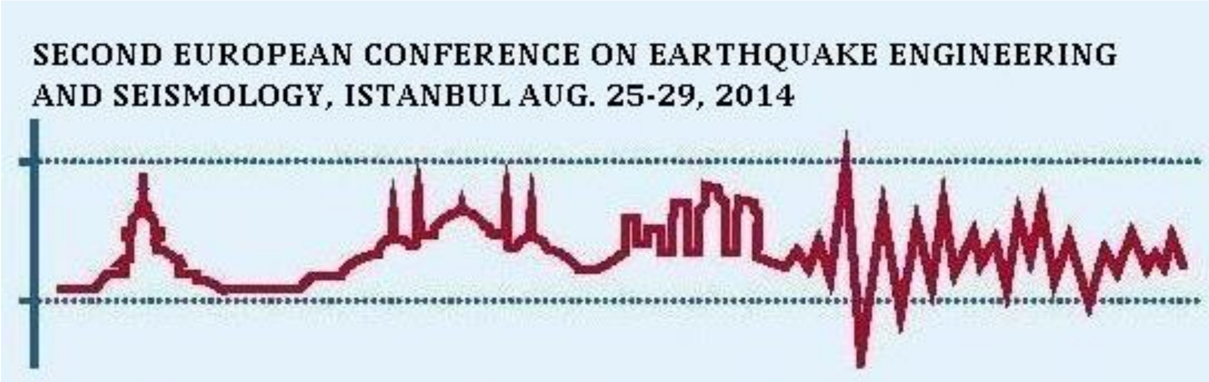

ANALISYS OF DYNAMIC BEHAVIOUR OF A BASE ISOLATED BUILDING: A RELEASE TEST IN AUGUSTA (SI), ITALY

Felice PONZO[1], Rocco DITOMMASO[2], Domenico NIGRO[3], Rosa ROMANIELLO[4]

ABSTRACT

On the 22th of May 2013, during several release tests, in order to acquire the dynamic response of a base-isolated structure, and their soil-structure interaction, several accelerometers have been installed within the structure and on the surrounding soil. The building is located in Augusta City (Italy) an earthquake-prone area. The dynamic behaviour of the structure, together with the soil, has been monitored and analysed. In fact, it is well know the capability of a fixed-base structure to modify the motion of the surrounding soil during an earthquake or a release test, but there is very little information about this kind of soil-structure effects for base-isolated structures. During this experimental campaign the dynamic behaviour of two surrounding structures has been monitored before, during and after each test. The base-isolated structure has been characterized in terms of eigenfrequencies, equivalent viscous damping factor and mode shapes in ambient noise (considering the superstructure as a fixed-base structure) and during release tests (monitoring the dynamic behaviour of superstructure, base isolation system and underground floor).

INTRODUCTION

The loss of life and the enormous damages occurred in civil engineering structure disasters during the last decades have exposed the importance of preventative actions to mitigate the effects of structural failures. The serious damages and structural collapses are caused by high vulnerability of the existing buildings, designed and built without seismic details, but also by the frequency and intensity of earthquakes. Therefore, the evaluation of potential effects to structures in different permanent and/or accidental load scenarios is an important issue to be considered in rehabilitation decisions and emergency measure planning. Furthermore, there is the need to ensure more effective protection of existing constructions in regard to earthquakes, in order to mitigate the damages associated with these events. For this reason it is very important to identify the real structural behaviour, using Structural Health Monitoring (SHM) and dynamic identification techniques. Using this kind of approach, it is possible, using ambient and/or forced vibration and/or release test, to evaluate all the dynamic characteristics of a monitored structure: eigenfrequencies, equivalent viscous damping factors and mode shapes.

In this article, we analysed the dynamic behaviour of a base isolated structure during ambient noise and during several release tests; dynamic tests were performed applying an initial displacement to the structure using a special kind of jack. Release tests have already been carried out in Italy on base

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isolated buildings of TELECOM Ancona (Bettinali *et al.*, 1991, 1992; Forni *et al.*, 1991). In that case it was applied to a shift of about 10 cm, through a complex system of synchronized cylinders with explosive charges in order to apply the instantaneous release. Other similar experiments have been carried out on the building of Rapolla in Potenza (Braga *et al*., 2001, 2004, 2005) and on some building of the University of Basilicata (Bixio *et al.*, 2001). In the first case, the experiment was carried out on a building composed two different interchangeable isolation systems. At Rapolla city, the initial displacement was applied by moving the structure just above the isolation system using the same mechanical set-up employed at the University of Basilicata. The device was redesigned to apply an initial displacements ranging from 0 to 20 cm. It consists of a three-hinged arch (two sets of trusses and three cylindrical shafts) vertically pulled on the middle hinge by means of a hydraulic jack equipped with a load cell. The release takes place when the three hinges reach the horizontal unstable alignment and the trusses detach from the middle hinge (central shaft).

In the second case, there was an experimental campaign finished with snap-back test, for a dynamic characterization of headquarters of the Department of Mathematics of the University of Basilicata. In this case many release tests were carried out, by using a mechanical device purposely designed to give the initial displacement to the building and then produce free damped vibrations.

In the summer of 2004 and in July of the same year another example of release tests were performed on two reinforced concrete building by base isolation in a small town of Solarino in Eastern Sicily. Dynamic tests were performed in the form of free vibrations after applying an initial displacement as close as possible to the design displacement (Athanasiou *et al.*, 2011, Oliveto *et al*., 2010). Free vibration tests performed on base-isolated buildings have also been reported in literature.

A four story building was built in 1992 in Santiago, Chile, on 8 HDRB and subjected to 5 free vibration tests under imposed displacements, ranging from a minimum of 6.1mm to a maximum of 19.5 mm, with corresponding deformations from 0.140 to 0.445. The main results were the measured periods of vibration and the equivalent damping ratio (Moroni *et al.*, 1998).

In literature there are also other examples of experimentation on structure using snap-back test for estimation behaviour of different type of structures (Pender *et al.*, 2011; Chugh *et al.*, 2011; Melkumyan; Seki *et al.*, 2000). Several authors have used accelerometric recordings of release tests also to analyse the problem of energy back-radiated from vibrating structures on both models (Guéguen *et al*., 2002) and real buildings (Mucciarelli *et al*., 2003; Gallipoli *et al*., 2006; Ditommaso *et al*., 2007, 2009).

In literature it is well known the capability of a fixed-base structure to modify the motion of the surrounding soil during an earthquake or a release test (Ditommaso *et al*., 2010), but there is very little information about this kind of soil-structure effects for base-isolated structures.

For this reason, exploiting a series of release tests carried out on a base isolated structure in Augusta city (Italy), the aim of this article is:

- to test the seismic performance of the base isolation system;
- to compare the dynamic characteristics of the structure before, during and after each test (individuating possible damage on non-structural elements);
- to evaluate soil-structure effects in terms of energy released into the ground and maximum acceleration produced on the surrounding structures during the released tests.

EXPERIMENT DESCRIPTION

During the experimental campaign carried out on the base isolated structure in Augusta city (Italy), a jack able to apply a maximum thrust force of about 200 tons has been applied. Following the test, the structure has shifted about 10 cm but without any damage, demonstrating the effectiveness of the isolation system. Figure 1a shows the tested structure and Figure 1b the device used to make the release test. The release test was carried out through the use of a specially designed system able to impart to the building a prefixed initial displacement. Then, the structure was instantaneously released in a free-oscillating condition. The displacement impressed to the building during different release tests were prefixed taking into account the target maximum design displacement. The dynamic "snap-back" tests, were carried out to verify the compliance of the isolation system to the expected behaviour derived from the numerical analyses.

(a) (b)

Figure 1. (a) Structure of Augusta (b) Thrust device of the release test

The Augusta building considered was built for commercial use. Figure 2 shows the plan of the building and Figure 3 shows the section A-A of structure.

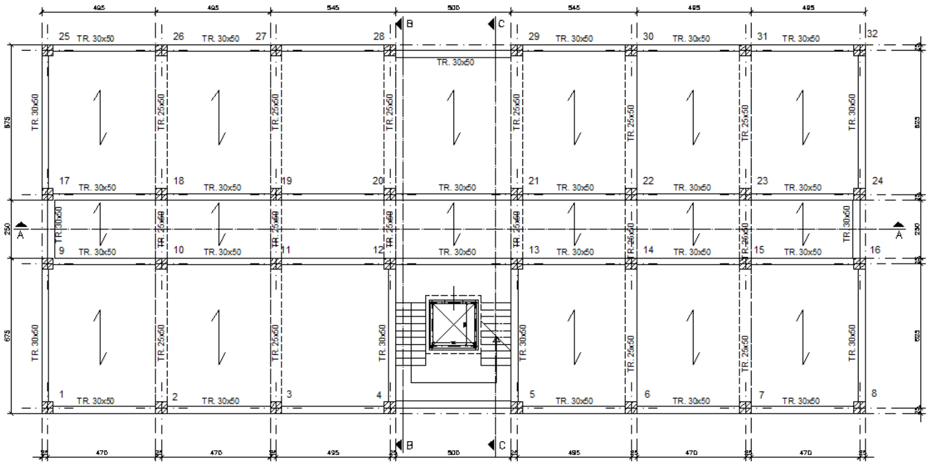


Figure 2. Plan of the building

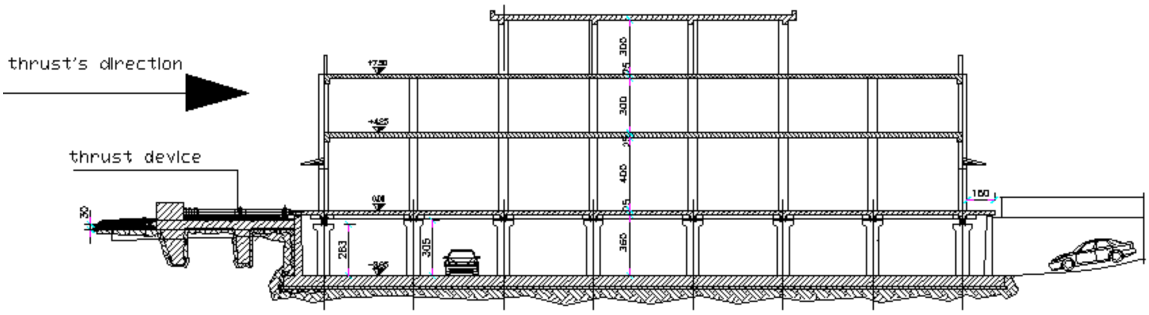


Figure 3. Section A-A of building

The building, designed and constructed using the new Italian technical regulations, D.M. 14/01/2008 (NTC08), is characterized by a hybrid base isolation system composed by 16 High Damping Rubber Bearings and 20 low friction sliding Bearing (Oliveto *et al.*, 2013).

The structure is made using reinforced concrete and characterized by three stories above the isolation plane and one story beneath it (Figure 3). The ground floor is characterized by an inter-story height equal to 3.85 m respect to the basement, the first floor is characterized by an inter-story height equal to 4.25 m and finally the last level is characterized by an inter-story height equal to 3.25 m.

The building has a rectangular shape with a length of 35.70 m, a width of 16 m and a maximum height above the ground at 10.50 m. The mass of the structure is equal to 2400 tons. The isolation plan runs along the top of the pillars of the basement story slightly above the ground level.

In order to evaluate the dynamic behaviour and the soil-structure interaction effects, several accelerometers were installed within the structure and on the surrounding area (in both condition ambient noise and release tests).

Figure 4 shows un example of arrangement of accelerometers on the last floor of the structure and Figure 5 a picture of the accelerometers n°125 -126 installed on the top floor.

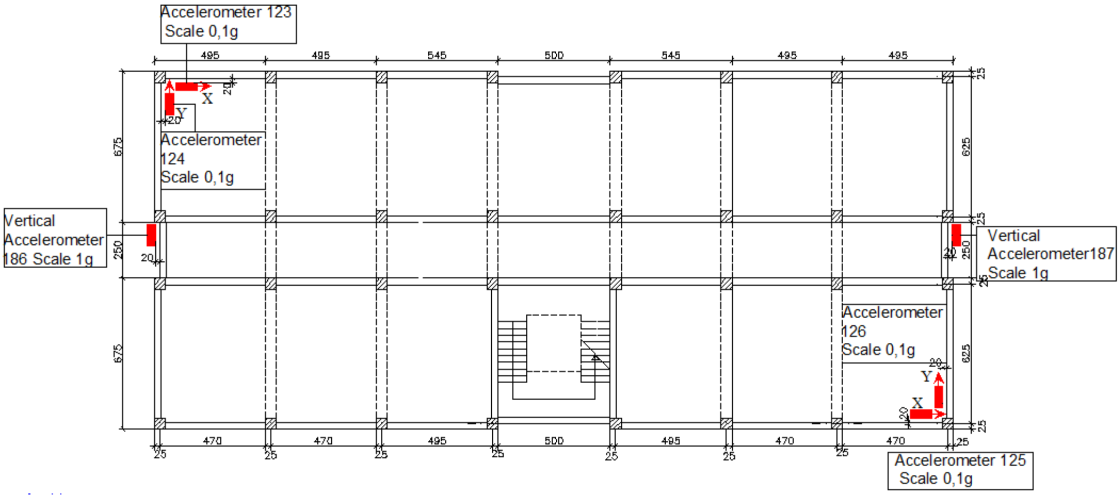
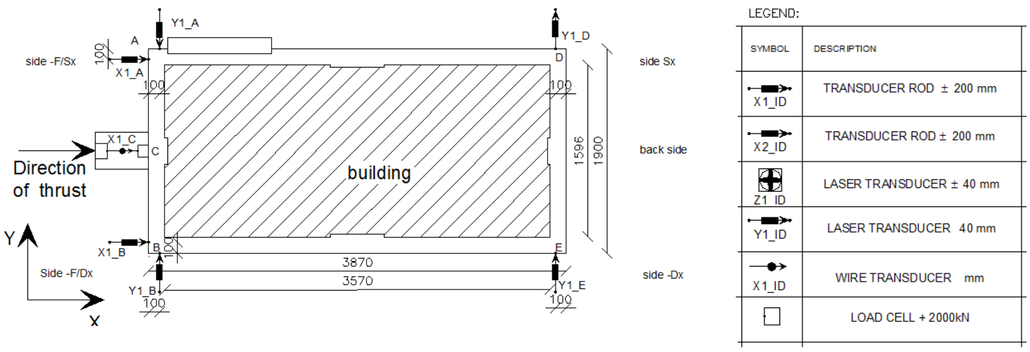


Figure 4. Arrangement of the accelerometers on the last floor for the first configuration

Figure 5. Accelerometers 125-126

The displacements of the structure were monitored through the use of appropriate transducers placed in correspondence of the elevator shaft, of the pillars and on two corner of the structure, along the same diagonal, as it is shown in the images below (Figure 6,7,8).



(a) (b)

Figure 6 . Arrangement of the transducers on the corner of the structure (a), and used transducers(b).

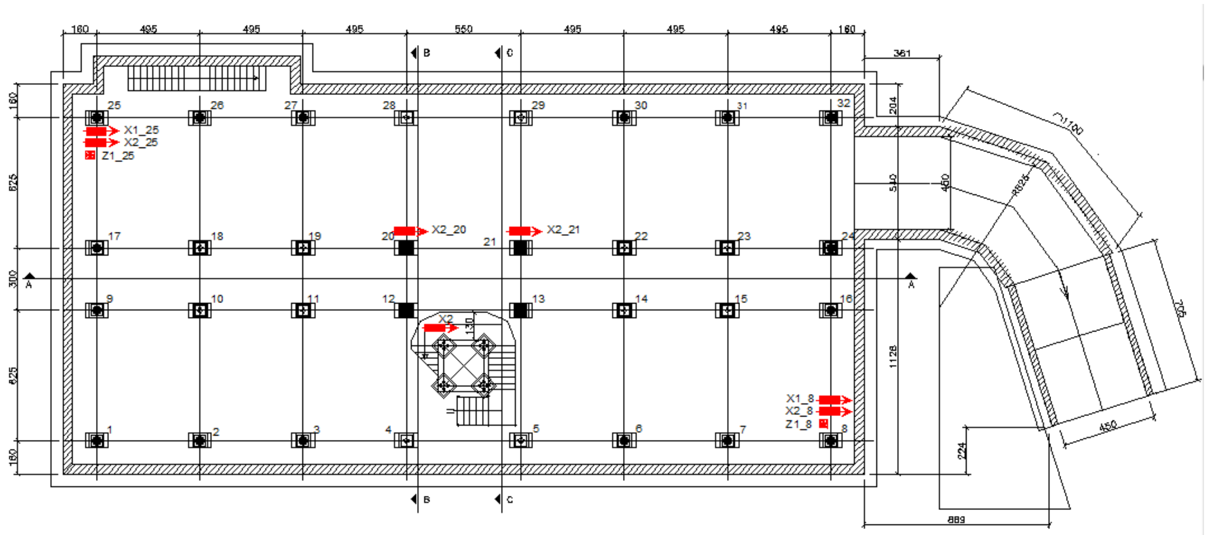
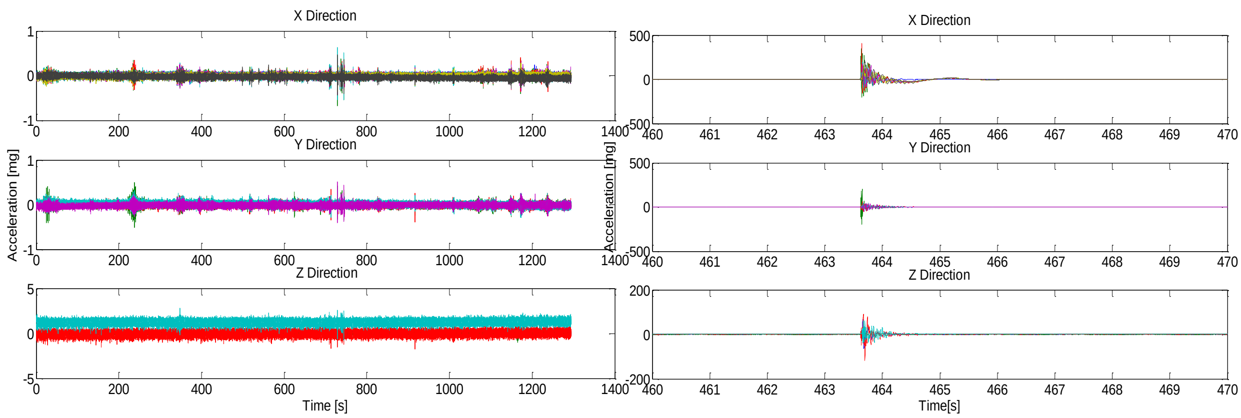


Figure 7 . Arrangement of transducers along the rubber bearings 25 and 8, the sliding bearing 20, 21and the sliding bearing of elevator shaft.

(a) (b)

Figure 8. Monitored displacement of the pillars (a) and along the perimeter of the structure (b).

In the figure below, it is possible to observe two examples of the recorded signals, of each level of test structure during an ambient noise (Figure 9a) and during a release test (Figure 9b)

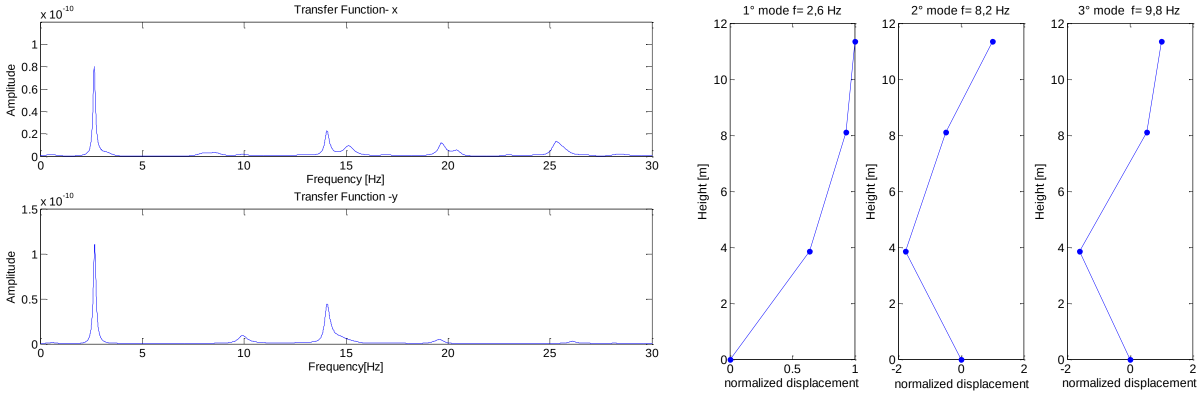


(a) (b)

Figure 9. Recorded signals on each level of structure in ambient noise (a) and forced vibration(b)

RESULTS: IDENTIFICATION OF THE DYNAMIC CHARACTERISTICS OF THE STRUCTURE DURING AMBIENT NOISE AND RELEASE TEST

In order to characterize the dynamic parameter of the monitored structure, in the fixed base condition, the transfer functions have been calculated using seismic noise recordings retrieved from the accelerometers installed at all floors. Figure 10a shows the transfer function evaluated using the accelerometric recordings performed on the base and the top floor of the building.

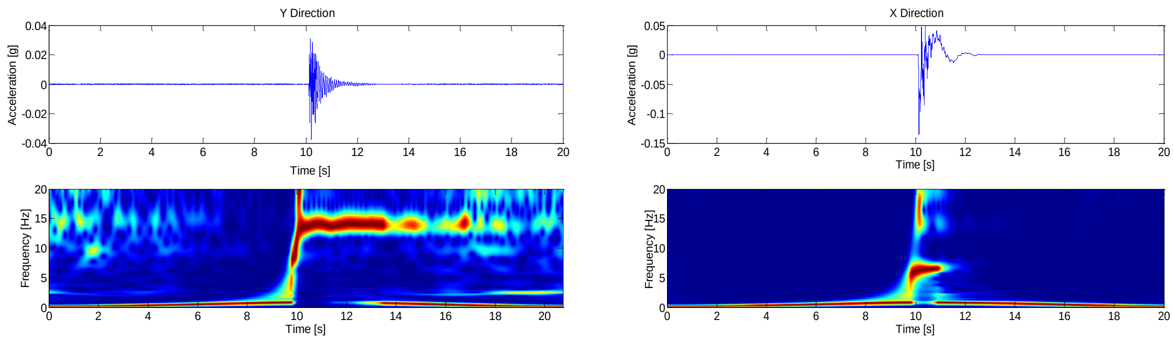


(a) (b)

Figure 10. (a) Transfer Function calculated using ambient noise and(b) mode shapes

In ambient noise condition, using the transfer function it has been possible to evaluate the main frequencies of the superstructure. The fundamental frequency of the superstructure is equal to 2.6Hz and, in terms of mode shape, it seems to be a torsional mode. It is important to highlight that the dynamic characterization has been performed using ambient vibration test (characterized by very small amplitude) where also the contribution of non-structural elements is considered. The second mode (translational) is characterized by a frequency equal to 8.2 Hz and the third mode (translational) by a frequency equal to 9.8 Hz. The mode shapes evaluated on the experimental data using time domain analyses are depicted in Figure 10b.

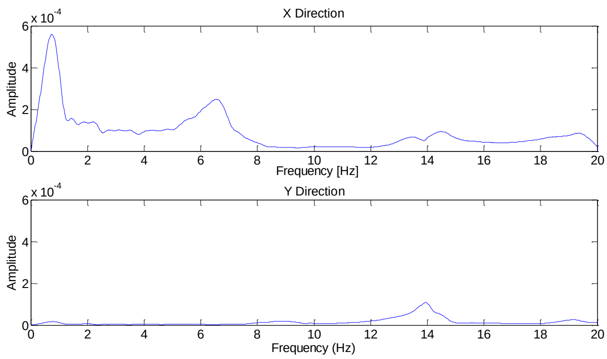
The accelerometric recording acquired on the top floor during the release tests were analysed using Stockwell transform (Stockwell *et al.*, 1996), operating on the time-frequency domain, and transfer function of the signal, operating on the frequency domain. From the time-frequency analyses (Figure 11) it was been possible to confirm the linear behaviour of the superstructure and to detect the main eigenfrequencies.



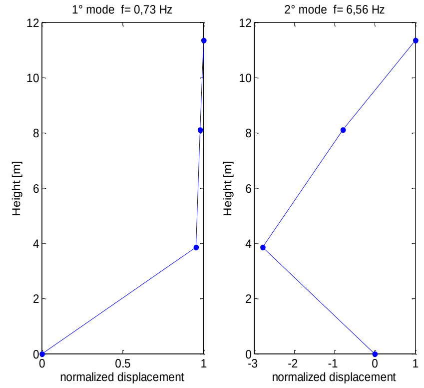
(a) (b)

Figure 11. Stockwell transform along x direction (a) and y direction(b)

Using the Stockwell transform on the signal recorded on the superstructure and on the base isolation level it was been possible to evaluate the frequency of the base isolation system, equal to 0.73 Hz while the first detected frequency for the superstructure is equal to 2.6 Hz. Analysing the data using the transfer function the same frequency for the base isolation system has been detected. These last results, together with the corresponding mode shapes are depicted in Figure 12.



(a)



(b)

Figure 12. Transfer Function evaluated on the accelerometric recordings during (a) the release test and the modal shape of the structural modes for the main frequencies(b)

The following tables (Table 1, Table 2) show the values of the main frequencies evaluated in ambient noise and release test.

Table 1. Frequencies of superstructure

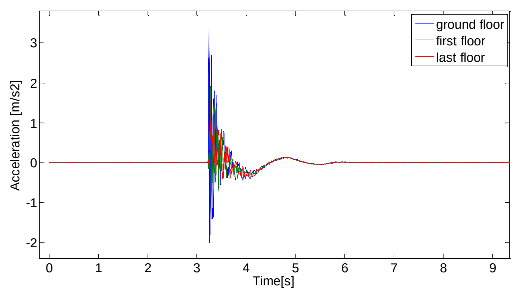
Frequencies of superstructure	
1° roto-translational Y mode	2,6 Hz
2° translational X mode	8,2 Hz
3° translational Y mode	9,8 Hz

Table 2. Characteristics of base isolation system

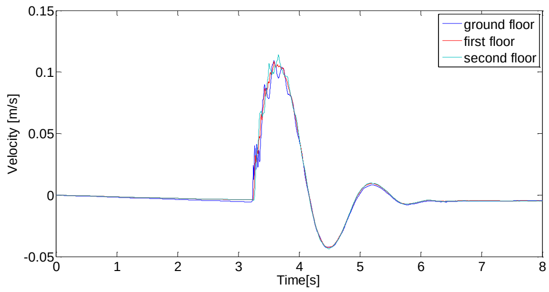
Characteristics of base isolation system	
1° translational X mode	0,73 Hz
Equivalent viscous damping factor	14,65%

The evaluation of the equivalent viscous damping factor of the structure was carried out using the logarithm decrement method. Particularly, the accelerometric recordings related to the station installed to the last level have been considered for the equivalent viscous damping factor evaluation along the x direction (test direction).

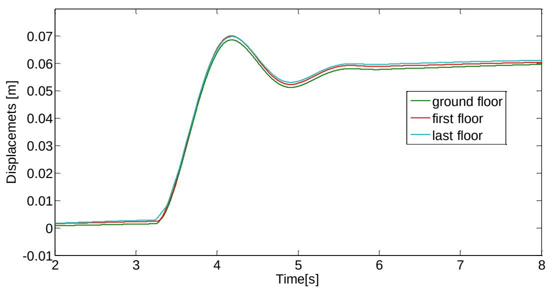
Figure 13 shows the kinematic parameter (acceleration, velocity and displacements) evaluated at each level of structure.



(a)



(b)



(c)

Figure 13. Cinematic parameters: acceleration(a), velocity (b), displacements (c)

Starting from the accelerometric recordings, the flow chart used to evaluate velocity and displacement is depicted in Figure 14:

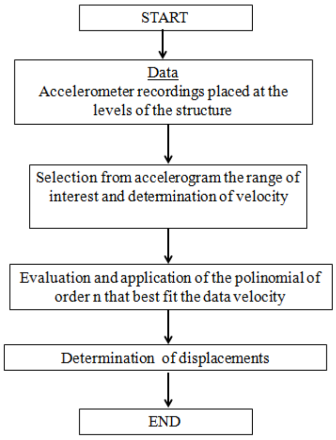


Figure 14. Flow chart of the routines developed in MATLAB for the calculation of the displacement

The main problem related to the determination of the displacement time-history starting from the accelerometric recordings, acquired during a release test, is related to the use of classical filter (standard approach) on impulsive signals. For this reason a special kind of filter was built using a routine implemented in MatLab. Comparing the displacement time-history retrieved from the accelerometric recordings with those acquired using the displacement transducers it is possible to observe a very good agreement. On the contrary, using the standard approach the displacement retrieved from the accelerometric recordings is very different from those acquired from the transducers (Figure 15).

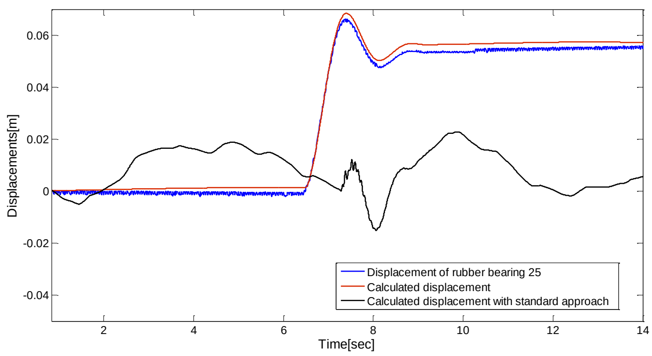


Figure 15. Comparison between the displacements evaluated using a MatLab routine, the displacements acquired using a displacement transducers (on the rubber bearing n° 25) and the displacements obtained with standard methods.

Figure 16. Area monitored during the experimental campaign

During ambient vibration and release tests, in order to evaluate soil-structure effects in terms of energy released into the ground some accelerometric station have been installed on the surrounding area and on the surrounding structures (Figure 16). For briefly reason the analyses and the results are not reported in this paper, but from the preliminary results it seems that also a base isolated structure during the motion is able to modify the motion on the surrounding area condition also the motion of the surrounding structures.

DISCUSSION AND CONCLUSIONS

In this paper the preliminary results of the experimental campaign performed on a base isolated structure are described, providing information about the test and consideration on the seismic behaviour of the structure. The release test allowed to simulate the maximum displacement occurred during a very strong earthquake occurred on the area where the building is located. Taking the advantage of the release test it has been possible to analyse the dynamic behaviour during ambient vibration, weak and strong motion earthquake. The maximum displacement reached during the experimental campaign is 10cm at the base isolation level. The dynamic behaviour of the structure and of the base isolation system was monitored using several kind of instrumentation: cabled accelerometric stations, displacement transducers and wireless accelerometric station. Also the soil-structure interaction has been considered in terms of capability of the oscillating building to radiate energy into the soil influencing also the dynamic motion of the surrounding building.

The analyses were performed both on ambient vibration and during the release test using transfer function and time-frequency analyses based on the S-Transform. In order to evaluate the displacement time-history, starting from the accelerometric recordings a special kind of filter has been designed. The results were compared with those acquired directly from the displacement transducers installed at the base isolation level.

The preliminary results obtained from the experimental campaign confirmed the high performance level of protection of the base isolation system installed on new buildings. Further analyses are necessary to in deep analyse the dynamic performance of the structure, to build a realistic numerical model (using model updating techniques) and to compare the experimental behaviour with those predicted from linear and nonlinear numerical models.

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