SECOND EUROPEAN CONFERENCE ON EARTHQUAKE ENGINEERING AND SEISMOLOGY, ISTANBUL AUG. 25-29, 2014

STRUCTURAL RESPONSE OF HISTORICAL AND RESIDENTIAL BUILDINGS DURING DREDGING ACTIVITIES IN THE GENOA HARBOUR

Simone Barani[1,2], Roberto De Ferrari[3,4], Claudio Eva[5], Sergio Lagomarsino[6], Serena Cattari[7] and Andrea Pieracci[8]

ABSTRACT

In this study, we apply spectral ratio techniques to study the structural response of some civil and historical buildings in the historic centre of the city of Genoa (Northwestern Italy) that, during the second half of 2012, were subjected to intense vibrations induced by the blasting excavation of the sea bed in the Genoa harbour. The study focuses on three selected masonry buildings.

The mode of vibrations of the buildings under study is determined either through horizontal-to-vertical spectral ratios (H/V spectral ratios) or through the analysis of the ratio between the corresponding components of the spectra recorded simultaneously inside the building and at a reference station installed in the basement. For all buildings, spectral ratios are calculated from blast and noise recordings. For one of them, we also analyse the seismogram of the October 3, 2012 Piacenza earthquake (local magnitude, M_l = 4.5).

INTRODUCTION

In recent years, the horizontal-to-vertical spectral ratio (HVSR) technique applied to noise recordings [also known as Nakamura's technique (Nakamura, 1989)] has been widely applied in the engineering seismology as it represents an economical and efficient alternative to traditional strong ground motion analyses based on standard spectral ratios (SSR) from earthquake recordings (Borcherdt, 1970) and numerical simulations. Its primary application is related to the analysis of the resonance frequency of soils (e.g., Lermo and Chavez-Garcia, 1993; Lermo and Chavez-Garcia, 1994; Lachet and Bard, 1994; Mucciarelli, 1998; Bard, 1999; Bindi et al., 2000; Mucciarelli and Gallipoli, 2001; Parolai et al., 2001; D'Amico et al., 2002; Gallipoli et al., 2004a; Parolai et al., 2004; Gosar, 2007; Parolai et al., 2010; De Ferrari et al., 2010). However, recent studies have demonstrated that this technique is also suitable for the characterization of the structural response of buildings (e.g., Nakamura et al., 1999; Gallipoli et al., 2004b; Parolai et al., 2005; Fäcke et al., 2006; Hans et al., 2005; Luo et al., 2008; Gallipoli et al., 2009; Massa et al., 2010). The knowledge of the resonance frequencies of a building in conjunction with the seismic response of the foundation soils is of paramount importance to avoid double

[1] Ph.D., GEAmb S.r.l. academic spin-off company, Genoa (Italy), barani@geamb.it
[2] Ph.D., DISTAV – University of Genoa, Genoa (Italy), barani@dipteris.unige.it
[3] Dr., GEAmb S.r.l. academic spin-off company, Genoa (Italy), deferrari@geamb.it
[4] Dr., DISTAV – University of Genoa, Genoa (Italy), deferrari@dipteris.unige.it
[5] Prof., GEAmb S.r.l. academic spin-off company, Genoa (Italy), eva@dipteris.unige.it
[6] Prof., DICCA – University of Genoa, Genoa (Italy), Sergio.Lagomarsino@unige.it
[7] Dr., DICCA – University of Genoa, Genoa (Italy), Serena.Cattari@unige.it
[8] Ing., Autorità Portuale di Genova, Genoa (Italy), a.pieracci@porto.genova.it

resonance effects during earthquakes. Moreover, in urban environments like historic towns, where nearby buildings may oscillate in the same frequency range, constructive interference may occur during earthquakes, thus producing an increase of the shaking level in that particular range of frequencies (Gallipoli et al., 2004). Therefore, the knowledge of the soil-structure response and the knowledge of the interaction of building vibrations on ground motion are fundamental to mitigate structural damage and, consequently, economic and human loss during strong earthquakes.

In this article, we investigate the effectiveness of the H/V spectral ratio technique to study the response of structures by analysing the data recorded in three buildings in the historic centre of the city of Genoa (Northwestern Italy) during the blasting excavation of the sea bed in the city harbour. H/V ratios from microtremors are compared with those from blast recordings and, for one site where a reference station was installed on the ground level, with SSRs. For this site, the floor spectra computed from the recordings of the October 3, 2012 Piacenza earthquake (M_l = 4.5) are also analysed in order to make observations about the effectiveness of analytical approaches in simulating filtering effects.

The historical centre of Genoa is the widest in Europe. It has been developed from the 12nd to the 17th centuries through an intensive building activity within an area just behind the ancient harbour and closed by the defensive town walls (Grossi Bianchi, 2005). Buildings, which were originally in Gothic forms, made by thick stone masonry walls, with vaults at the lower stories and timber floors, have been continuously transformed by extension and raising. Some technical solutions, such as the systematic use of iron tie rods or the progressive projections of the façades (to increase the available internal space), are recurrent. The lack of available space within the town walls forced to increase the building height (most of them are 7 to 8 storeys buildings) and to narrow the width of the pedestrian streets (named “caruggi”). The difficulty of transporting building material limited demolitions and pushed the reuse of materials. From the late 16th century, when the Republic of Genoa was at the height of its financial and seafaring power, the system of the “Palazzi dei Rolli” (Rolli palaces), which were public lodging in private residences, was developed; 42 Renaissance and Baroque buildings of the 114 Rolli palaces are in the World Heritage List of UNESCO. Most of ordinary buildings in the historical centre are of good workmanship, because rich people had the opportunity of investing money in their estates. The good quality of these buildings under static actions has been proved by the time, but the assessment of seismic vulnerability, considering the height and the complexity of the buildings, is still an open issue.

DESCRIPTION OF THE EXPERIMENT

During the second half of 2012, many residential buildings and historical monuments dislocated through the historic centre of Genoa were subjected to intense vibrations induced by the excavation and dredging of the sea bed in the Genoa harbour. In particular, the blasting excavation of the sea bedrock (marly limestone) implied the monitoring of the induced vibrations in many historical buildings and churches. Figure 1 shows the location of the monitoring stations (tri-axial velocimetric sensors) superimposed on a simplified geological map. For each site, the figure indicates the maximum value of p.c.p.v. (peak component particle velocity) recorded along the horizontal (Figure 1a) and vertical (Figure 1b) components during the monitoring period, which lasted approximately two months. As evidenced by the figure, the values of p.c.p.v. exceeded the threshold of 3 mm/s provided by the Italian norms (Ente Nazionale Italiano di Unificazione, 2004) only in the vicinity of the blasting area. At distances greater than approximately 400 m from it, the p.c.p.v. values drop below 2 mm/s.

In this study, we apply spectral ratio techniques to investigate the structural response of three buildings: Vico Indoratori 2 (B1), Santa Maria di Castello (B2), and Piazza Cavour 4 (B3). Two of them are civil buildings (B1 and B3) and one (B2) is the monastery complex of Santa Maria di Castello. All these buildings are masonry structures, typical of the historic centre of Genoa.

The vibration modes of the three buildings under study are determined through the analysis of the ratio between the horizontal and vertical components of the spectra recorded at single stations inside the buildings. H/V spectral ratios are calculated both from ambient noise recordings and from blast signals (recorded in time windows of 10 s). These latter are also employed to calculate SSRs at site B3, which was equipped with two monitoring stations, one on the third floor and one at level ground. Specifically, SSRs are computed as the ratio between the corresponding components of the

Fourier spectra of the blasts recorded simultaneously inside the building and by the reference station on the ground floor. For this building, we also analyse the seismogram of the October 3, 2012 Piacenza earthquake (M_l = 4.5), which occurred at approximately 80 km from Genoa. All spectra are smoothed using the Konno and Ohmachi (1998) function with a smoothing coefficient of 20.

The instruments used during the monitoring period were Solgeo Veloget 3D (eigenperiod 1 second) equipped with dataloggers Solgeo Dimas 24 (installed at B1 and B2) and Lennartz LE-3D/5s (eigenperiod 5 seconds) equipped with Lennartz MARSlite (installed at B3). The instruments were placed close to vertical load resisting elements (e.g., walls) with the longitudinal axis (X axis) parallel to the longer side of the building.

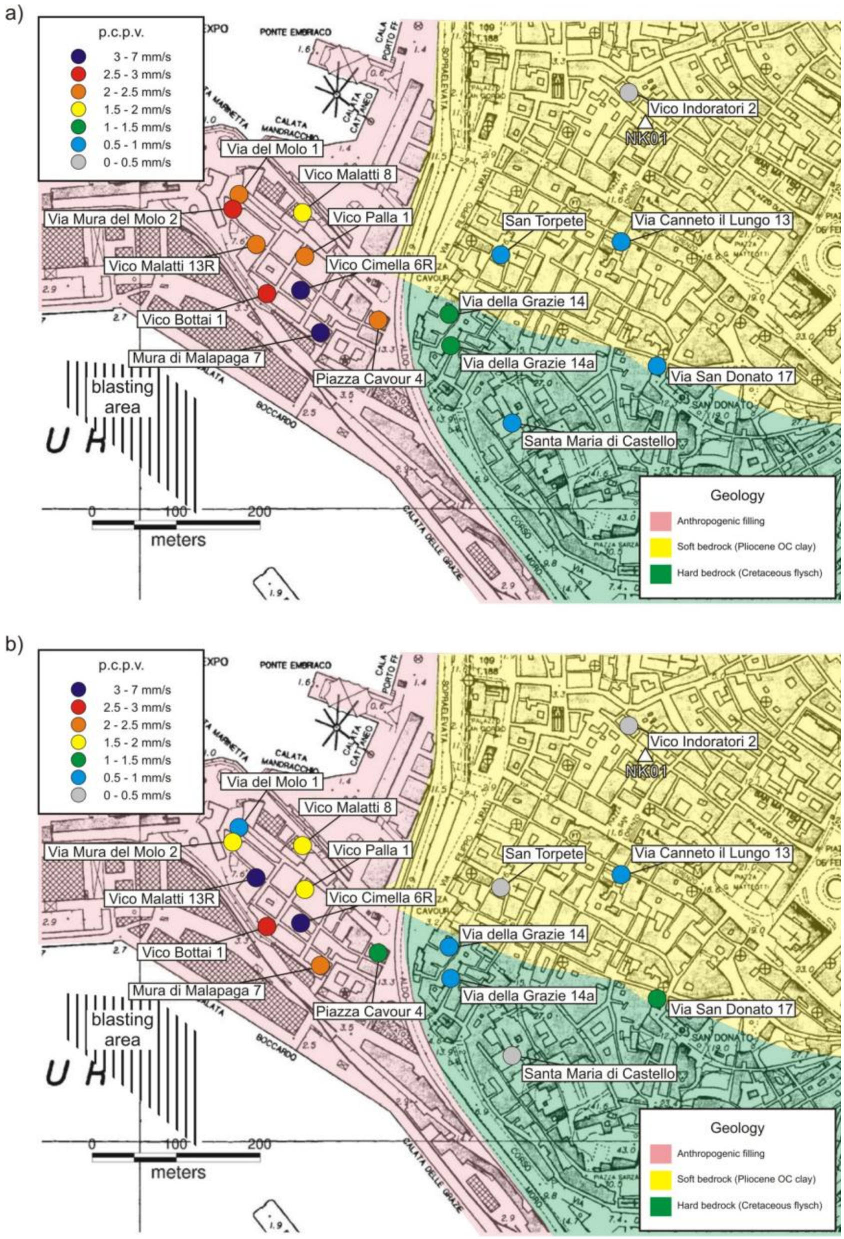
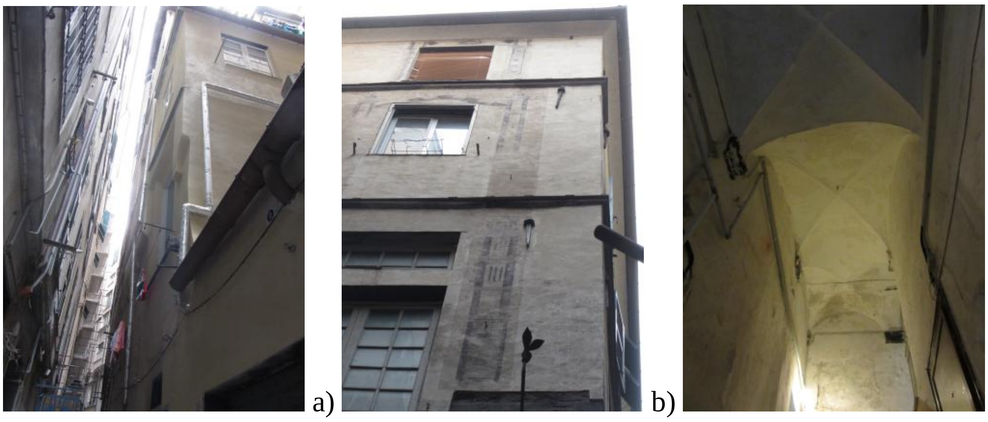


Figure 1. Simplified geological map and maximum p.c.p.v. values recorded on the top floor of each building along the horizontal (a) and vertical (b) components; NK01 indicates a "free field" noise measurement

Before proceeding with the description of the three case studies, we spend a few words about local geology. The knowledge of local geology may be helpful for separating the soil response from that of the adjacent buildings. The historic centre of Genoa is mainly built either on soft rock of Pliocene age or on Cretaceous hard rock (Figure 1). The area close to the harbour is characterized by anthropogenic filling, which lies over the soft and hard bedrock. The former is composed by over-consolidated (OC) clays, which sedimented in an EW-elongated graben developed in the Cretaceous flysch during a tectonic extensional phase (Marini, 1987). The thickness of the OC clays varies from a few meters near the geological contact with the Cretaceous flysch to some tens of meters (more than 50 m) in the central part of the graben.

STRUCTURAL RESPONSE OF B1, VICO INDORATORI 2

This is a four-storey building (Figure 2a) that has been known since the half of the XIII century as it was the birthplace of St. Catherine of Genoa. This is a masonry building characterized by timber floors and vaults (Figure 2c) with a thickness of perimeter walls that varies from 0.5 to 0.6 m; systematic tie rods are present in the upper levels (Figure 2b). Moreover, as typical of buildings of the historic centre of Genoa, it overlooks a very narrow alley. The seismic station was installed on the third floor.



a) b) c)

Figure 2. a) Overview of building B1; b) particular of tie rods in the upper levels; c) masonry vaults of stairwell

Figure 3 shows the amplitude Fourier spectra (top panel) and the H/V spectral ratios (bottom panel) as determined from noise (Figure 3a) and blast recordings (Figure 3b). Both spectral ratios clearly identify a pronounced peak at around 3 Hz, with that derived from noise recordings just shifted towards lower frequency (≈ 2.8 Hz). Besides this marked peak, which can be related to the fundamental eigenmode of the structure, a further amplification effect can be distinguished between around 1.4 Hz and 2.3Hz. This effect is also deducible from the Fourier spectra, particularly from those relative to the transversal component (Y). Is this less pronounced amplification attributable to the building under study (e.g., to the eigenmode along the Y axis) or is it related to the resonance of the soil? To answer this question, two H/V measurements, one on the ground floor of the building (Figure 4a) and one in the free field (Figure 4b), were performed. The term "free field" is used improperly here and, generally, in an urban environment with a high concentration of nearby buildings as in the historic centre of Genoa. In such cases, the fundamental frequency of vibration of the ground from free field measurements near buildings may be influenced by the presence of the structures. In other words, the response of the ground could be masked by the eigenmodes of the adjacent buildings. Therefore, according to Guèguen et al. (2002), it would be advisable to perform ground response measurements at a distance of at least ten times the foundation depth of the structures in the proximity of the free field site. Similarly, Mucciarelli et al. (1996) and Castro et al. (1998) suggest that the influence of a structure vanishes at a distance greater than the height of the structure. However, Gallipoli et al. (2004) show that the influence of a structure remains even at a distance of twice the height of the structure. Unfortunately, there are not real "free field" sites in the vicinity of the building under study. Hence, our free field recording (the measurement site is indicated as "NK01" in Figure 1) may be affected by the vibration of the adjacent buildings. Both Figure 4a and Figure 4b show peaks in the spectral ratios with amplification exceeding two – the threshold for a reliable peak (e.g., Fäcke et al., 2006) – at frequencies of around 1.4-1.8 Hz and 1.7-2.3 Hz, respectively. Given the average height of the buildings in the historic centre of Genoa (18 m), which therefore have a fundamental frequency between 2.5 and 4 Hz (as deduced from period-height relationships), and given the local geology, which presents a deep graben filled by thick OC clays overlapping a rigid bedrock, the amplification observed between 1.4 and 2.3 Hz is presumably related to the response of the ground.

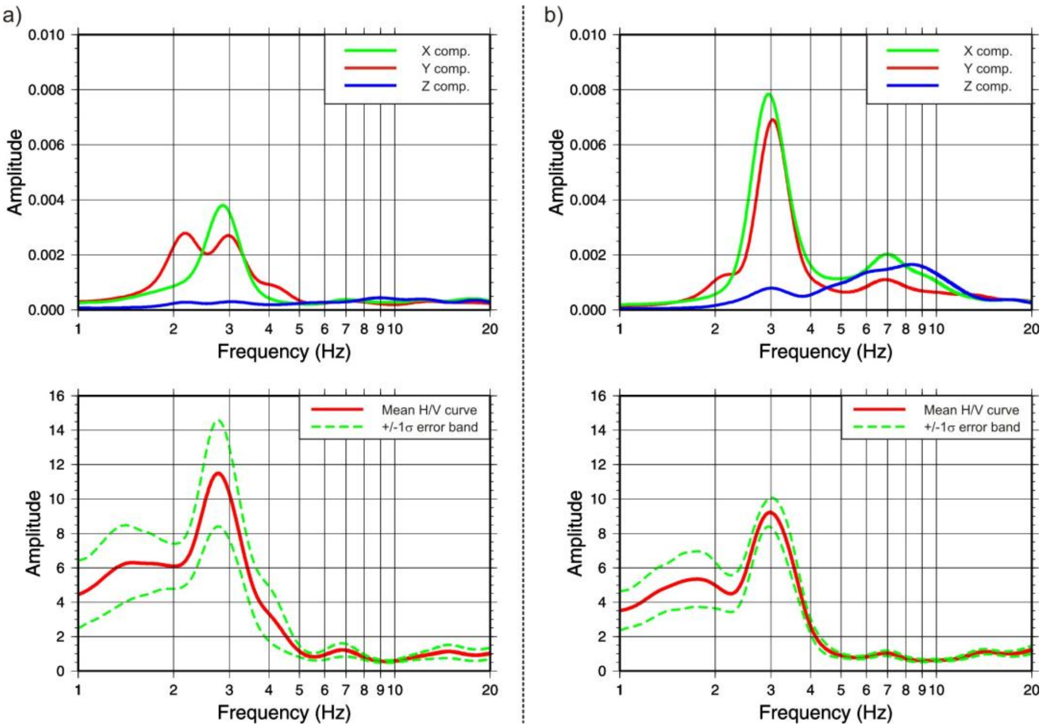


Figure 3. Fourier spectra (top panel) and average H/V spectral ratios (bottom panel) as computed from noise (a) and blast signals (b) recorded at the third floor of building B1

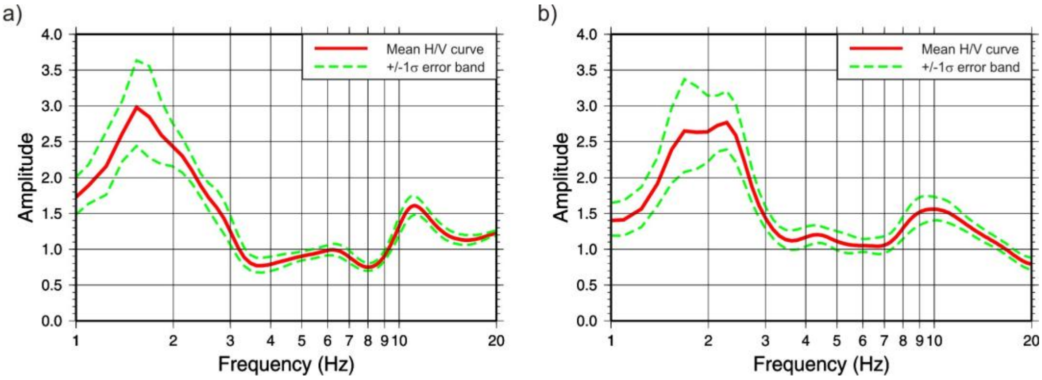


Figure 4. H/V spectral ratios at the basement of building B1 (a) and in the free field (b)

STRUCTURAL RESPONSE OF B2, SANTA MARIA DI CASTELLO

This is a monastery which was built between the IX and X century with a very articulated and complex configuration. Despite its extension and complexity, only one seismometer was installed. The station was placed in a chapel (Grimaldi Chapel) located at a higher level inside the monastery. This location was chosen as, according to the monastery monks, the walls of the chapel started to crack following the blasting activity in the harbour. Note that the monastery was built along a flank of a little rocky hill (see Figure 1). Consequently, its response is presumably not affected by site effects.

The H/V spectral ratios in Figure 5 do not evidence any particular amplification peak. However, a mild amplification, just above or close to a value of two, can be distinguished in a large frequency band, up to approximately 8 Hz. Analysing the Fourier spectra indicates that this amplification is more pronounced along the Y axis. This single measurement is insufficient to exhaustively describe the structural response of a complex historical building as Santa Maria di Castello. Similarly to the study of Fäcke et al., (2006), where the authors assessed the vibrational frequencies of the Cathedral of Cologne (Germany), further ambient noise measurements should be performed in the future in order to investigate in depth the structural response of the key blocks of this important historical monument.

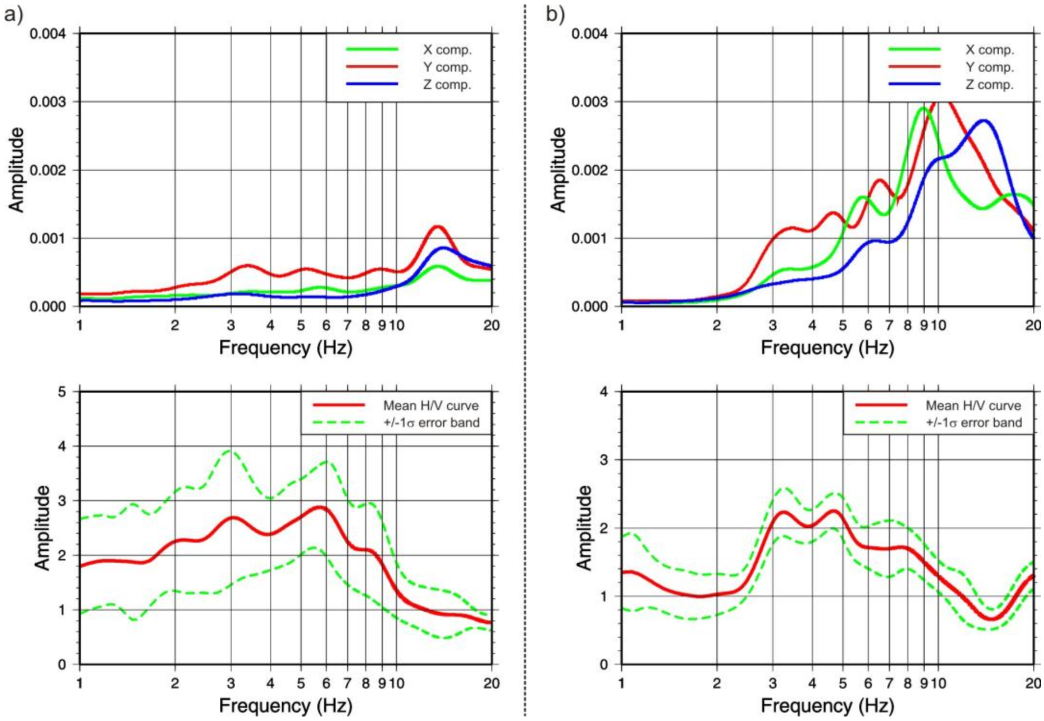


Figure 5. Fourier spectra (top panel) and average H/V spectral ratios (bottom panel) as computed from noise (a) and blast signals (b) recorded inside one key block (Grimaldi Chapel) of building B2

STRUCTURAL RESPONSE OF B3, PIAZZA CAVOUR 4

This is a seven-storey building inserted in a more complex aggregate (Figure 6a). Also in this case systematic tie rods (tracks of ancient and modern interventions) are present at both lower and upper levels; the thickness of perimeter walls varies from about 0.5 to 0.9 m (passing from the ground floor to the top level); some cracks occurred (Figure 6c) during the blasting excavation of the seabed.

The building is located a few meters from the main road. Two seismometers were installed inside the building, one at level ground and one on the third floor. Thus, it was possible to calculate both H/V spectral ratios and SSRs.

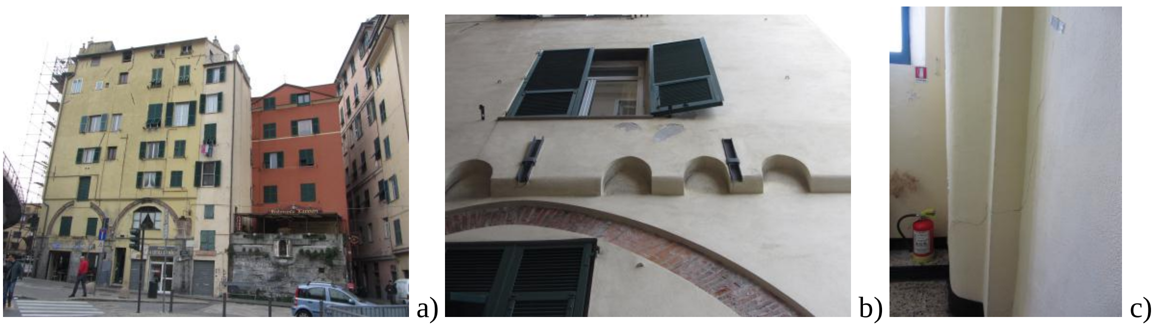


Figure 6. a) View of building B3 (with the yellow façade); b) tie rods track of a modern intervention; c) crack

Figure 7 compares the H/V spectral ratios from ambient noise (Figure 7a) and blast recordings (Figure 7b) for the basement and third floor. The structure shows a fundamental frequency at around 3 Hz. This peak is present both at the basement, where it is just distinguishable, and at the third level, where it is clearly more evident. As known, the higher the level inside a building, the more evident will be the fundamental frequency of the structure. Note that this peak appears shifted towards 4 Hz in the H/V curve determined from noise recordings on the 3rd floor. Analysing the Fourier spectra (not shown here), we can presume that this apparent shift is due to the smoothing level adopted. Besides the 3 Hz peak, the H/V spectral ratios identify two further peaks, at about 7.5 Hz and 11 Hz (this latter peak is more evident from the ambient noise measurements). Examining SSRs (Figure 9, to come), we can exclude that these peaks are generated by the resonance of the ground. As known, SSRs have the advantage of deleting the influence of the soil cover, which could mask some eigenfrequencies of vibration of the building. Although the cause of these peaks remains uncertain, the former could be related to the second mode of vibration of the structure while the latter could be indicative of the response of the building to traffic noise (Beijing Jiaotong University, 2007; Luo et al., 2008).

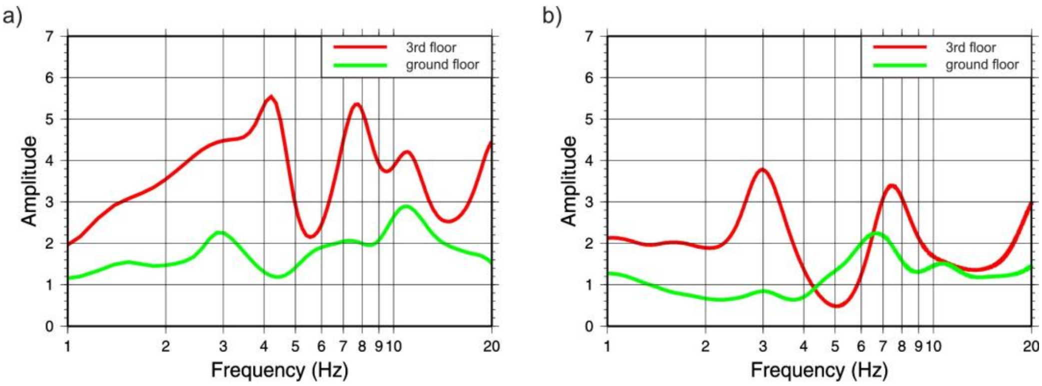


Figure 7. Average H/V spectral ratios at the basement and third floor of building B3 as computed from ambient noise (a) and blast recordings (b)

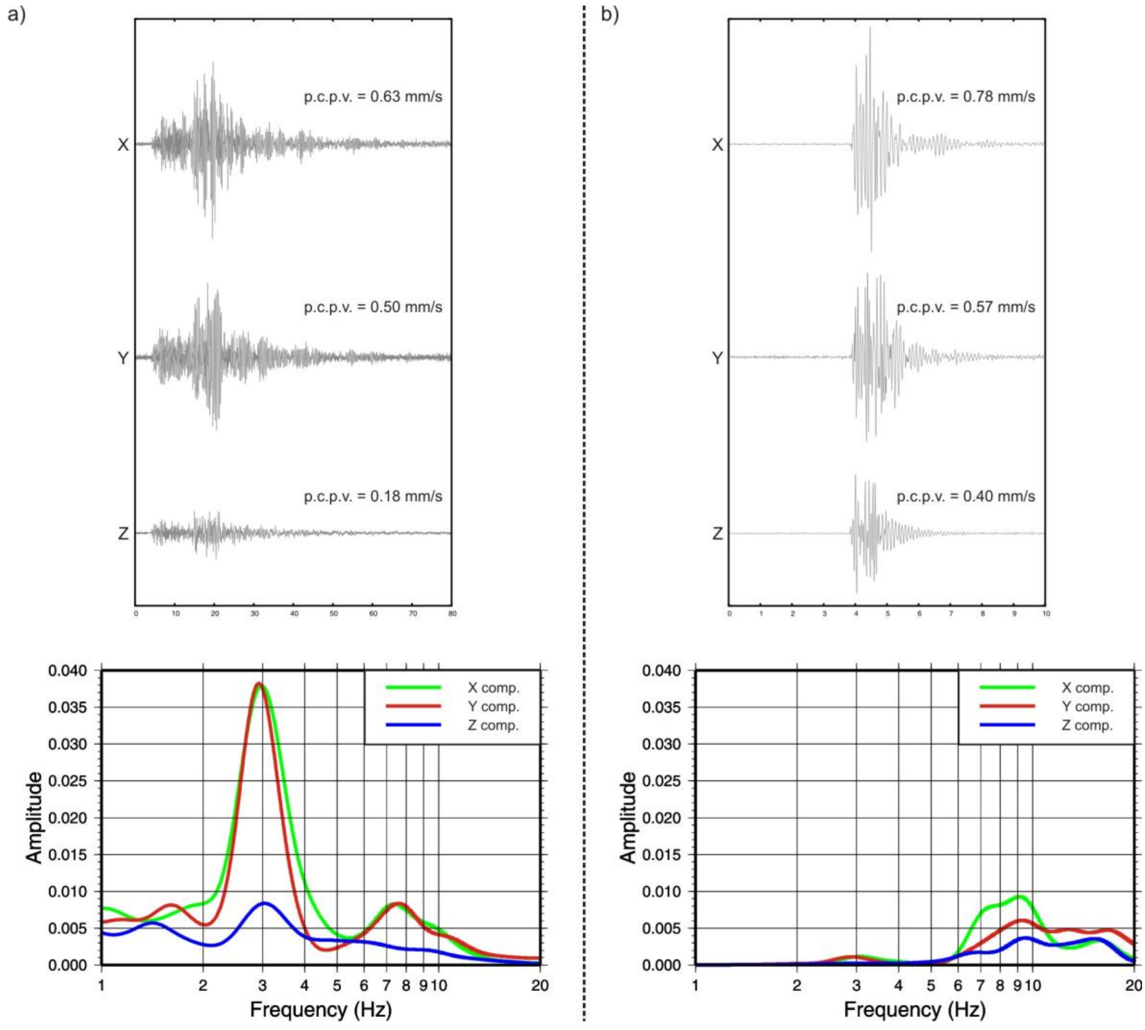


Figure 8. Comparison between the time histories (top panel) and Fourier spectra (bottom panel) of the October 3, 2012 Piacenza earthquake (a) and those of a blast (b) recorded on the third floor of building B3

Before examining SSRs, it could be of interest comparing a blast recording with the signal of the October 3, 2012 Piacenza earthquake (M_l = 4.5), which was recorded at the same location (third floor) inside the building (Figure 8). The figure clearly evidences the different frequency content of the two recordings and, above all, the different behaviour of the monitored building to the incoming motion. Specifically, the amplitude spectra (bottom panel of Figure 8) relative to the earthquake recordings are dominated by frequencies around 3 Hz (this is particularly evident for the horizontal components). On the other hand, the frequency content of the time series produced by the rock blasting is dominated by frequencies between 6.5 and 10 Hz.

Figure 9 show the SSRs obtained for the two horizontal components separately (Figure 9a and 9b) and for the vertical one (Figure 9c). The SSR based on the recordings of the Piacenza earthquake is also shown for comparison. Again, one can clearly distinguish the first eingenfrequency of vibration of the building (≈ 3-3.2 Hz) and the two secondary peaks mentioned above (≈ 7.5 Hz and ≈ 11 Hz). Note, however, the difference in the amplitude of the peaks obtained from H/V spectra ratios (see Figure 7) and SSRs. All these peaks are clearly evident along both the horizontal components but can also be discerned from the SSR relative to the vertical axis where, however, are just pronounced.

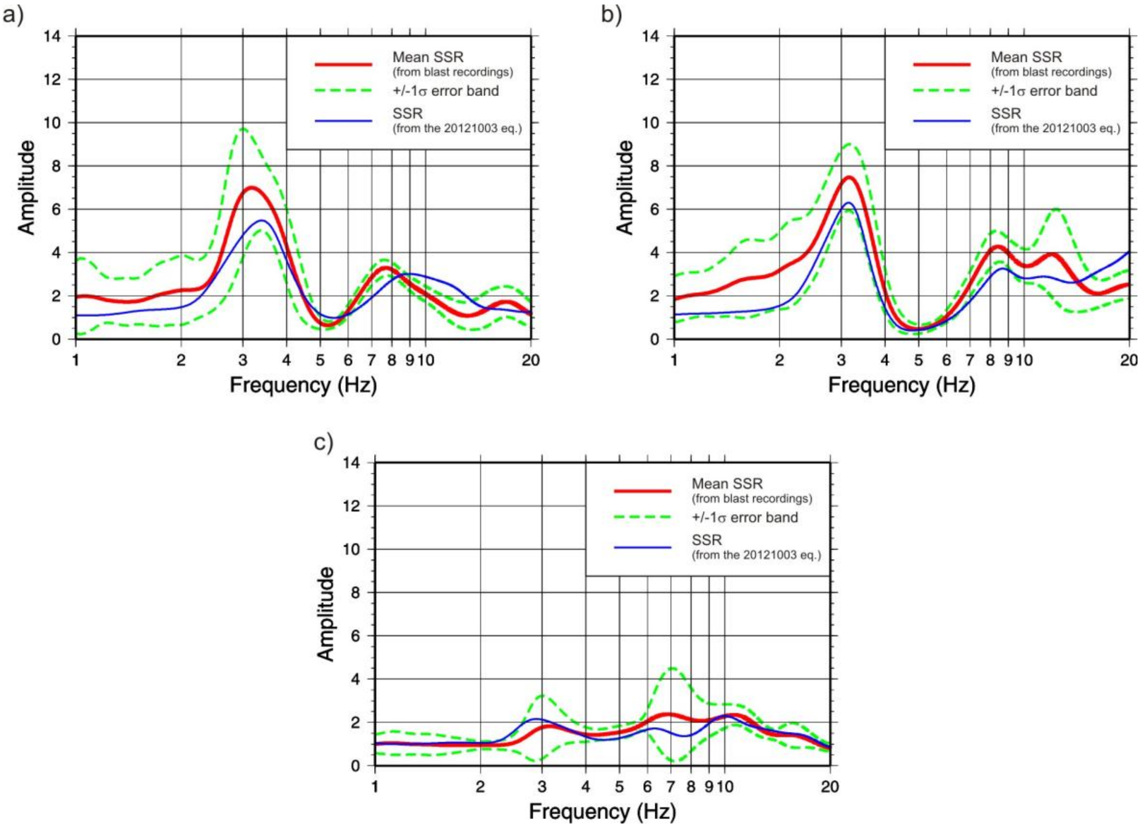


Figure 9. Standard spectral ratios along X (a), Y (b), and Z (c) directions

ANALYSIS OF FILTERING EFFECTS FOR THE SEISMIC ASSESSMENT

Because of the seismic vulnerability of masonry structures, the seismic assessment and the protection of historical centres is a very important and complex topic. The seismic behaviour of this kind of structures is influenced by numerous factors deriving from their articulated configurations, which are often the result of different spontaneous transformations stratified during their life time. Hence, they are often prone to the activation of out-of-plane mechanisms (Figure 10), which may cause structural failures for the loss of equilibrium of local portions.

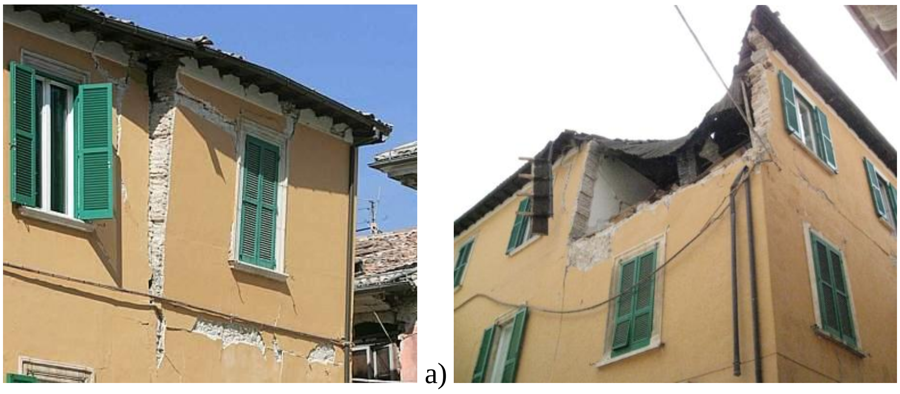

a) b)

Figure 10. Example of local mechanism in a masonry building: a) after the activation and b) until the complete collapse (L'Aquila earthquake, 2009)

A standard approach to analyse such type of response is the adoption of Macro Block Models (MBM) and a nonlinear kinematic analysis for the seismic assessment according to a displacement-based approach (Lagomarsino, 2014). According to the MBM modelling strategy, the local portions of the masonry involved in the mechanism are assumed to behave as rigid blocks. The application of a kinematic approach requires the "a priori" definition of the collapse mechanism, which derives from an in-depth analysis of the constructive features of the urban fabric (e.g., presence of thrusting elements of roofs, quality of connection wall-to-wall and wall-to-floor, effectiveness of steel tie rods).

Besides the issues related to the modelling and assessment procedures, since local mechanisms generally involve masonry portions placed in the upper part of a building, an important issue is that related to the adoption of proper spectra taking into account the filtering effect provided by the structure (namely *floor spectra*). Starting from the analytical floor spectra originally proposed by Suarez and Singh (1987), some approximate formulations have been derived and proposed by Curti (2007) and Lagomarsino (2014). Also in MIT (2009) some analytical expressions are proposed. In such context, the measurements and experimental data discussed in the previous sections are particularly useful to validate such analytical formulations and to calibrate, in a more reliable way, the filtering effect provided by the examined structures. To this end, by way of example, the recordings of the October 3, 2012 Piacenza earthquake are processed in order to compute the corresponding acceleration spectra at the base and third level of building B3 (Figure 11). It is possible to observe two main amplifications in the floor spectrum in correspondence of the fundamental period ($T_1 \approx 0.33$ s) and the second mode ($T_2 \approx 0.13$ s) of the structure, being these values in agreement also with those discussed in the previous section.

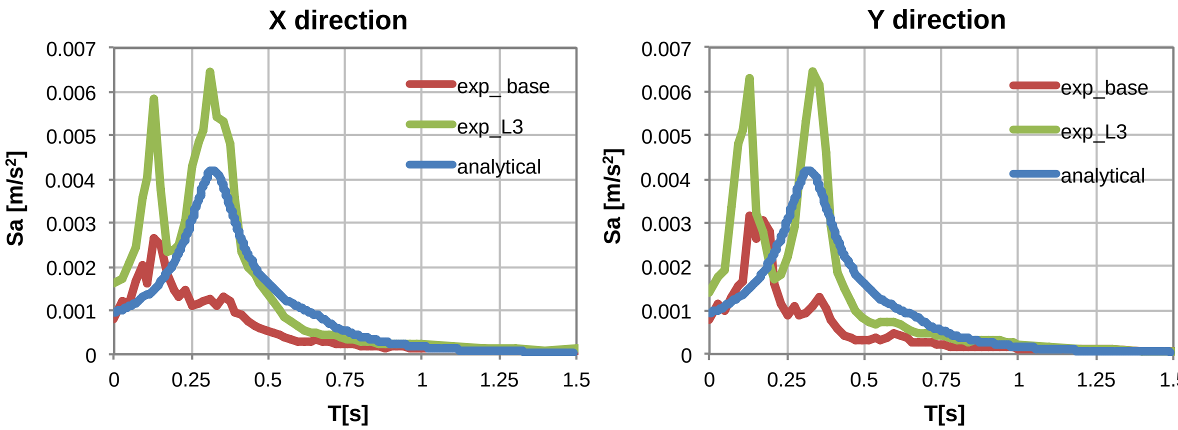


Figure 11. Comparison between the analytical floor spectrum and the acceleration response spectra relative to the October 3, 2012 Piacenza earthquake

In order to verify the reliability of the aforementioned expressions proposed in the literature, the floor spectrum obtained from the experimental results has been compared with the analytical formulation recently proposed by Lagomarsino (2014), which expresses the displacement response spectrum $S_{dZ}(T)$ of the filtered acceleration time history at a level *z* of the building as:

$$S_{dZ}(T,z) = \max\left[S_d(T); \sum_{1}^{r} S_{dZ,k}(T,z) \right] \qquad (1)$$

where $S_d(T)$ is the displacement response spectrum of the ground motion; *r* is the number of building modes considered; $S_{dZ,k}(T,z)$ is the contribution of mode *k*.

Starting from the more general formulation of $S_{dZ,k}(T,z)$ proposed in the article of Lagomarsino (2014), it is possible to compute the values of the spectral acceleration in $T = 0$ s and $T = T_k$ as follows:

$$S_a(0) = \gamma_k \left|\psi_k(z)\right| S_a(T_k) \qquad (2)$$

$$S_a(T_k) = \frac{\gamma_k \left|\psi_k(z)\eta(\zeta)\eta(\zeta_b)\right| S_a(T_k)}{\sqrt{0.05}} \qquad (3)$$

where T_k, ψ_k and γ_k are the period, modal shape and coefficient of participation of mode *k*, respectively; η is a damping correction factor [e.g., assumed as proposed in Eurocode 8 (CEN, 2005)]; ξ_b is the damping of the building and ξ that of the mechanism. The coefficient of participation may be estimated by the approximate formula $3N/(2N+1)$, being *N* the number of stories.
By assuming ψ_k equal to 0.7 and a damping correction factor equal to 1 (since the response is analyzed in elastic phase), expressions (2) and (3) provide values of $S_a(0)$ and $S_a(T_1)$ equal respectively to 0.0009 and 0.00418 m/s^2. The complete acceleration spectrum, which accounts for the contribution of the first mode only, is plotted in Figure 11. This assumption justifies the lower value of amplification estimated by the analytical floor spectrum with respect to the experimental ones.

CONCLUSIONS

In this study spectral ratio techniques have been applied to study the response of three buildings in the historic town of Genoa using noise and blast recordings. While the results for each single building are presented in the previous sections, we want here to make general considerations, remarking what known both in the scientific literature and in the engineering practice:

1. H/V spectral ratios from noise recordings are consistent with those calculated using blast signals, thus indicating that the eigenfrequency of vibration of a structure is insensitive to source signal (i.e., input excitation). Note, however, that changes in the resonance frequencies may occur due to building damage after strong earthquakes.
2. Although ambient noise H/V measurements represent an economical and flexible alternative to SSRs, because of the less equipment involved and because no earthquake recordings are needed, they could lead to misleading results in the sense that it may not be possible to distinguish the eigenfrequencies of the building from the resonance frequencies of foundation soil (unless they are known from free field measurements). Therefore, the application of the SSR technique may be preferable in densely urbanized environments where free field H/V measurements may be affected by the presence of buildings.
3. The amplitude of the peaks obtained from H/V spectral ratios differ from those determined by using a reference station. As a consequence, H/V curves can not be assumed as representative of the absolute amplification level.

4. H/V spectral ratios and SSRs may be very useful to support the seismic assessment of buildings, in order to calibrate both numerical models and the seismic demand to be adopted in the evaluation of local mechanisms that involve the upper parts of the structures.

A final comment regards the filtering effect of buildings, topic which was briefly examined here keeping into account the case study of the Piazza Cavour site. Despite the simplified approach used, the comparison of the experimental floor spectra with the analytical ones has shown the promising capabilities of the analytical approach adopted in this study.

REFERENCES

Bard PY (1999) "Microtremor measurements: a tool for site effect estimation?", *State-of-the-art paper, Second International Symposium on the Effects of Surface Geology on seismic motion*, Yokohama, December 1-3, 1998, Irikura, Kudo, Okada & Sasatani, (eds), Balkema 1999, 3:1251-1279

Beijing Jiaotong University (2007) "Report on cultural relic protection along the subway line"

Bindi D, Parolai S, Spallarossa D, Cattaneo M (2000) "Site effects by H/V ratio: comparison of two different procedures", *Journal of Earthquake Engineering*, 4(1):97-113

Borcherdt RD (1970) "Effects of local geology on ground motion near San Francisco Bay", *Bulletin of the Seismological Society of America*, 60(1):29-61

Castro RR, Mucciarelli M, Pacor F, Federici P, Zaninetti A (1998) "Determination of the characteristic frequency of two dams located in the region of Calabria, Italy", *Bulletin of the Seismological Society of America*, 88(2):503-511

CEN (2005) Eurocode 8: Design of structures for earthquake resistance - Part 3: Assessment and retrofitting of buildings. EN1998-3:2005. ComitéEuropéen de Normalisation, Brussels

Curti E (2007) Seismic vulnerability of bell towers: mechanical and macroseismic models, Ph.D. Thesis, University of Genoa, Italy (in Italian)

Ente Nazionale Italiano di Unificazione (2004) "UNI 9916, Criteria for the measurement of vibrations and the assessment of their effects on buildings", Milan, Italy

Fäcke A, Parolai S, Richwalski SM, Stempniewski L (2006) "Assessing the vibrational frequencies of the Cathedral of Cologne (Germany) by means of ambient seismic noise analysis", *Natural Hazards*, 38:229-236

Gallipoli MR, Mucciarelli M, Castro RR, Monachesi G, Contri P. (2004b) "Structure, soil-structure response and effects of damage based on observations of horizontal-to-vertical spectral ratios of microtremors", *Soil Dynamics and Earthquake Engineering*, 24:487-495

Gallipoli MR, Mucciarelli M, Tropeano M, Gallicchio S, Lizza C (2004a) "HVSR measurements in the area damaged by the 2002 Molise, Italy earthquake", *Earthquake Spectra*, 20:81-94

Gallipoli MR, Mucciarelli M, Vona V (2009) "Empirical estimate of fundamental frequencies and damping for Italian buildings", *Earthquake Engineering and Structural Dynamics*, 38, 973-988

Gosar A (2007) "Microtremor HVSR study for assessing site effects in the Bovec basin (NW Slovenia) related to the 1998 M_w5.6 and 2004 M_w5.2 earthquakes", *Engineering Geology*, 91:178-193

Guéguen P, Bard P-Y, Chavez-Garcia FJ (2002) "Site-city seismic interaction in Mexico City-like environments: an analytical study, *Bulletin of the Seismological Society of America*, 92(2):794-811

Grossi Bianchi L (2005) "Abitare alla moderna. Il rinnovo architettonico a Genova tra XVI e XVII secolo", All'Insegna del Giglio Ed. (in Italian), ISBN 88-7814-497-5

Hans S, Boutin C, Ibraim E, Roussillon P (2005) "In situ experiments and seismic analysis of existing buildings. Part I: experimental investigations", *Earthquake Engineering and Structural Dynamics*, 34(12):1513-1529

Konno K. Ohmachi T (1998) "Ground-motion characteristics estimated from spectral ratio between horizontal and vertical components of microtremors", *Bulletin of the Seismological Society of America*, 88(1):228-241

Lachet C, Bard PY (1994) "Numerical and theoretical investigations on the possibilities and limitations of Nakamura's technique", *Journals of Physics of the Earth*, 42:377-397

Lagomarsino S (2014) "Seismic assessment of rocking masonry structures", *Bulletin of Earthquake Engineering*, doi:10.1007/s10518-014-9609-x

Lermo J, Chavez-Garcia FJ (1993) "Site effect evaluation using spectral ratios with only one station", *Bulletin of the Seismological Society of America*, 83(5):1574-1594

Lermo J, Chavez-Garcia FJ (1994) "Are microtremors useful in site response evaluation?", *Bulletin of the Seismological Society of America*, 84(5):1350-1364

Luo G, Liu L, Qi C, Chen Q, Chen Y (2008) "Structural response analysis of a reinforced concrete building with the excitation of microtremors and passing subway trains", *Proceedings of the 14th World Conference on Earthquake Engineering*, Beijing, China, 12-17 October

Marini M (1987) "Le deformazioni fragili del Pliocene Ligure. Implicazioni nella geodinamica alpina*", Memorie della Società Geologica Italiana*, 29:157-169.

Massa M, Marzorati S, Ladina C, Lovati S (2010) "Urban seismic stations: soil–structure interaction assessment by spectral ratio analyses", *Bulletin of Earthquake Engineering*, 8:723-738

MIT – Ministry of Infrastructures and Transportation (2009), Circ. C.S.Ll.Pp. No. 617 of 2/2/2009. Istruzioni per l'applicazione delle nuove norme tecniche per le costruzioni di cui al Decreto Ministeriale 14 Gennaio 2008. G.U. S.O. n.27 of 26/2/2009, No. 47 (in Italian)

Mucciarelli M (1998) "Reliability and applicability range of the Nakamura's technique", *Journal of Earthquake Engineering*, 2(4):625-638

Mucciarelli M, Bettinali F, Zaninetti A, Mendez A, Vanini M, Galli P (1996) "Refining Nakamura's technique: processing techniques and innovative instrumentation", *Proceedings of XXV General Assembly of the European Seismological Commission*, Reykjavik, Iceland, 9-14 September, 411-416

Mucciarelli M, Gallipoli MR (2001) "A critical review of 10 years of Nakamura technique", *Bollettino di Geofisica Teorica e Applicata*, 42(3-4):255-256

Nakamura Y (1989) "A method for dynamic characteristics estimations of subsurface using microtremors on the ground surface", *Quarterly Rep. RTRI Jpn.*, 30(1):25-33

Nakamura Y, Gurler ED, and Saita J (1999) "Dynamic characteristics of leaning Tower of Pisa using microtremor-preliminary results", *Proceedings of the 25th JSCE Earthquake Engineering Symposium*, 2:921-924

Parolai S, Bormann P, Milkereit C (2001) "Assessment of the natural frequency of the sedimentary cover in the Cologne area (Germany) using noise measurements", Journal of Earth. Eng., 5(4):541-564

Parolai S, Fäcke A, Richwalski SM, Stempniewski L (2005) "Assessing the vibrational frequencies of the Holweide Hospital in the city of Cologne (Germany) by means of ambient noise analysis and FE-modelling", *Natural Hazard*, 34(2):217-230.

Parolai S, Orunbaev S, Bindi D, Strollo A, Usupaev S, Picozzi M, Di Giacomo D, Augliera P, D'Alema E, Milkereit C, Moldobekov B, Zschau J (2010) "Site Effects Assessment in Bishkek (Kyrgyzstan) Using Earthquake and Noise Recording Data", *Bulletin of the Seismological Society of America*, 100(6):3068-3082

Parolai S, Richwalski SM, Milkereit C, Bormann P (2004) "Assessment of the stability of H/V spectral ratios from ambient noise and comparison with earthquake data in the Cologne area (Germany)", *Tectonophysics*, 390:57-73

Suarez LE, Singh MP (1987) "Floor Response Spectra with Structure-Equipment Interaction Effects by a Mode Synthesis Approach", *Earthquake Engineering and Structural Dyn*amics, 15(2):141-158