4th International Conference on
Earthquake Geotechnical Engineering
June 25-28, 2007
Paper No. 1434

SEISMIC LANDSLIDE HAZARD ANALYSIS FOR THE GENOA DISTRICT, LIGURIA - ITALY

Simone BARANI [1], Roberto DE FERRARI[2], Gabriele FERRETTI[3], Daniele SPALLAROSSA[4]

ABSTRACT

The paper describes some analyses carried out to establish the slope stability under seismic condition of some sites within the Genoa district (Italy). For this purpose, the simplified Newmark sliding block analysis (Jibson, 1993) is applied. This method is based on an empirical regression equation to estimate the Newmark displacement as a function of the Arias intensity and the critical acceleration. The Jibson analysis is applied to some slopes affected by stabilized landslides and generally characterized by low values of the safety factor. A probabilistic seismic hazard analysis (PSHA) is performed in order to estimate the ground motion, defined in terms of Arias intensity, with a 10% probability of exceedance in 50 years. A logic tree approach is adopted since it allows us to account for the epistemic uncertainty due to the insufficient knowledge of the input data. The values of the Arias intensity, greater than 0.11 m/s, show that some sites could be subjected to seismic landslides activation (or re-activation) as inferred by Keefer and Wilson (1989). As a comparison, for the site of Campegli the Newmark displacement is also calculated by applying the original Newmark method (1965). To this purpose, a seismogram of the Salò earthquake (M_l = 5.2) which occurred at distance of above 180 km in November 25, 2004 and was recorded at above 10 km from Campegli by a station of the RSNI seismic network (Regional Seismic Network of Northwestern Italy) is used. This earthquake could be related to the acceleration of the Campegli landslide body that was observed from inclinometer and piezometer measures.

Keywords: probabilistic seismic hazard analysis, Arias intensity, Seismic Slope Stability, Newmark analysis.

INTRODUCTION

The evaluation of slope stability under seismic condition is one of the most important topics in geotechnical earthquake engineering. Several methods exist in order to assess it but a rigorous solution to this problem need the knowledge of geotechnical parameters that sometimes are not available.
In many cases, the rigid block displacement model developed by Newmark (1965) is applied. This method simplifies a potential failure mass as a block resisting on an inclined plane. If the total driving forces (static plus dynamic) exceed the available resting forces acting on the block, the potential failure mass is no longer in equilibrium and starts moving relative to the plane. The block continues to accelerate until the earthquake-induced accelerations become lower than a critical value a_c (critical acceleration), which is defined as the minimum ground acceleration required to produce instability of

[1] Dr., Dipartimento per lo studio del Territorio e delle sue Risorse, University of Genoa, Italy, Email: barani@dipteris.unige.it
[2] Dr., Dipartimento per lo studio del Territorio e delle sue Risorse, University of Genoa, Italy, Email: deferrari@dipteris.unige.it
[3] PhD., Dipartimento per lo studio del Territorio e delle sue Risorse, University of Genoa, Italy, Email: ferretti@dipteris.unige.it
[4] Professor, Dipartimento per lo studio del Territorio e delle sue Risorse, University of Genoa, Italy, Email: daniele@dipteris.unige.it

the block. Then the block is decelerated by the friction force acting on its base, and its velocity progressively decreases to zero.

In this study, the simplified Newmark sliding block analysis proposed by Jibson, 1993 is applied. This method is based on an empirical regression equation to estimate the Newmark displacement, D_n, as a function of the shaking intensity and the critical acceleration, which depend on the safety factor and slope angle. Hence, the Newmak displacement, an index of the slope performance under seismic actions, is estimated as a function of the critical acceleration, a_c, and the Arias intensity (ground shaking intensity), I_a. The Arias intensity (Arias, 1970) is a measure of the total seismic energy absorbed by the ground and unlike PGA, it accounts for the full range of frequencies of an earthquake and the duration of the ground motion. The Arias intensity is obtained by integration over the duration of an accelerogram $a(t)$:

$$I_a = \frac{\pi}{2g} \int_0^{T_d} a(t)^2 \, dt$$

In this study, the Arias intensity is assessed by means of a Probabilistic Seismic Hazard Analysis (PSHA). In particular, the Newmark displacement is estimated as a function of the Arias intensity with a 10% probability of exceedance in 50 years (Mean Return Period, MRP, of 475 years).
However, both the original Newmark method and that proposed by Jibson, unlike more complex dynamic analyses (e.g. Biondi et al., 2000), do not account for the pore pressure increment and the shear strength reduction of undrained materials due to a ground acceleration $a(t)$ (seismic loading). As a consequence, these methods might lead to an unconservative and unsafe estimation of slope stability.

The Jibson analysis is applied to some sites within the Genoa district (Liguria Region – Italy). In this paper, we present the results obtained for the Campegli village only, which is locally characterized by values of the safety factor close to 1.0 and was affected by landslide phenomena of thick debris deposits in the past (Formigoni et al., 1986; Olcese et al., 1991).

PROBABILISTIC SEISMIC HAZARD ANALYSIS

The methodology originally proposed by Cornell (1968) and subsequently improved by many others is applied. A logic tree approach (e.g. Senior Seismic Hazards Analysis Committee - SSHAC, 1997) is adopted in order to consider the uncertainty in the selection of different models and parameter values. In particular, the logic tree includes different source zone models, several values of earthquake recurrence parameters and maximum earthquake magnitude values (interpreted as the upper bound of magnitude for a given seismogenetic zone). In the application presented here all the branches of a node have the same weight. No attempt has been made to assign more credibility to any of the alternative branches.
Two alternative seismogenetic zonations are considered: the first, called ZS9 (Gruppo di Lavoro, 2004b), is the source zone model developed for the Italian seismic hazard map (Gruppo di Lavoro, 2004a); the second, ZSL (Barani et al., 2006), which is derived from the seismogenetic zonation ZS4 (Meletti et al., 2000), takes into consideration the recent regional seismicity and the seismogenetic structures characterizing the western part of the Liguria region.
For each source zone the frequency-magnitude parameters (earthquake annual rate of occurrence above a minimum threshold magnitude, υ; negative slope of the Gutenberg-Richter relation, b) and the maximum magnitude ($M_{\max}$) values are quantified. To this purpose, we consider the earthquake data collected in the seismic catalogue DTR.1a (Barani et al., 2006) that was properly compiled for seismic hazard analyses of this region. Two approaches are applied to evaluate the values of the frequency-magnitude parameters: one is based on the least mean square method (LMS) and the other estimates the values of (υ, b) following the maximum likelihood approach proposed by Weichert (1980). The value of $M_{\max}$ is computed by using a straightforward procedure based on the extrapolation of the standard log-linear Gutenberg-Richter equation (Barani et al., 2006). Regarding ground motion prediction, expressed in terms of Arias intensity (I_a) for rock conditions, the equation by Sabetta and Pugliese (1996) is used. This attenuation relationship, calibrated on Italian strong

motion data, has been adjusted to account for the style of faulting by applying the average correction factors, $F_{mech:eq}$, proposed by Bommer et al. (2003) that were also adopted for the evaluation of the Italian seismic hazard map (Gruppo di lavoro, 2004a) and in Montaldo et al. (2005).
For each seismogenetic source, the logic tree approach generates a large number of alternative branches for the computation of the hazard at a site. The hazard at a site is computed by adding the contribution from each source, that is the hazard curve is obtained by independently sampling the hazard contribution from each source. Hazard calculations are performed using the computer program HAZ_MULTI which is briefly described in Barani et al. (2006).

Figure 1 shows the seismic hazard map in term of mean Arias intensity corresponding to a MRP of 475 years and the mean, 15%-ile, and 85%-ile hazard curves for I_a values calculated for the Campegli village. The map shows that I_a increases from SW to NE where is up 0.45 m/s according to the expected path of increasing seismic activity. The site under study is characterized by modest mean I_a values for a MRP of 475 years (I_a = 0.127 m/s). According to Keefer e Wilson (1989), such I_a values, greater then 0.11 m/s, are sufficient to trigger landslides in the area under study.

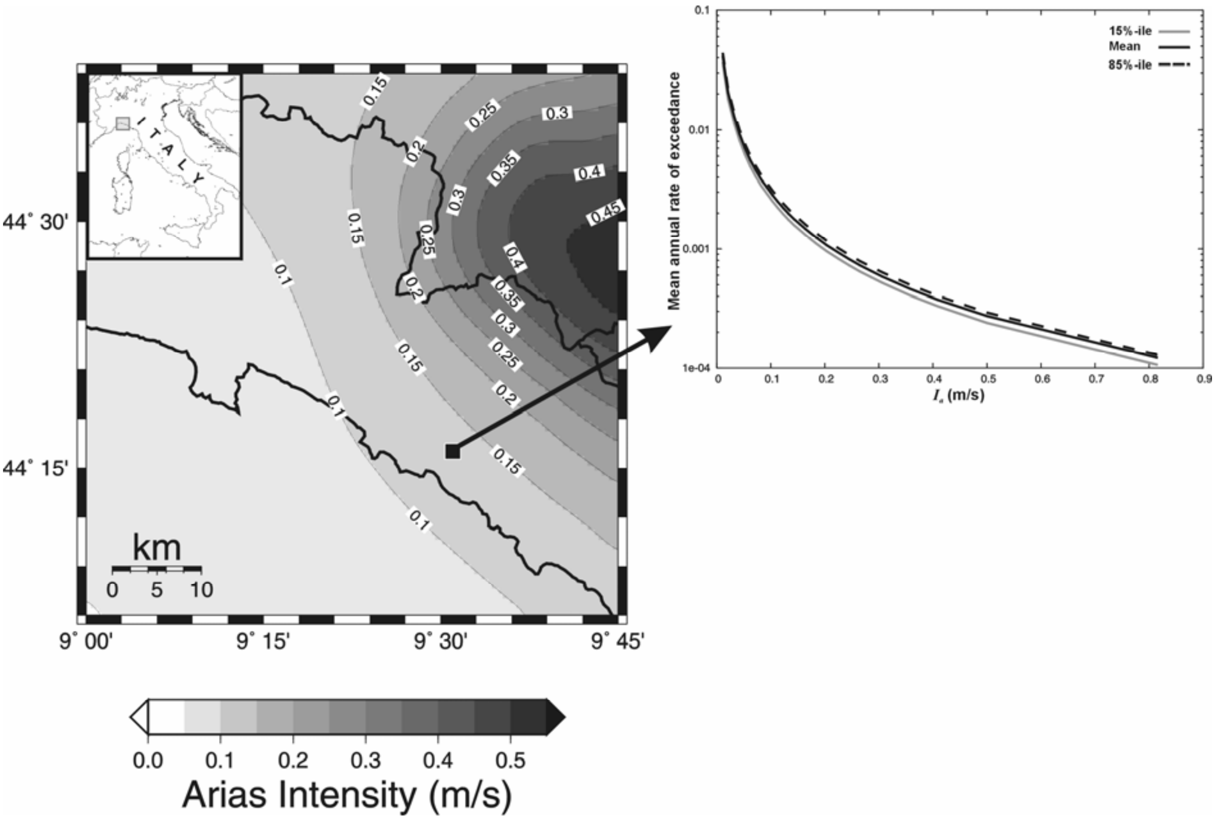

Figure 1. Probabilistic Arias intensity map corresponding to a MRP of 475 years and hazard curves evaluated for the Campegli village.

GEOLOGICAL SETTING

The area investigated in this study is situated in the Northern Apennine and geologically belongs to Internal Liguride Domain (Decandia F.A. and Elter P. 1972). In particular, it belongs to the "Supergruppo della Val di Vara" which is characterized by flyschoid and ophiolitic rocks.
This paleogeographical domain was affected by an intense tectonization in the past. Therefore, the presence of landslide bodies might be related to pre-existing tectonic lineaments along which landslides could be triggered in high angle slopes.

The collection of geologic, geomorphologic and geotechnical data is fundamental to reconstruct the site geology. Therefore, several surveys were aimed to investigate the physical and the geometrical

properties of the Campegli landslide. Data from 10 geotechnical boreholes with NSPT tests, 4 seismic refraction profiles, 7 vertical electric profiles and an array of 9 inclinometers and 4 piezometers were firstly collected (data are provided by the Government of the Genoa district). These data show that the landslide body is characterized by a 30 m thick layer of sandy gravel overlaying gabbroic hard bedrock. The NE sector of the slope is stable under static conditions while inclinometric measurements indicate a very slow displacement of debris deposits in the SW sector.
To better define the thickness and the seismic response of the deposits characterizing the SW sector of the landslide, further geophysical surveys comprising 3 seismic refraction profiles (white lines in Figure 2) and 3 microtremor measurements (black triangles in Figure 2) have been subsequently planned. The refraction profiles have been carried out by using 24 sensors (the natural frequency of each sensor is 4.5 Hz) at a distance of 2 m from each other and a 5 kg weight dropper as seismic source. The tomographic images resulting from the seismic refraction data (Figure 3) show that eluvial - colluvial materials (down to 5-8 m) with V_p < 1000 m/s overlay a layer (down to 15 – 20 m) characterized by debris pebbly material with V_p < 2500 m/s. The bedrock, deeper than 20 m, is composed by gabbroic rocks with V_p greater than 3200 m/s.

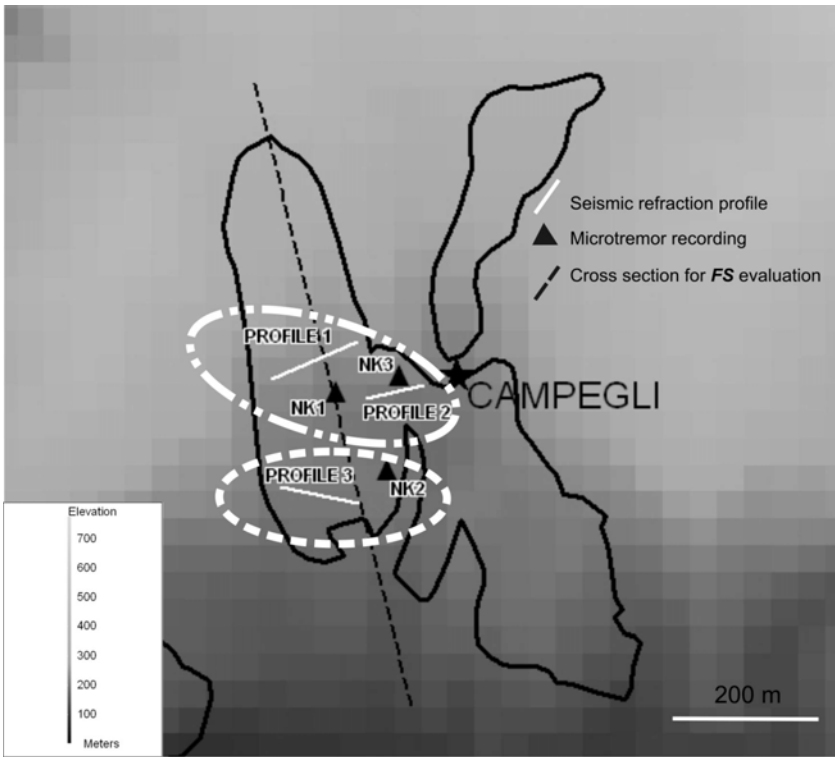

Figure 2. Campegli landslide body (black line). White ellipses indicate areas characterized by low (dotted-dashed line) and high (dotted line) values of the slope angle

The application of the standard HVSR (horizontal to vertical spectral ratio) technique on microtremor recordings (Nakamura, 1989) allow us to define the fundamental frequency of the soil deposits at different points along the landslide (Figure 2). The microtremor recordings (each recording consists of three 40 minutes long signals each of which corresponds to the NS, EW, and vertical components of motion) are filtered between 0.2 – 20 Hz and then divided into 40 seconds dimensioned temporal windows. Then, the Fourier spectra of both the horizontal and vertical components of each signal window are smoothed by applying a Hanning window. Finally, the mean H/V ratios (and their standard deviation) are computed. The H/V spectral ratios relevant at sites 1 (NK1) and 2 (NK2), which are located in the southern part of the landslide body where deposits are thicker, clearly show a fundamental frequency of about 2.5 Hz (Figure 4).

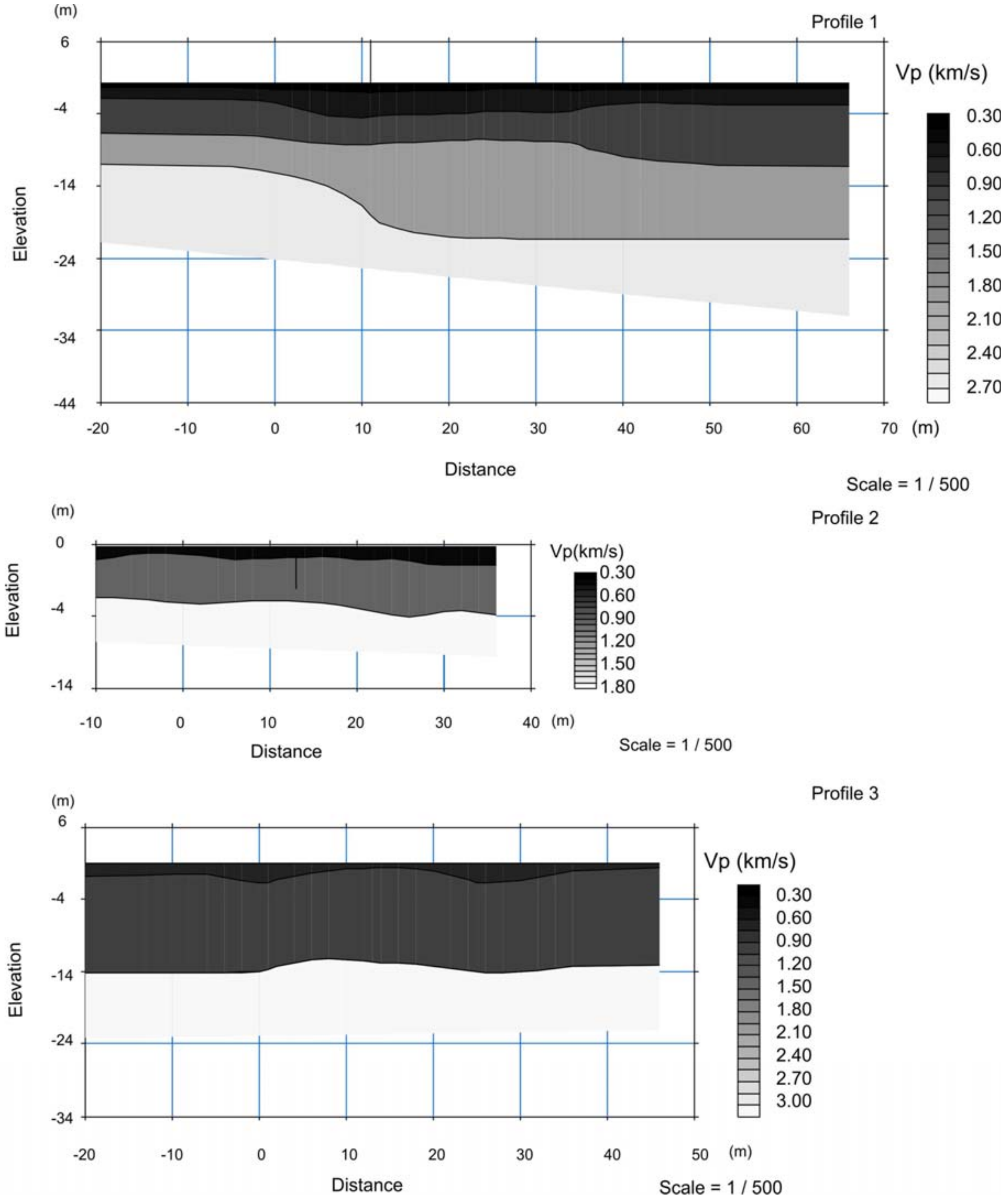

Figure 3. Seismic refraction tomography images corresponding to the three profiles shown in Figure 2

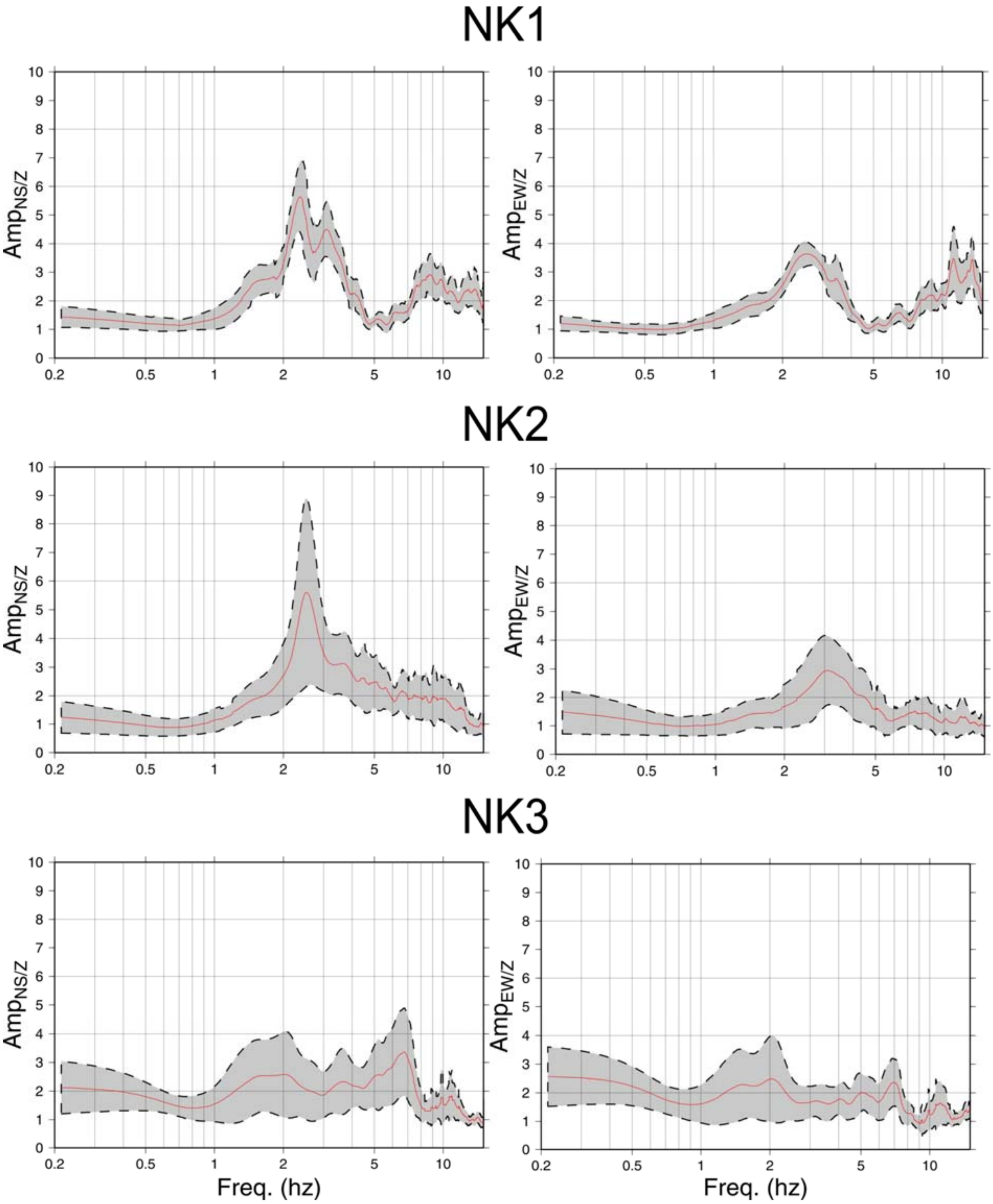

Figure 4. Horizontal to vertical spectral ratios at site NK1, NK2, and NK3. Red lines indicate the mean value of the H/V curves while the gray shaded area represents ± 1 standard deviation.

SEISMIC SLOPE STABILITY: RESULTS AND DISCUSSION

Safety factor assessment

The safety factor, an index of slope stability, can be evaluated by applying dynamic analyses and/or limit equilibrium methods (static and pseudostatic analyses). In this work, both static and pseudostatic

analyses are applied since the lack of detailed geotechnical parameters does not allow us to perform dynamic analyses.
Limit equilibrium methods require the definition of a critical surface for which the ratio between resisting and driving forces acting on a slope (safety factor) is minimum:

$$FS = \frac{available\_resisting\_force}{available\_driving\_force} \qquad (1)$$

Distinction is made between static and pseudostatic methods. In the static approach, the safety factor (static safety factor, FS_s) depends on the intrinsic slope properties, such as soil properties, slope geometry and groundwater. In the pseudostatic approach, a seismic loading, defined by an acceleration value, is applied as a driving force which reduces the slope stability.
The SW sector of the slope can be divided in two areas characterized by different values of the slope angle (ϕ) and water table depth (Figure 2). Higher values of FS_s ($FS_s > 2.0$) are obtained for the area with a gentle slope angle ($\phi < 15°$) while values of FS_s down to 1.059 characterize the area with $\phi > 15°$ (Figure 5).

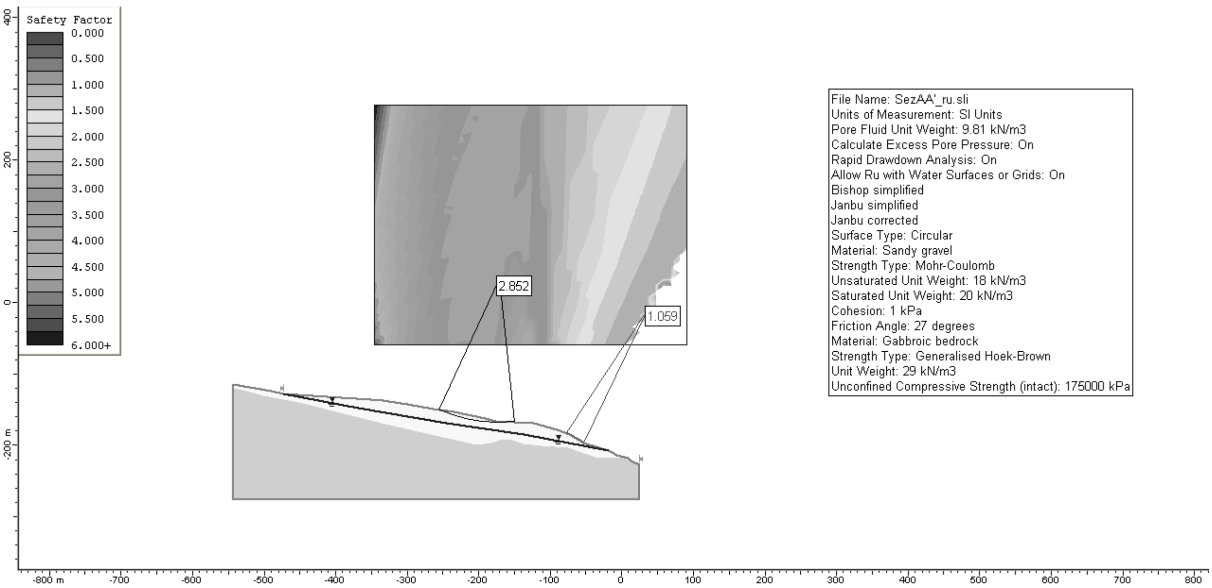

Figure 5. Static safety factors evaluated along the cross section shown in Figure 2 (black-dotted line)

The introduction of a horizontal acceleration (seismic loading) increases the driving forces and decreases the available resisting forces. The value of the pseudostatic safety factor, FS_{ps}, is equal to 0.860 in the area characterized by $\phi > 15°$ (Figure 6). The value of the horizontal seismic loading corresponds to the horizontal Peak Ground Acceleration (PGA) with a 10% probability of exceedance in 50 years (PGA = 0.09 g) resulting from a PSHA study which is not presented here. It is worth noting that the pseudostatic analysis accounts for a single acceleration value instead of a time history, neglecting duration, frequency content and shape of a real accelerogram (dynamic analysis). This might lead to an overestimation of FS_{ps} as much as the fact that our analysis does not account for the earthquake-induced pore pressure variation (Biondi et al., 2000; Biondi et al., 2002).

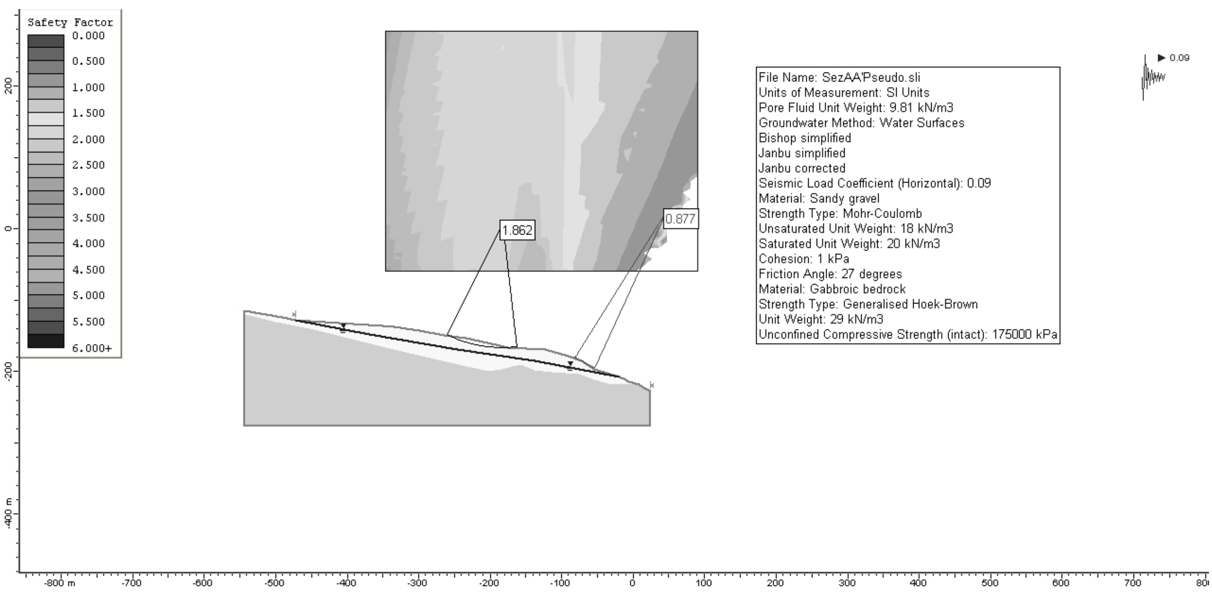

Figure 6. Pseudostatic safety factors evaluated along the cross section shown in Figure 2 (black-dotted line)

Newmark displacement analysis

As stated in the introduction, the Jibson method provides a measure of the Newmak displacement, D_n, which is estimated as a function of the critical acceleration, a_c, and the Arias intensity, I_a:

$$\log D_n = 1.46 \log \mathrm{Ia} - 6.642\, a_c + 1.546 \qquad (2)$$

where:

$$a_c = (FS_s - 1)\, g \sin\phi \qquad (3)$$

Assuming $\phi = 18°$, that is $a_c = 0.018$ g, and $I_a = 0.127$ m/s, the resultant finite displacement D_n is about 3.7 cm in the area characterized by higher slope angles. The other sectors of the landslide body do not show any resultant Newmark displacement ($D_n = 0$ cm).

Since inclinometer and piezometer measurements showed a displacement of the Campegli landslide body after the Salò earthquake ($M_l = 5.2$), which occurred at distance of above 180 km in November 25, 2004, we have applied the standard Newmark approach (1965) by using the accelerograms relevant at the previously mentioned earthquake recorded at above 10 km from Campegli by a station of the RSNI seismic network (Regional Seismic Network of Northwestern Italy). However, results do not show any displacement for the landslide body.

In this paper, the Newmark displacement is evaluated using the computer program developed by Jibson R. W. and Jibson M. W. (2003), which is freely available at the following web site: http://earthquake.usgs.gov/resources/software/slope_perf.php

CONCLUSIONS

In this study the Newmak displacement, D_n, of a quiescent landslide within the Genoa district is evaluated. To this purpose, the simplified Newmark analysis developed by Jibson (1993) is applied.
The area under study is characterized by a modest seismic activity and, consequently, by a low seismic hazard. In particular, this area is characterized by mean I_a values with a 10% probability of exceedance in 50 years ranging between 0.10 and 0.15 m/s.
The Newmark displacement reaches its maximum value ($D_n = 3.7$ cm) in the South-Western part of the landslide body which is characterized by higher values of the slope angle and lower values of both the static safety factor ($FS_s = 1.059$) and the pseudostatic safety factor ($FS_{ps} = 0.870$).

However the application of the original Newmark analysis (1965) by using a weak motion recording does not indicate any displacement for the Campegli landslide. This fact might be explained because the Newmark analysis does not account for earthquake-induced pore pressure variation whose effect might be significant in cohesionless materials characterized by low values of the friction angle. In fact, according to Biondi et al. (2002), the earthquake-induced pore pressures might strongly reduce the critical acceleration, above all in sandy-gravel material like those characterizing the Campegli landslide. Moreover, the amplification of ground motion, indicated by the H/V ratios, might lead to higher seismic loading which are neglected in this study. Future analyses will accounts for the effect of both the earthquake-induced pore pressure variation and the site amplification of ground motion due to local geological conditions.

REFERENCES

Arias A. "A measure of earthquake intensity", In: Seismic design for Nuclear Powerplants, MIT Press, Cambridge (MA), 438-483, 1970.

Barani S, Spallarossa D, Eva C and Bazzurro P. "Sensitivity analysis of parameters for probabilistic seismic hazard assessment of Western Liguria (North Western Italy)," accepted for publication on Bollettino di Geofisica Teorica e Applicata, 2006.

Biondi G, Cascone E and Maugeri M. "Flow and Deformation Failure of Sandy Slopes," Soil Dynamics and Earthquake Engineering, 22, 1103-1114, 2002.

Biondi G, Cascone E, Maugeri M and Motta E. "Seismic Response of Saturated cohesionless Slopes," Soil Dynamics and Earthquake Engineering, 20, 209-215, 2000.

Bommer JJ, Douglas J and Strasser FO. "Style-of-faulting in ground motion prediction equations," Bull. Earth. Eng., 1, 171-203, 2003.

Cornell CA. "Engineering seismic risk analysis," Bull. Seis. Soc. Am., 58, 1583-1606, 1968.

Decandia FA and Elter P. "La zona ofiolitifera del Bracco nel settore compreso fra Levanto e la Val Graveglia (Appennino Ligure)," LXVI Congr. Soc. Geol. St., Pisa, 37-64, 1972.

Formigoni G, Olcese A and Giusti G. "Progetto di messa in sicurezza del movimento franoso di Campegli ," Atti XVI Convegno Nazionale di Geotecnica, Vol. II, 1986.

Gruppo di lavoro. "Appendice 2 al Rapporto Conclusivo – Zonazione sismogenetica ZS9," Internet web site: http://zonesismiche.mi.ingv.it/documenti/App2.pdf, 2004b.

Gruppo di lavoro. "Redazione della mappa di pericolosità sismica prevista dall'Ordinanza PCM del 20 marzo 2003, Rapporto conclusivo per il dipartimento di Protezione Civile," INGV, Milano – Roma, aprile 2004, 65 pp. + 5 appendici, Internet web site: http://zonesismiche.mi.ingv.it/documenti/rapporto_conclusivo, 2004a.

Jibson RW and Jibson MW. "Java programs for using Newmark's method and simplified decoupled analysis to model slope performance during earthquakes," United States Geological Survey, Open-File Report 03-005, 2003. Internet Web Site: http://earthquake.usgs.gov/resources/software/slope_perf.php

Jibson RW. "Predicting earthquake-induced landslide displacements using Newmark's sliding block analysis," Trans. Res. Rec., 1411:1–15, 1993.

Keefer DK and Wilson RC. "Predicting earthquake-induced landslides, with emphasis on arid and semi-arid environments," In: Landslides in a semi-arid environment, Inland Geological Society, Sadler and Morton (Ed.), 2, 188-149, 1989.

Meletti C, Patacca E and Scandone P. "Construction of a seismotectonic model: the case of Italy," Pure Appl. Geophys, 157, 11-35, 2000.

Montaldo V, Faccioli E, Zonno G, Akinci A and Malagnini M. "Treatment of ground-motion predictive relationships for the reference seismic hazard map of Italy," Journal of Seismology, 9, 295-316, 2005.

Nakamura Y. "A Method for Dynamic Characteristics Estimation of Subsurface using Microtremor on the Ground Surface," Quarterly Report of Railway Technical Research

Institute (RTRI), Vol. 30, No.1.,1989
Newmark NM. "Effects of earthquakes on dams and embankments," Geotechnique, 15-2, 139–160, 1965.
Olcese A, Vescovo C, Boni S and Giusti G. "Stabilisation of a landslide with submerged motor-driven pumps," The Institution of Civil Engineers, Conference 15-18 April 1991.
Sabetta F and Pugliese A. "Estimation of response spectra and simulation of nonstationary earthquake ground motions," Bull. Seism. Soc. Am., 2, 337-352, 1996.
Senior Seismic Hazards Analysis Committee. "Recommendations for probabilistic seismic hazard analysis: Guidance on uncertatinty and the use of experts," NUREG/CR6372, Nuclear Regulatory Commission, Washington, 256 p., 1997.
Weichert DH. "Estimation of the earthquake recurrence parameters for unequal observation periods for different magnitudes," Bull. Seis. Soc. Am., 70, 1337-1346, 1980.