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Dynamic characterization of a suspended ceiling system based on ambient vibration measurements

*Andrea Lucchini[1)], Giuseppe Quaranta[2)] and Marco Bonaventura[3)]

[1), 2), 3)] *Department of Structural Engineering and Geotechnics,*
Sapienza University of Rome, Italy
[1)] *andrea.lucchini@uniroma1.it*

ABSTRACT

Experiences from earthquakes worldwide keep showing how significantly nonstructural components contribute to the seismic performance of buildings. Nonstructural damage may indeed cause the loss of functionality and also increase the risk of fatal injury to the building's occupants. Despite the important role played by these components, reliable methodologies for predicting their response under earthquakes are still lacking. In this perspective, new equations for generating floor spectra have been recently developed, which improve the accuracy of the seismic demand estimation. The problem with these equations, however, is that the required input, consisting in the dynamic properties of the components, is unknown in most cases. In order to overcome this limitation, nonstructural components usually are simply classified as rigid or flexible: in the latter case, a period value equal to that of the significant mode of vibration of the structure is assumed whereas a damping ratio conventionally set to 5% is adopted. So doing, the seismic demand is typically overestimated. In-situ tests are attractive to identify the main dynamic features of nonstructural components, especially because they can depend on the specific installation conditions. Therefore, the possibility of performing cheap and rapid measurements for the experimental dynamic characterization of suspended ceiling systems is critically examined in the present work, by highlighting the potentials as well as the emerged issues.

1. INTRODUCTION

Damage reports developed after past earthquakes have clearly shown how often nonstructural components significantly contribute to the seismic performance of buildings. Nonstructural damage, in fact, may largely affect the cost of repairing seismic damage and be among the major causes of functionality interruption of buildings after earthquakes. Suspended ceilings have frequently been reported among the most

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[1), 2)] Assistant Professor
[3)] Laboratory Technician

widely damaged types of components (Badillo-Almaraz et al. 2006). Their high vulnerability, as that of many other nonstructural components, depends on lack of proper seismic design, which is in turn due also to the lack of reliable models to estimate seismic capacity as well as analysis tools that allow an accurate prediction of seismic demand. The latter in the case of acceleration-sensitive components (ASCE/SEI 41-06 2007) is expressed in terms of pseudo-acceleration and derived from floor response spectra given the period of vibration and the damping ratio of the component. Unfortunately, these two parameters are usually not provided by manufacturers and their prediction may be affected by large uncertainty due to dependency on the specific installation conditions, as it is the case of suspended ceilings. The objective of this work is to exploit the dynamic response under ambient vibrations for determining the properties of those nonstructural components for which information on period and damping are not available. The main advantage of this approach is the possibility of determining the dynamic features of the component onsite. The case of a suspended ceiling is studied, and the results of the identification reported and finally discussed.

2. EXAMINED CEILING AND TEST SETUP

The considered case study is the ceiling shown in Fig. 1, which is installed in a classroom of the Faculty of Architecture at the Sapienza University of Rome. It is a suspended lay-in tile ceiling system, with mineral fiber tiles and a suspension grid system consisting of main beams and cross tees made from hot dip galvanized steel. Vertical suspension is provided using hanger wires. The ceiling is floating, not connected to the perimeter walls and not provided by any specific lateral resisting system to carry the seismic load. Ceiling panels sit on the grid without hold down clips that ensure vertical restraint. This type of ceiling, widely used in Rome both for office and administrative buildings, provides acoustical comfort and covers ductwork and pipes while leaving the system accessible for repair. Fig. 1 reports also some pictures of the hanger wires. It can be observed that their length is not always the same. In some cases the wires are attached to the profiled steel decking and in some others to the steel beams that support the floor. In addition, some of them are inclined to avoid contact with the suspension system of the HVAC duct.

Fig. 1 Some pictures of the suspended ceiling

The experimental testing campaign is based on the recording of the dynamic response of the suspended ceiling under ambient vibrations. The main goal is to assess potentials and shortcomings of dynamic tests under serviceability conditions of suspended ceiling systems based on single measurement points and performed by means of all-in-one sensing units. This goal is motivated by the need of developing a cheap and rapid protocol for the characterization of a large number of suspended ceiling systems through in-situ dynamic tests. The maximum velocity under ambient vibrations is expected in the order of few millimeters per second or less, and thus a sensor suitable to record micro-tremors is required. In accordance with the designated objectives and specifications, the velocity response of the considered suspended ceiling has been recorded by means of Tromino®. The main features of the sensor are the following: three velocimetric channels with adjustable dynamic range and ultra-high sensitivity for ambient noise recordings up to $\pm$ 1.5 mm/s, operating frequency 0.1−1024 Hz on all channels with A/D conversion at 24 real bits. The independent measurement points and a picture of the sensor are illustrated in Fig. 2.

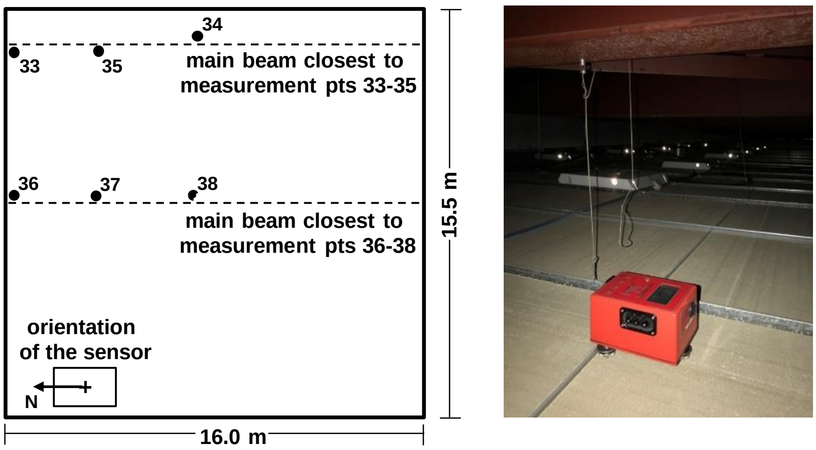

Fig. 2 Schematic plan of the ceiling with location of the measurement points (left), and a picture of the sensor (right)

Frequency sampling and time window were assumed equal to 128 Hz and 16 minutes, respectively. The experimental campaign was performed with the whole building in use as in regular daily conditions.

3. RESULTS OF THE ANALYSES

The Fourier Transform of the recorded velocities resulted no effective for the analysis of the frequency content of the response in the frequency band of interest, i.e., between 1 s and 2 s (band limits set to include the expected value of the period of vibration of the ceiling estimated through a simple pendulum model). This was somewhat expected because the response magnitude is extremely low for most of the time and exhibits a series of pulses otherwise since the relative low inertial mass of the tested component. A time-frequency domain approach via Wavelet Transform is thus more appropriate, as pointed out for instance by Zhang and Tamura (2003). A sample of the performed elaborations for the N-S component is shown in Fig. 3. The records have been first filtered in order to remove the pseud-static component with a Butterworth filter assuming a cut-off period equal to 3 s. A complex Gaussian mother wavelet is adopted.

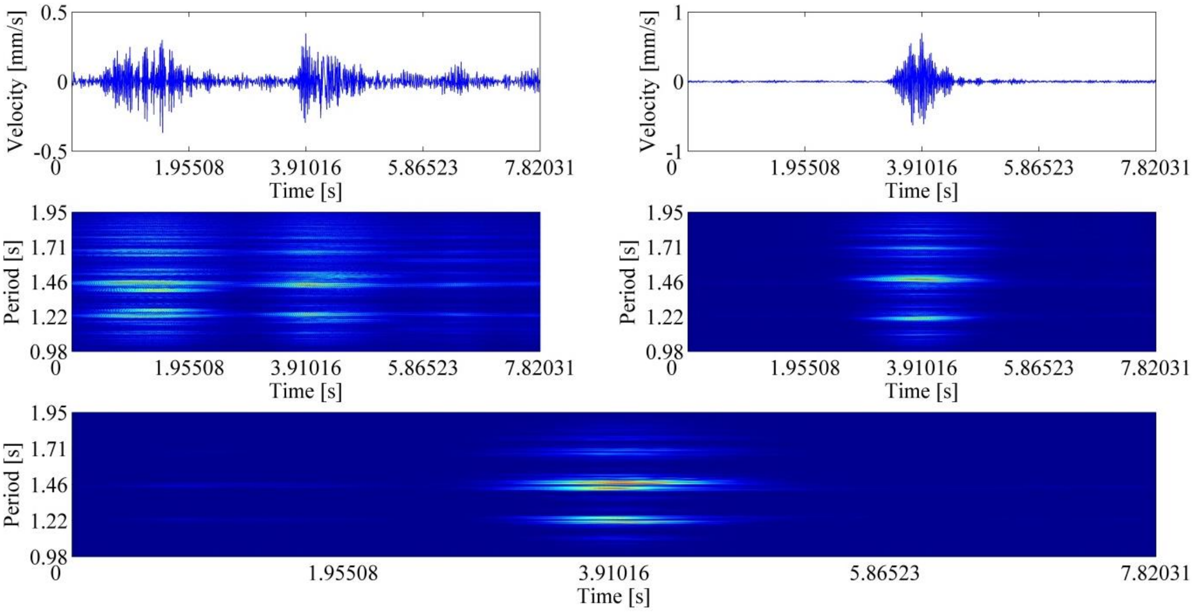

Fig. 3 Time-frequency domain analysis (measurement points 33 and 35): velocity records (upper row), time vs pseudo-period from continuous wavelet transform (central row), time vs pseudo-period from the cross wavelet spectrum (bottom row); the plots refer to the time-window around the peak velocity

The time-domain analysis confirms that the recorded velocity is almost null, except when the occurrence of some pulses causes velocity peaks in the order of 1 mm/s or less. By the way, such peak values are close to the lower bound of the typical range of the structural response under ambient ground-born vibrations reported in ISO 4866. No well-defined concept of periods exists for wavelets such as there in Fourier analysis, but the period associated with the maximum Fourier amplitude of a wavelet can be used to define the so-called pseudo-period (period for short in Fig. 3 and henceforth). The results in Fig. 3 and the others carried from the available records highlight a period equal to 1.46 s, which is rather close to the numerical prediction obtained through a simple pendulum model. The difference between the two is basically due to the irregular installation conditions of the tested component. The estimated damping ratio value lies between 1.7% and 2.4%. As expected, such values are lower than the ones reported in Riu and Reinhorn (2017). This can be explained by noting that these results have been obtained under micro-tremors whereas the outcomes in Riu and Reinhorn (2017) were carried out under much higher excitation levels. The difference can also by attributable to geometrical and mechanical differences among the tested components.

5. CONCLUSIONS

The present study has pointed out the importance of determining the dynamic features of suspended ceiling systems from in-situ tests, since they can strongly depend on the installation conditions. Within this framework, recording the dynamic response under ambient vibrations using a single all-in-one measurement station is very attractive because it is cheap and preserves the regular use of the structure. However, differently from laboratory tests on shaking table, the typical issues due to the very low magnitude of the dynamic response arise. The modest dynamic loading also explains the low damping ratio value estimated in the presented work as compared to previous laboratory experiments performed under much higher excitation levels. Moreover, the irregular installation conditions of the tested component are expected to influence to a large extent the estimates of fundamental period and corresponding damping ratio.

ACKNOWLEDGMENTS

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