C1SMA PROJECT: A MECHANICAL DEVICE MEANT TO EXCITE BUILDINGS SLATED FOR DEMOLITION

Alexandre DE LA FOYE

ABSTRACT

In France, as elsewhere, many buildings are regularly demolished as part of urban renewal policy. These buildings have constructive systems which usually reflect our real estate holdings. We set forth a mechanical device made to excite these buildings before demolition in order to define their dynamic behavior for acceleration peaks situated between 0.1g and 0.5g. Features and target performances of this device are presented here. The first prototype has been ready to be used since November 2017. First in-situ tests and resulting adjustments are foreseen for 2018.

Keywords: building demolition; real-scale experimentation; forced oscillations

1. INTRODUCTION

1.1 Context

The theoretical foundations of earthquake engineering are generally inspired or validated by in situ observations or in the laboratory. In the first case building behaviors are either analysed in the context of significant seismic events (but building motions are usually not measured), or in the context of a planned measurement campaign (with weak amplitude excitations not leading to significant mechanical non linearities). In the second case, the studies are imperfect reproductions of physical phenomena (small-scale models incorrectly accounting for building production methods or material ageing…) but experimental protocols lead to a better control of phenomena.

The C1SMA (Constructions à l’échelle 1 Instrumentées soumises à un Séisme Modéré Artificiel) research project, initiated in 2014, co-financed by ENSA-Marseille and the PACA region and operational since November 2017, is a combination of two approaches: it is meant to reproduce the ground vibration effects on real buildings while benefiting from laboratory conditions. Two to twenty story buildings, intended for demolition in urban renewal operations and well instrumented, go through oscillations of increasing amplitude through a mechanical device reproducing on each floor the inertia forces that would be generated by an acceleration at basement level. After complete demolition of the building, using excavators or explosives, samples from rubbles should allow to better characterize the nature of the structure.

1.2 Objectives of C1SMA research project

The objective is first to characterize the evolution of the frequencies and modal damping according to the amplitude of the response ($10^{-4}$ m/s$^2$ to 5 m/s$^2$). The influence of the other parameters (foundations, dividing walls) will also be studied. The vibration effects of the building on the ground (soil) and nearby buildings, the efficiency or the behavior of seismic devices (reinforcement techniques, dampers…) could also be studied. The device is made to nourish the researches of all the laboratories and firms interested that can install their own devices or sensors in the excited building or on the exterior. The results obtained are made to be shared with the whole scientific community concerned by the dynamic behaviors of buildings.

1Professor, École Nationale Supérieure de Marseille, Marseille, France, delafye@marseille.archi.fr
2. GENERAL DESCRIPTION OF EXCITATION DEVICE

2.1 Unbalanced mass mechanical vibration exciter principle

The excitation device consists in equipping each slab of the studied building with two counter-rotating eccentric masses. Thus each story is subjected to a unidirectional sinusoidal force, the intensity of which depends on the turning radius, angular frequency and mass (Equ. 1).

Both vertical drive trains are positioned in such a way that point of application of the resultant force (F) corresponds to the building’s center of gravity (exact position being previously evaluated through ambient noise measurements). If slabs meet all the criteria to be considered as rigid diaphragm, the excitation produced by the unbalanced masses may then be considered as equivalent to inertial forces that would be produced by sinusoidal ground accelerations.

\[ F(t) = 2mR\omega^2 \sin(\omega t) \]  

where \( F(t) \) = force exerted on slab; \( m \) = rotating eccentric mass ; \( R \) = turning radius; and \( \omega \) = angular frequency.

![Diagram of force exerted by unbalanced masses on concrete slab](Image1)

Several eigen modes may be alternately excited (even combined) by managing at the same time fine-tuning of angular frequency, mass values and turning radius at each story.

2.2 Target performance

Table 1 presents, for different number of stories (n), the expected responses in terms of acceleration and displacements at the top of the building, as well as some of the data used to pre-size the device:
- Fundamental period of building: \( T_0 \)
- Each of the 2n unbalanced masses: \( M \)
- Total moment of inertia of 2n unbalanced masses: \( J \)
- Force exerted by each pair of unbalanced masses: \( F \)
- Maximum torsion torque applied to each vertical drive shaft on ground floor: \( T \)
- Minimum motor power required: \( P \)

<table>
<thead>
<tr>
<th>n</th>
<th>( T_0 ) (s)</th>
<th>M (kg)</th>
<th>J (kg.m²)</th>
<th>F (kN)</th>
<th>T (kN.m)</th>
<th>P (kW)</th>
<th>a (g)</th>
<th>d (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.2</td>
<td>70</td>
<td>40</td>
<td>78</td>
<td>220</td>
<td>18</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>5</td>
<td>0.3</td>
<td>50</td>
<td>460</td>
<td>60</td>
<td>560</td>
<td>28</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>10</td>
<td>0.5</td>
<td>100</td>
<td>2000</td>
<td>30</td>
<td>1200</td>
<td>30</td>
<td>0.22</td>
<td>1.4</td>
</tr>
<tr>
<td>15</td>
<td>0.8</td>
<td>150</td>
<td>4400</td>
<td>20</td>
<td>1800</td>
<td>30</td>
<td>0.15</td>
<td>2.1</td>
</tr>
<tr>
<td>20</td>
<td>1.0</td>
<td>190</td>
<td>7600</td>
<td>15</td>
<td>2200</td>
<td>28</td>
<td>0.11</td>
<td>2.8</td>
</tr>
</tbody>
</table>

The previous estimations are based on the following assumptions:
- Whole story mass: 200 tons
- Damping: 5%
- Fundamental period: \( n/20 \) (lateral-force-resisting system made of RC bearing walls)
- Turning radius: 1 m for \( n > 3 \); 0.3 m for \( n = 3 \)
3. TECHNICAL DESCRIPTION

3.1 Unbalance exciter

The mechanical device, which can be dismantled after each use and stored in a container (Figure 2), is essentially composed of the following elements:
- An asynchronous motor controlled by a variable speed drive connected to two horizontal drive shafts connected to cardan shafts and angular gearboxes with reduction ratios. All of these elements are situated on the building’s ground level.
- Two vertical drive trains connected to horizontal drive trains through two angular gearboxes with reduction ratios. These devices pass through all the floors (to which they are connected by ball bearings).
- Two eccentric mass exciters per floor rotated by the vertical drives and turning at the same speed in opposite directions (the synchronization is purely mechanic). Two models of eccentric mass structures are considered. The « slow » ones are used for buildings of low-order fundamental frequencies (1 to 3 Hz). They are made of a wood horizontal structure equipped with two high-resistance wheels rolling on the floor and bear masses of approximately 100-200 kg with a turning radius of 1 meter. The « fast » ones are used for buildings of high-order fundamental frequencies (4 to 10 Hz). They are made of a steel structure and bear masses of approximately 20-50 kg with a turning radius of 0.3 meter. The masses are made of blocks of solid concrete.

3.2 Motorisation

All of the eccentric mass vibrators are driven by the same engine. Two rotation speed ranges can be obtained by interchangeable reducers. For each configuration, the excitation frequency can be adjusted by the variable speed drive. The rated power of the engine is 30 kW.

Each testing includes three phases: the start-up phase with a progressive increase of the rotation speed and distance of the moving masses, a phase of steady-state (rotation frequency of the unbalanced masses slightly equal to the building’s natural frequency), and a phase of progressive breaking.

3.2.1 Start-up phase

The moment of inertia of all masses at startup can reach 4000 kg.m\(^2\) for a building twenty stories high (value doubled when the moving masses are on the stop). This phase, which lasts tens of seconds, requires an engine torque output in the range of 100 to 200 N.m.

3.2.2 Steady state phase

In the steady state, the resistant torque to overcome is not related to the moment of inertia of the vibrators but to the inertia forces exercised by the acceleration of the building on the masses. The objective is to maintain a constant rotation speed for one to three minutes. In case of resonance, the most demanding situation in terms of torque, the resistant torque follows a \(C\times\cos^2(\omega t)\) law type (figure 2).

![Figure 2. Torsion torque signal](image)

In the most demanding case (20-story buildings) the maximum torque output of the motor is approximately 300 N.m (2200 N.m at each vertical drive shaft on ground floor).
3.2.3 Breaking phase

Once the steady state phase is finished the variable speed drive should reduce the rotation speed of the unbalanced masses following a deceleration ramp function of one to three minutes.

3.3 Vertical drive trains

The two vertical drive trains consist of a succession of steel round bars and tubes connected to each other by cone clamping elements. This connection system allows one not only to transmit high torques but also to adapt the device to a large range of floor-to-floor heights. Connections between vertical trains and eccentric masses structures (fabricated in steel for the fast version and in wood for the slow version) are also performed by cone clamping elements.

3.4 Instrumentation

The basic instrumentation allowing one to characterize the building’s dynamic behavior before, during, and after the mechanical excitation is composed of:
- An acquisition chain, based on 2 CMG-40T three-axis seismometers, intended for ambient vibration measurements, before and after the mechanical excitation.
- An acquisition chain, based on 8 single axis low-frequency accelerometers (sensitivity of 1 V/g) intended for acceleration measurement under mechanical excitation.
- 10 digital cameras allowing one to characterize damage mechanisms of bearing walls.
Other sensors might be mounted on the tested buildings or in its surroundings according to goals of testing and resources of firms and laboratories involved in the operation.

4. INTENDED APPLICATIONS

4.1 Academic applications

In all cases, the aim will be to characterize mechanical behaviors of tested buildings for a wide range of accelerations. When several identical or similar buildings are available (routine cases in urban renewal projects), the opportunity will be given to lead parametric studies with a few parameters changing from one case to the other: structural and partition walls characteristics, basement, foundations or soil types, etc. An ongoing project consists in characterizing the vulnerability of primary schools built in Guadeloupe in the 1930s and 1950s. Many of these buildings are made with the same construction system (RC frame with concrete masonry infill) in similar conditions. By testing those which are slated for demolition, it would be possible to better characterize the ductility of their lateral force resisting system and consider the most suitable retrofitting strategies for remaining buildings.

4.2 Industrial applications

Seismic retrofitting measures (reinforcements or damping devices for example) or sensors in development might also be implemented in partnership with the industry concerned and their efficiency can be characterized for a large range of accelerations.

4.3 Testing protocol

In principle each testing protocol is specific, depending on objectives that have been set with partners. For each tested building, however, the general testing protocol should be approximately the following:
- 1 day for ambient noise measurements: estimation of first mode shapes, period and damping for low top floor accelerations (approximately $10^{-3}$ to $10^{-2}$ m/s²).
- 1 to 3 days to set up the device (including floor piercing) according to building dimensions.
- 1 day for forced oscillations measurements: estimation of first mode shapes, period and damping for increasing values of top floor accelerations (from $10^{-3}$ to a few m/s²).
- 1 day for last ambient vibration measurements, dismantling the device and storing it in its container.
Figure 3. Mechanical device: asynchronous motor (1), angular gearboxes with reduction ratio (2 & 3), horizontal drive shaft (4), vertical drive shaft (5), eccentric mass structure (6)
5. CONCLUSIONS

A new mechanical device made to excite buildings before demolition has been presented. Target accelerations at the top of buildings are of approximately 0.1 g for 20-story buildings and 0.5 g for 3-story buildings. The experiments are intended to provide inputs into research concerning the dynamic behavior of buildings ranging from weak to high amplitude responses, the influence of non-structural elements on mechanical behavior, damage mechanisms of structures, soil-structures interactions, etc. The goals of each testing shall be redefined according to the needs of involved partners. Performance tests with industrial products dedicated to vibration reduction or seismic retrofitting could be considered as well as tests for academic research purposes. The first prototype has been ready to be used since November 2017. First in-situ tests and resulting adjustments are foreseen for 2018.

6. REFERENCES


