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

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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. In fact 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
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 (SV1, SV2 and SV3) 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 (SN1, SN2 and SN3) have been developed. SPT tests were performed in the boreholes SN1, SN2 and SN3, cross-hole (CH) tests in the borehole SN1 and SN2 and a down-hole (DH) test in borehole SN3. 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 Cu, friction angles φ and Kd 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.
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 $D_{5-95} = 7.58$ 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,
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 ac-
curate evaluation of soil stresses and deformations than
the 6-node triangular mesh [Capilleri et al., 2016; Capil-
leri et al., this issue].

Two faults are present in the geological section in Fig-
ure 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 in-
terface elements with a Mohr-Coulomb constitutive law.
The fault interface parameters are cohesion \( c' = 0 \), friction
angle \( \phi = 35^\circ \), young modulus \( E = 300 \text{ MPa} \).

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 6. Seismic input used in 2-D FEM analysis: a) accelero-
gram; b) Fourier spectrum.](image)

![FIGURE 7. Geometrical model utilized in the FEM analysis.](image)

| TABLE 1. Geotechnical parameters deduced from geotechni-
ical investigation. |
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| TABLE 2. Seismic parameters according to Italian seismic
code. |
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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, \( \alpha_R \) and \( \beta_R \), an initial damping ratio \( D = 5\% \) was utilized and the same procedure used in Capilleri et al. [this issue] has been applied.

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 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.

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