDL shaking table in Europe
- maximum payload 100 tons

- square plate,
- 6 meters wide
- 2 meters deep
- 36 welded aluminium “boxes”
- 4 lateral anchorages for the horizontal actuators.
- mass of the platform 23.6 tons
• *Several modelizations have been realized*
• Simple analytical models using common springs and plates, → did not match correctly the more complex details of the “Azalée” geometry

• linear, FE model using thin shell elements has been made

• dully simplified in order to be easily reproduced on any FE software.

• *Two boundary conditions were then analysed*:
• For the first one, the platform was considered supported by 4 air cushions (64 springs in the model). This configuration will be used in the next section to validate the platform model.
• For the second one, the platform was considered fixed to 8 rigid actuators (86 unidirectional restraints).
Azalée platform

Detailed CASTEM model of the Azalée platform

Simplified Azalée platform model

Platform on the actuators - mode 6
- The validation of the linear FE model was done using 2 reference experimental tests that were performed in 1989 and 2000 with the platform simply supported by 4 air cushions without any actuators

**Table 1.** Experimental and calculated frequency with air cushions.

<table>
<thead>
<tr>
<th>Boundary conditions</th>
<th>Mode 1</th>
<th>Mode 2</th>
<th>Mode 3</th>
<th>Mode 4</th>
<th>Mode 5</th>
<th>Mode 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 air cushions</td>
<td>80.5</td>
<td>95.7</td>
<td>116.2</td>
<td>129.2</td>
<td>129.3</td>
<td>151.1</td>
</tr>
<tr>
<td></td>
<td>80.0</td>
<td>95.0</td>
<td>117.0</td>
<td>134.5</td>
<td>134.5</td>
<td>162.2</td>
</tr>
</tbody>
</table>

- Table 2 shows frequencies determined when the platform is fixed to 8 rigid vertical and horizontal actuators

**Table 2.** Calculated frequency with 8 rigid actuators.

<table>
<thead>
<tr>
<th>Boundary conditions</th>
<th>Mode 1</th>
<th>Mode 2</th>
<th>Mode 3</th>
<th>Mode 4</th>
<th>Mode 5</th>
<th>Mode 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 rigid actuators</td>
<td>54.3</td>
<td>54.3</td>
<td>65.7</td>
<td>73.5</td>
<td>73.5</td>
<td>99.0</td>
</tr>
</tbody>
</table>

- These boundary conditions change mainly the behaviour of the platform.
- Five modes appear between 54 and 74 Hz.
  - The two first modes are generated by the deformation of the horizontal actuators anchorages to the platform.
  - The other modes are due to the global flexion of the platform.
The evaluation of the platform with the structure is done through a study of the decrease of the mock-up frequency between the configurations “on a rigid soil” and “on the shaking table platform”.

2 linear FE models of structures have been created

Simple model 1 used to make a parametric study.

- A beam fixed on a very rigid square plate (with no local deformation at the bottom of the beam).

- Several masses and stiffness of the beam have been used to evaluate the frequency decrease of the beam between the configurations “on a rigid soil” and “on the shaking table platform”.

From these initial computations and results, some abacuses have been drawned
- More complex and realistic structures to compare with a real test. These structures allow the analysis of different boundary conditions of the mock-up on the platform (local deformations influences).

- The first structure is a non-symmetric reinforced concrete mock-up tested in 2008 during the SMART project in the CEA Saclay laboratory.

  - The mass of the mock-up is 45 tons.
  - Its main dimensions are 3.6 m high and a surface of 2.5 m x 3 m.
- The second structure is a reinforced concrete frame with 2 storeys. This mock-up was tested in the CEA Saclay laboratory in 2004, being one of the mock-ups tested for the ECOLEADER European project.
- The mass of the mock-up is 33 tons.
- Its main dimensions are 7 m high and a surface at the base of 4 m x 4 m.
ANALYSES

• The evaluation is done by studying the frequency decrease of the mock-up between the configurations “on a rigid soil” and “on the shaking table platform”.
• This study was just performed for each flexion and vertical mode of the mock-up; generally the major ones.

• The different results from realistic structures have been reported on the initial abacus.

• On the abacus for flexion modes, 4 points for the SMART mock-up are considered. Two of them are related to the SMART mock-up with a rigid plate between it and the platform. The two other are related to the SMART mock-up directly fixed to the platform of the Azalée shaking table. The comparison between these configurations “with a rigid plate” and “without a rigid plate” gives an estimation of the decrease generated by the boundary conditions between the mock-up and the platform:
  • 9 % to 23 % for the first mode. Then, for this mode, more than half of the decrease is generated by local deformations between the mock-up and the platform.
  • 21 % to 33 % for the second mode. For this mode, more than 30 % of the decrease is generated by the same local deformations.
examples : SMART and CAMUS

**Mock up frequency decrease due to table interaction**

<table>
<thead>
<tr>
<th>Boundary condition</th>
<th>On Rigid foundation</th>
<th>On Shaking table + rigid plate</th>
<th>On Shaking table (real testing configuration)</th>
<th>On Shaking table (real testing configuration)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Numerical</td>
<td>Numerical</td>
<td>Numerical</td>
<td>Experimental</td>
</tr>
<tr>
<td><strong>SMART</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; mode (flexion)</td>
<td>8.9 Hz</td>
<td>7.6 Hz</td>
<td>6.3 Hz</td>
<td>6.7 Hz</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; mode (flexion)</td>
<td>15.9 Hz</td>
<td>12 Hz</td>
<td>9.6 Hz</td>
<td>9.2 Hz</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; mode (torsion)</td>
<td>31.1 Hz</td>
<td>23.8 Hz</td>
<td>20.9 Hz</td>
<td>18.3 Hz</td>
</tr>
<tr>
<td><strong>CAMUS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; mode (flexion)</td>
<td>6.8 Hz</td>
<td>5.8 Hz</td>
<td>-</td>
<td>5.8 Hz</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; mode (flexion)</td>
<td>7.3 Hz</td>
<td>6.2 Hz</td>
<td>-</td>
<td>6.3 Hz</td>
</tr>
</tbody>
</table>
Step 1: SMART Momentum = 70 t.m

Step 2: Computation: SMART on soil = 8,02 Hz

Step 3: SMART minimum frequency decrease = 10 %

Step 4: 8,02 Hz - 10% = 7,2 Hz

Computation: SMART on rigid plate = 7,3 Hz
Momentum at the bottom of the mock up (ton.m) = modal mass \times height of the centre of mass

Abacus for Flexion modes: Local effects

- Computation: SMART mode 1 on a rigid plate
- Computation: SMART mode 2 on a rigid plate
- Computation & Experimental: SMART mode 1 without rigid plate
- Computation & Experimental: SMART mode 2 without rigid plate

Effect of SMART Boundary conditions

Camus Ox et al
Abacus for vertical modes

Frequency of the mock up on a rigid soil

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CONCLUSION

Most of these comparisons with experimental results are made for the flexion modes. For the CAMUS, ECOLEADER frame and SMART mock-ups with a rigid plate, the abacus prediction of the frequency decrease is very correct. That means that the actuators are indeed rigid and that the frequency decrease is not due to them.

- This study demonstrates that, for large shaking tables, most of this interaction is due to the platform deformation during the tests.

- These simple abacuses are a first approximation allowing a quick evaluation of the frequencies decrease for a mock-up fixed to the Azalée platform.

- When a very high decrease is expected, it is now possible to perform a numerical analysis with the mock-up placed on the simplified model of the Azalée platform.

- This study will permit experimental and numerical engineers to better take care, before tests (during the design), of the boundary conditions between the platform of the shaking table “Azalée” and the mock-up.

- On the Azalée shaking table, more precise comparisons to numerical analyses of large shaking table tests will be performed. A special interest will be made on the ratio between the stiffness of the structure and of the platform which seems the main parameter (and not the mass of the structure).