ANNALS OF GEOPHSICS, 61, 2, SE218, 2018; doi: 10.4401/ag-7703

"SITE SEISMIC RESPONSE FOR A STRATEGIC BUILDING IN THE CITY OF MESSINA BY TWO-DIMENSIONAL FINITE ELEMENT ANALYSIS"

Piera Paola Capilleri[1,*], Maria Rossella Massimino[1], Ernesto Motta[1], Maria Todaro[1]

[1] Department of Civil Engineering and Architecture (DICAR), University of Catania, Catania, Italy

Article history
Receveid March 13, 2017; accepted February 2, 2018.
Subject classification:
FEM analysis; Seismic response; Earthquake; Amplification factors; Hazard.

ABSTRACT

It is well recognized that local seismic effects can exert a significant influence on the distribution of damages during earthquakes. Traditionally, these effects have been studied by means of simple one-dimensional (1-D) models of seismic wave propagation which take only the influence of the stratigraphic profile and soil/bedrock properties into account on the seismic response. Conversely, local effects derived from surface topography such as ridge, cliffs etc., which are typically two-dimensional (2-D) and three-dimensional (3-D) problems, have received less attention because of computational time, lack of experimental data and the need of more refined models. It is therefore of great interest to quantitatively evaluate the relative contribution on seismic response of stratigraphic as well as of topographic effects, which can be very different depending on the specific morphological conditions and geotechnical characteristics of the site.

1. INTRODUCTION

In the last 900 years, the east coast of Sicily has been struck by several disastrous earthquakes. Many towns were destroyed or severely damaged during the above-mentioned earthquakes. Since this area is densely populated and the seismicity produces a high hazard, these factors cause a great seismic risk in the region. On December 28, 1908, a devastating earthquake, also known as the Messina Earthquake, occurred along the Messina Straits. This event caused severe ground shakings throughout the region, triggered a local tsunami, which struck within minutes and destroyed about ninety percent of the existing buildings in Messina [Barbano et al., 2005] with the worst damage in the central and northern parts of the city. It still today remains the earthquake that killed the largest number of people in Europe [RMS Special Report, 2008]. Figure 1 shows an image of the disaster happened at that time in an area where many public buildings are located now. The main damage occurred in the sites characterized by soft foundation soils.

As it is well known, the site seismic response is strongly influenced by stratigraphic and topographic features. Infact site geotechnical properties [e.g. Capilleri and Maugeri, 2008; Lai et al., 2009; Cavallaro et al., 2013a; Cavallaro et al., 2013b; Capilleri et al., 2014; Imposa et al. 2016; Castelli et al., this issue] and topographic conditions [e.g. Biondi et al., 2004; Biondi and Maugeri, 2005] , can reduce or amplify the earthquake induced ground motion. For this reason, in the design or in the seismic urban upgrading, a proper study aimed to the seismic response is recommended. This paper describes the results of a two-dimensional seismic response for a site, in the central part of Messina (Sicily), where a "strategic" building is located. The building concerned is the Regional Department of Civil Protection (DRPC) that is a reference building for emergency management in the case of natural disasters.

2. SITE CHARACTERIZATION

The site under study is located on the lowest part of the slopes of Peloritani Mts, within an alluvial depression generated by sediments and alluvial cones produced by the streams behind the city. A plan view and a geological cross section of the area of interest with some geological references and with the location of the DRPC building, is

FIGURE 1. Rubble along Solferino street in Messina (Sicily) as a result of the 1908 Messina Earthquake (http://www.rms-republic.com/gallery/Earthquake/adh).

shown in Figure 2. The geological section in Figure 2 indicates that the building is located over a coast alluvial deposit overlying sedimentary and metamorphic rocks.

Soil properties, required for the seismic response analysis, have been defined through two geotechnical surveys including site and laboratory investigations. In the first geotechnical survey, carried out in 2007, three boreholes (S_{V1}, S_{V2} and S_{V3}) were performed with Standard Penetration Tests (SPT). In addition, undisturbed samples were taken for laboratory tests such as soil classification, oedometer and shear tests. In the second geotechnical investigation, carried out in 2014, three further boreholes (S_{N1}, S_{N2} and S_{N3}) have been developed. SPT tests were performed in the boreholes S_{N1}, S_{N2} and S_{N3}, cross-hole (CH) tests in the borehole S_{N1} and S_{N2} and a down-hole (DH) test in borehole S_{N3}. The depth of CH and DH tests was more than 60 meters. In addition, seismic dilatometer tests (SDMT), named "SDMT 1a" and "SDMT 1b", were carried out. The location of SDMT tests and all boreholes of both surveys is shown in Figure 3 together with the plan view of the ground floor of the DRPC building.

Geotechnical soil properties deduced by SPT tests during the site investigation in 2007 are reported in Table 1. The shear wave velocities, deduced from NSPT data range from 100 to 400 m/s while the shear modulus G0 is ranging from 200 up to 2700 kPa. However, except for the first few meters, the shear modulus ranges between about 1000 and 2700 kPa. Friction angle ranges approximately from 30° to 45°. Data of soil properties deduced from laboratory tests can be found in Castelli et al., this issue.

Figure 4 shows the profile of soil parameters deduced from SDMT test, that is material index *Id*, drained constrained modulus *M*, undrained shear strength C_u, friction angles ϕ' and K_d index. The SDMT profiles indicate a silty-sandy soils with a great variation of the drained constrained modulus, ranging from 5 to 120 MPa. Undrained shear strength is very low while the friction angles ranges about between 25° and 40°. Except for the first few meters, the Kd index is about 2.5. Figure 5 refers to shear wave velocities deduced from CH, DH and SDMT tests carried out during the 2014 site investigations [Capilleri et al., 2014]. The SDMT measures are referred to test 1b which was performed up to 30 m while test 1a was stopped at 8 m.

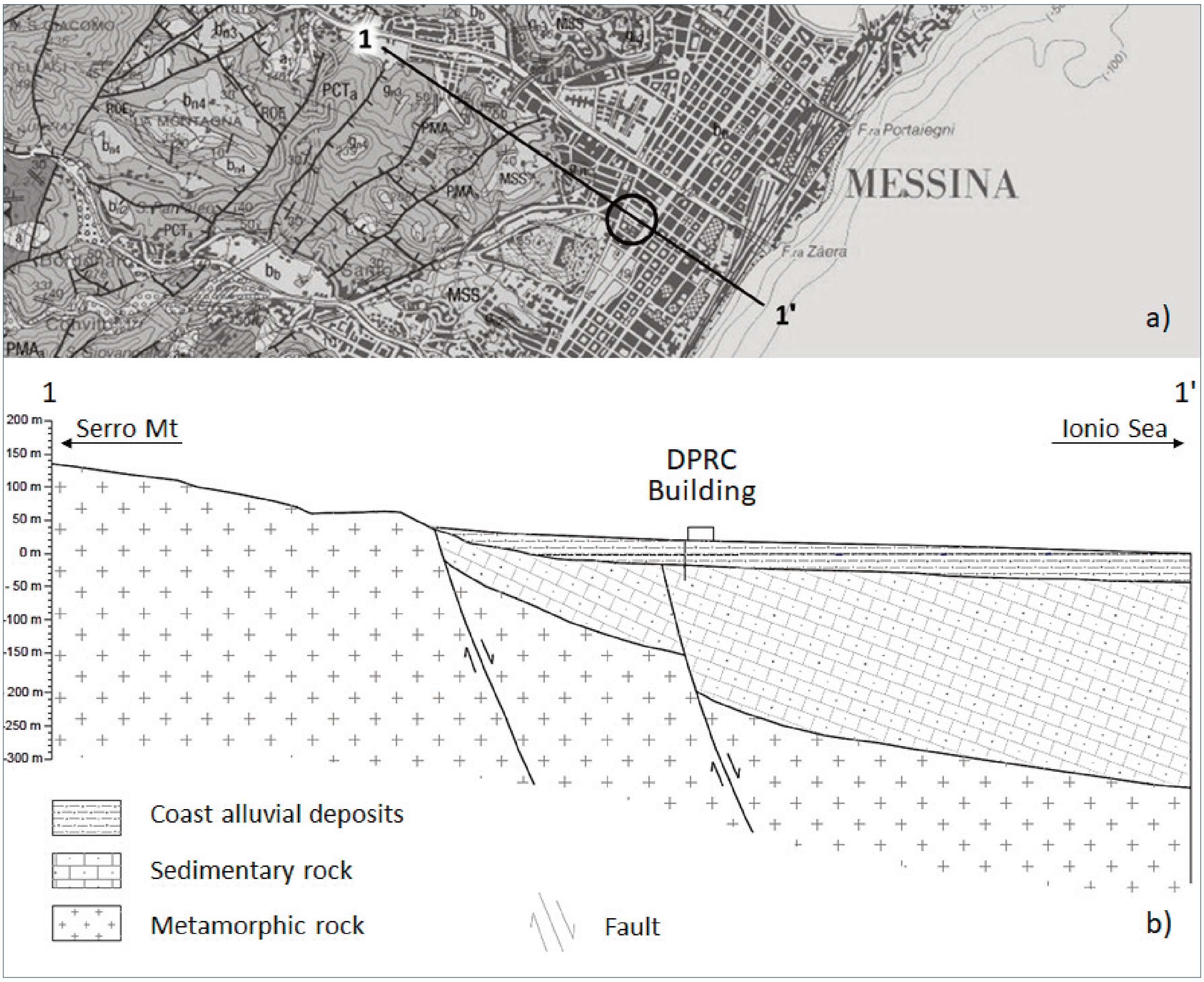

FIGURE 2. Plan view and geological section of the area where the DRPC is located [after Scolaro et al. this issue, modified].

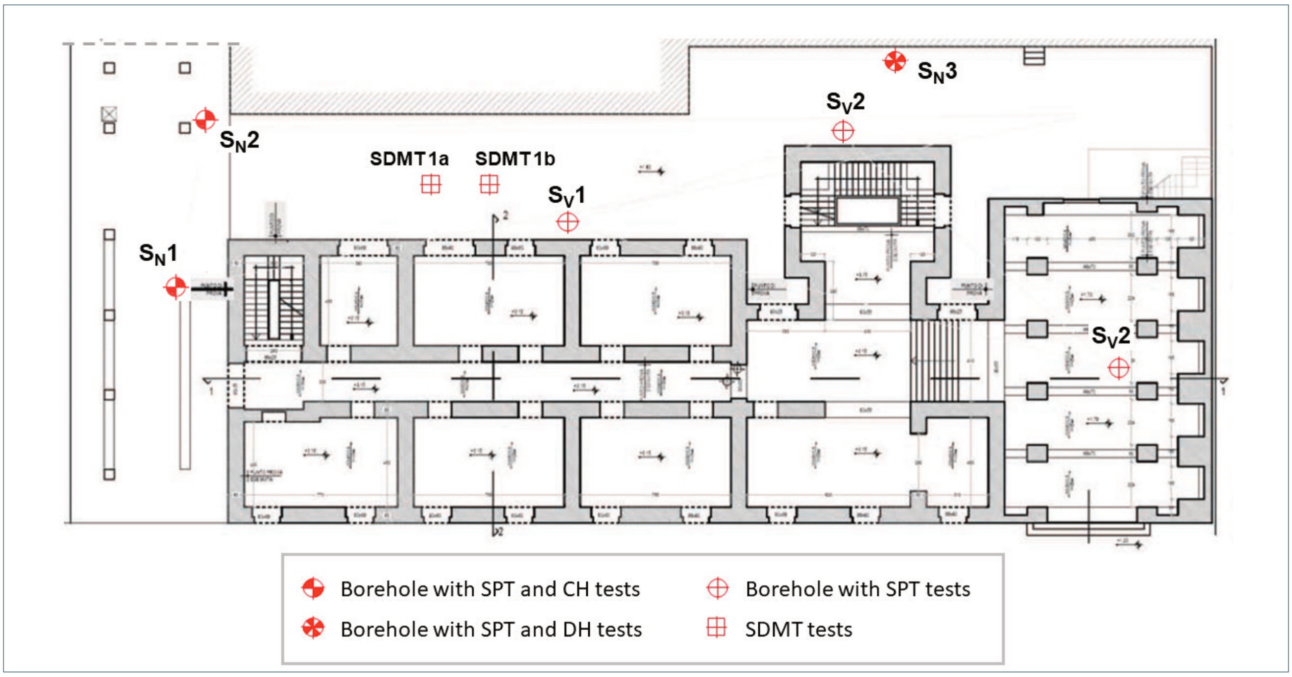

FIGURE 3. Location of boreholes and SDMT tests in the DRPC site.

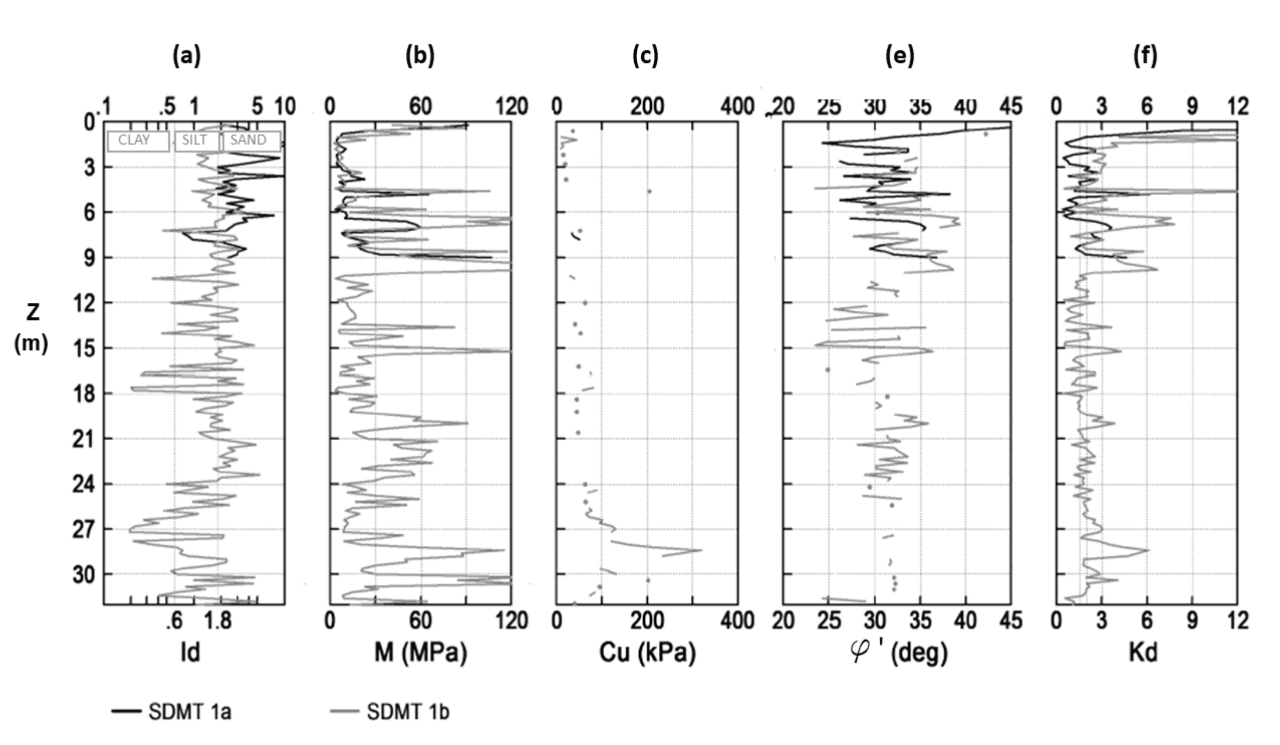

FIGURE 4. Geotechnical parameter deduced from SDMT tests.

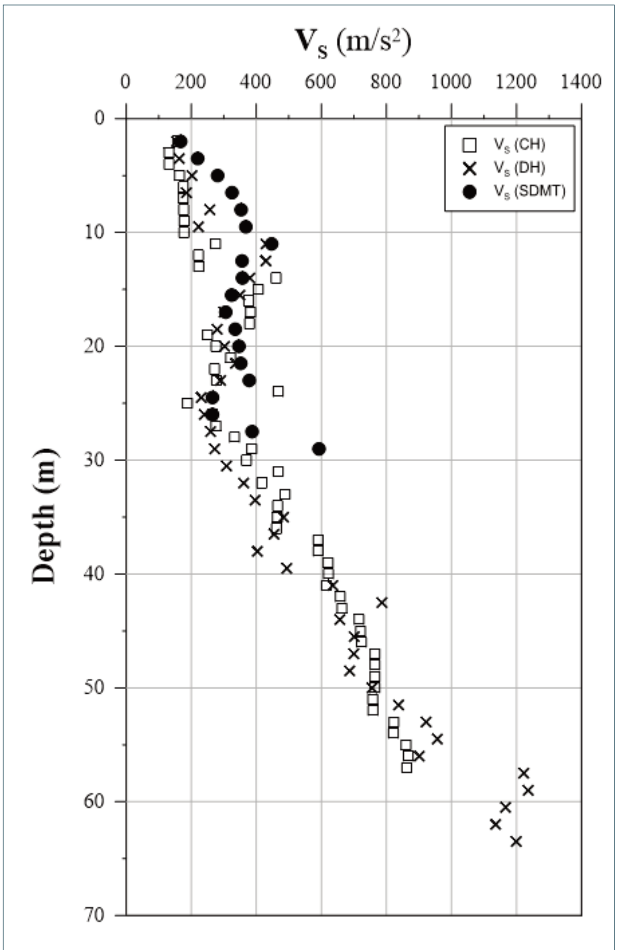

FIGURE 5. Shear wave velocities profile vs depth from different tests.

There is good agreement in shear wave profiles determined by the different tests. CH, DH and SDMT tests show that shear wave velocities are increasing with the depth with a roughly linear way.

3. TWO-DIMENSIONAL SEISMIC RESPONSE ANALYSIS

For the seismic response analysis, the synthetic accelerogram in Figure 6 has been utilized. This, referred to the city of Messina, was chosen on the basis of the study carried out at the university of Messina [Scolaro et al., this issue]. The seismogram was deduced based on source parameters given by Tortorici et al. [1995].

The peak acceleration of the selected accelerogram is about 0.27g, however the analyses have been carried out scaling the accelerogram at the peak values prescribed by Italian seismic code for different limit states (damage, life and collapse). For the unscaled record, the strong motion duration and the Arias intensity are equal to $D_{5\text{-}95}$ = 7.58 s and I_a = 88.7 cm/s, respectively; the number of equivalent loading cycles, evaluated according to the procedure proposed by Biondi et al. [2012], is N_{eq} = 19.1.The maximum values of peak ground acceleration at bedrock a_g considered are listed in Table 2 together with the corresponding return period T_r.

The geometrical model utilized for the 2-D Finite Element Analysis, performed with Plaxis 2-D code, is shown in Figure 7. The analysis was performed considering two different locations of the bedrock, that is at depth 60 and 200 m below the ground surface. The response analyses,

S.	Depth [m]	G [Kg/cm²]	V_s [m/s]	φ [°]
	3.45	239.25	110	29.12
	6.45	2230.35	360.66	40.04
S_V1	9.45	2034.35	343.47	38.92
	12.45	2521.72	385	41.72
	15.45	2714.77	400.41	42.84
	3.45	459.01	155.56	30.24
	6.45	1739.07	315.95	37.24
	9.45	1035	239.74	33.32
S_V2	12.45	1936.52	334.55	38.36
	15.45	2714.77	400.41	42.84
	18.45	2618.36	392.78	42.28
	3.45	880.62	220	32.48
S_V3	6.45	2762.89	404.17	43.12
	9.45	2376.32	373.03	40.88
	15.45	2034.76	343.47	38.92

TABLE 1. Geotechnical parameters deduced from geotechnical investigation.

LIMIT STATE	T_r [year]	a_g [g]
Damage	101	0,118
Life	949	0,332
Collapse	1950	0,440

TABLE 2. Seismic parameters according to Italian seismic code.

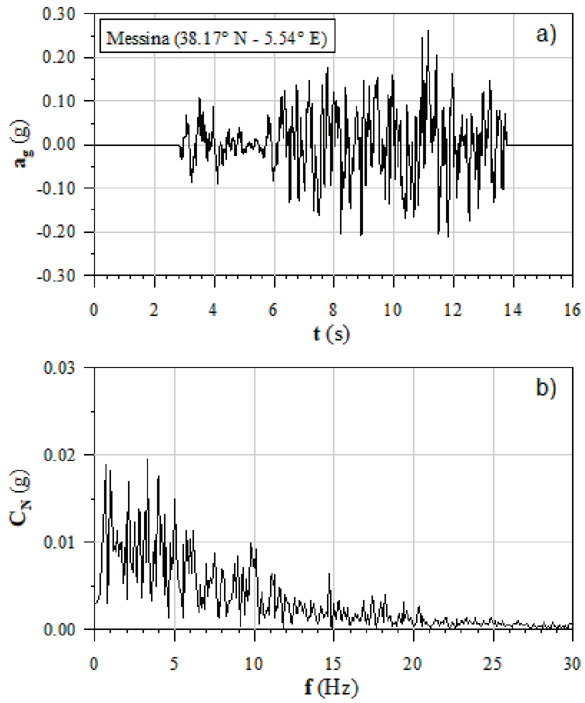

FIGURE 6. Seismic input used in 2-D FEM analysis: a) accelerogram; b) Fourier spectrum.

considering both the depths of the bedrock gave very a similar seismic response, so only the results for the bedrock located at 60 m are presented. The FEM model was meshed using 15-node triangular elements that, allow a more accurate evaluation of soil stresses and deformations than the 6-node triangular mesh [Capilleri et al., 2016; Capilleri et al., this issue].

Two faults are present in the geological section in Figure 2 and, even if preliminary analyses indicated that their presence was not very significant to the seismic response, for a more realistic analysis, these were modelled by interface elements with a Mohr-Coulomb constitutive law. The fault interface parameters are cohesion c'=0, friction angle φ'=35°, young modulus E=300 MPa.

In order to reduce the wave reflections a 1600 m large mesh was utilized [Amorosi et al., 2008; Rizzitano et al., 2015]. In addition, to minimize the outgoing waves from the truncated lateral sides, viscous adsorbent boundaries were introduced, based on the method described by Lysmer

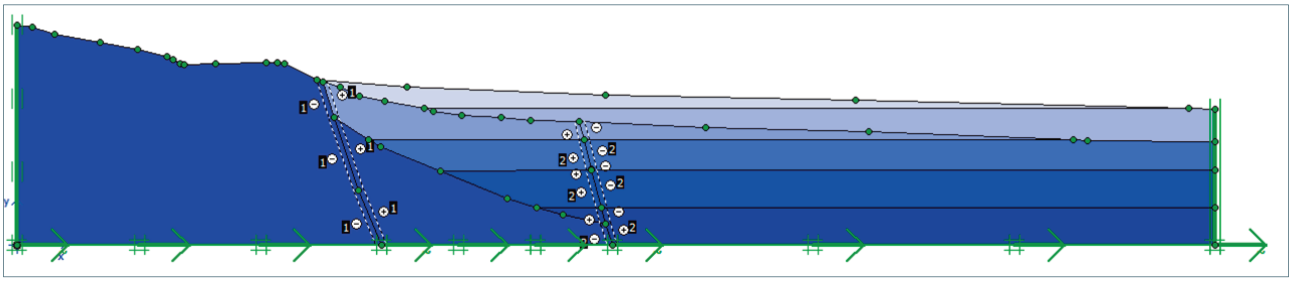

FIGURE 7. Geometrical model utilized in the FEM analysis.

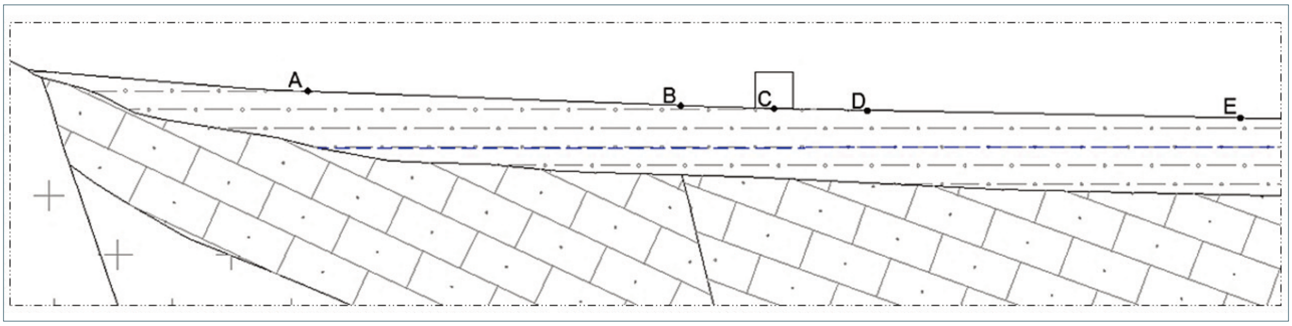

FIGURE 8. Location of points A, B, C, D and E.

and Kuhlmeyer [1969]. For an accurate representation of wave transmission through the soil model, the spatial element size was set around 1/8 of the wavelength associated with the highest frequency component of input wave [Kuhlemeyer and Lysmer, 1973]. A non-linear finite element analysis was utilized and the material damping was simulated with the well-known Rayleigh formulation [Lanzo and Silvestri, 1999; Lanzo et al., 2004, Capilleri et al. 2005]. To define Rayleigh coefficients, α_R e β_R, a initial damping ratio D = 5% was utilized and the same procedure used in Capilleri et al. [this issue] has been applied.

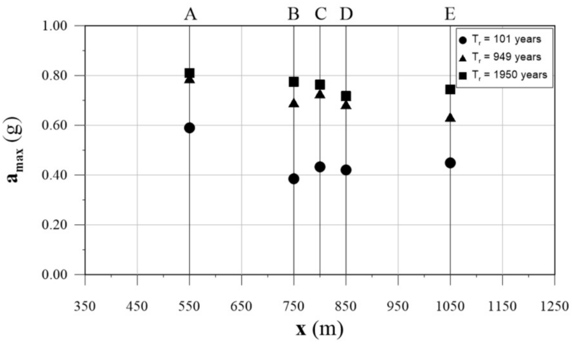

FIGURE 9. Peak accelerations values computed at the different selected points (A, B, C, D, E) and for different return periods (Tr).

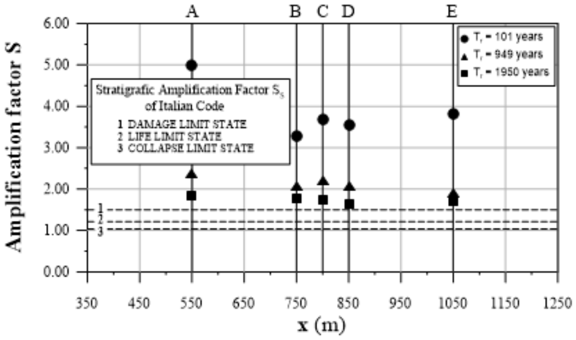

FIGURE 10. Peak accelerations values computed at the different selected points (A, B, C, D, E) and for different return periods (Tr).

Five reference points, named A, B, C, D and E, were chosen at the ground surface in order to detect amplifications at different locations (Figure 8).

Results from FEM analysis, in terms of maximum acceleration along the ground surface [e.g. Massimino e Biondi, 2015] in the reference points, are shown in Figure 9. The analysis shows that in all reference points the computed accelerations are significantly greater than the bedrock acceleration, denoting an amplification effect due to soil stratigraphy. For example at point A the analysis computes peak accelerations of 0.8g for the collapse limit state and 0.6g for the damage limit state. However, because the point A is the closest point to the foot of the slope, some topographic effects could have been generated at that point.

Figure 10 shows amplification factors along the ground surface for the three peak accelerations utilized. The largest amplification factor was computed for the damage limit state, that is for the lowest acceleration. At the point A the amplification factor for the damage limit state is about 5; this factor, however, takes both stratigraphic and topographic effects into to account.

4. CONCLUSIONS

A two-dimensional FEM analysis has been carried out to investigate the seismic response of the site where the DRPC strategic building in Messina is located. Preliminarily this study was preceded by site investigation and laboratory tests that allowed to determine the soil parameters and to model the subsoil. Three different peak accelerations at the bedrock were utilized, corresponding to three different limit states, according to the Italian seismic code.

Limited to this analysis, results seems to indicate that the computed amplification factors are much greater than the stratigraphic amplification factor prescribed by seismic Italian code. However, because this analysis was performed by using one accelerogram only, this topic needs major attention. The 2-D FEM analysis allowed to detected both topographic and stratigraphic effects. By comparing the ground accelerations at different points it has been deduced that topographic effects could play some role in the site seismic response analysis. This study confirms that a 2-D seismic response analysis is to be preferred to the 1-D analysis if also topographic amplifications are expected.

REFERENCES

Amorosi A., Boldini D., Sasso M., 2008. Modellazione numerica del comportamento dinamico di gallerie superficiali in terreni argillosi. Technical Report, Politecnico di Bari. 490 pp.

Barbano, M.S., Azzaro, R. and Grasso, D.E., 2005. Earthquake damage scenarios and seismic hazard of Messina, North-eastern Sicily (Italy) as inferred from historical data. Journal of Earthquake Engineering 9(6): 805-830.

Biondi, G., Condorelli, A., Maugeri, M., Mussumeci, G. (2004). Earthquake-triggered landslide hazards in the Catania area(Article). Management Information Systems, Volume 9, 1 January 2004, Pages 115-130.

Biondi G., Maugeri M. (2005). Seismic response analysis of Monte Po hill (Catania). Advances in Earthquake Engineering, Volume 14, 2005, Pages 177-195.

Biondi, G., Cascone, E., Di Filippo, G. (2012). Reliability of empirical relationships for the evaluation of the number of equivalent loading cycles. [Affidabilità di alcune correlazioni empiriche per la stima del numero di cicli di carico equivalente]. Rivista Italiana di Geotecnica Volume 2012, Issue 2, 2012, Pages 11-41.

Capilleri P., Lanzo G., Maugeri M., Pagliaroli A. (2005). Site Effects Evaluation in Sellano (Italy) by means of 1-D and 2-D numerical analysis (Italy). 5th World Conference on Earthquake Resistant Engineering Structures, ERES 2005; Skiathos; Greece; 30 May 2005 Volume 81, 2005, Pages 73-82.WIT Press.

Capilleri P., Cavallaro A., Maugeri M., (2014). Static and dynamic soil characterization at Roio Piano (AQ). Italian Geotechnical Journal, Volume XXXV, n0 2 pp 38-52.

Capilleri P., E. Motta, E. Raciti, M. Todaro (2016). Seismic Response of a Strategic Building in Catania (Italy) by 2-D FEM Analysis. VI Convegno Nazionale dei Ricercatori di Ingegneria Geotecnica (CNRIG) Bologna, 22 - 23 Settembre 2016.

Capilleri P.P., M.R. Massimino, E.Motta, and M. Todaro. “Two-dimensional site seismic response analysis for a strategic building in Catania”. Annals of Geophysics This issue.

http://www.rms-republic.com/gallery/Earthquake/adh

Castelli F., Cavallaro A., Ferraro A., Grasso S., Lentini V., Massimino M.R. (2018). ”Dynamic characterisation of a test site in Messina (Italy)”. Annals of Geophysics. This issue.

Cavallaro, A. Grasso, S. Maugeri, M. Motta, E. (2013a). Site characterisation by in situ and laboratory tests of the sea bed in the Genova Harbour, Italy. Geotechnical and Geophysical Site Characterization 4 - Proceedings of the 4th International Conference on Site Characterization 4, ISC-4 Volume 1, 2013 pp.415-422 Pernambuco; Brazil; 18 September 2012.

Cavallaro, A. Grasso, S. Maugeri, M. Motta, E. (2013b) An innovative low-cost SDMT marine investigation for the evaluation of the liquefaction potential in the Genova Harbour, Italy. Geotechnical and Geophysical Site Characterization 4 - Proceedings of the 4th International Conference on Site Characterization 4, ISC-4 Volume 1, 2013, Pages 637-644 Pernambuco; Brazil; 18 September 2012.

Imposa S., Motta E., Capilleri P., Imposa G. (2016). HVSR and MASW seismic survey for characterizing the local seismic response: a case study in Catania area (Italy). 1st International Workshop on Metrology for Geotechnics, Benevento, Italy, March 17-18, 2016.

Kuhlemeyer R. L. and Lysmer J., 1973. Finite element method for accuracy for wave propagation problems. Journal of Soil Mechanics & Foundation Division, ASCE Vol. 99, No. SM5, pp. 421-427.

Lysmer J., Kuhlmeyer R.L., 1969. Finite Dynamic Model for Infinite Media. ASCE, Journal of Engineering and Mechanical Division, Vol. 90 No. 4, pp. 859-877.

N.T.C. (2008). Norme Tecniche per le Costruzioni (Italian Technical Regulation for Constructions). Decreto del Ministro delle Infrastrutture 14.01.2008, published on Gazzetta Ufficiale 04.02.2008, Roma, 2008.

Massimino, M.R., Biondi G. (2015). Some experimental evidences on dynamic soil-structure interaction. Proc. COMPDYN 2015 - 5th ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering 2015, pp.: 2761-2774.

Lai C.G.., Foti S. Rota M. (2009). Input sismico e stabilità geotecnica dei siti di costruzione. Collana di manuali di progettazione antisismica. Volume 6 Fondazione Eucentre. IUSS Press.

Lanzo G., Silvestri F., (1999). Risposta sismica locale: teorie ed esperienze. Hevelius Edizioni.

Lanzo G., Pagliaroli A., D’Elia B., 2004. L’influenza della modellazione di Rayleigh dello smorzamento viscoso nelle analisi di risposta sismica locale. ANIDIS, XI Congresso Nazionale “L’Ingegneria Sismica in Italia”.

25-29, Genova, IT.

RMS Special Report -The 1908 Messina earthquake: 100-year retrospective - Risk Management Solutions, Inc. 2008.

Rizzitano, S.,Cascone, Biondi, G. (2015). Coupling of topographic and stratigraphic effects on seismic response of slopes through 2D linear and equivalent linear analyses. Soil Dynamics and Earthquake Engineering . Vol. 67, December 01, 2014, Pages 66-84.

Scolaro S., Pino P., Orecchio B., Presti D., Torre A., Totaro C., Farruggia D., Neri G. Geophysical measurements for site response investigations in the town of Messina. Annals of Geophysics .This issue.

Tortorici, L., C. Monaco, C. Tansi and O. Cocina 1995 Recent and active tectonics in the Calabrian arc (Southern Italy). Tectonophysics, 243, 37-55.

*CORRESPONDING AUTHOR: Piera Paola CAPILLERI,
Department of Civil Engineering and Architecture (DICAR),
University of Catania, Catania, Italy;

email: pcapille@dica.unict.it