Rend. Online Soc. Geol. It., Vol. 41 (2016), pp. 139-142, 3 figs. (doi: 10.3301/ROL.2016.113)

Comparison of different approaches for landslide-induced damage assessment: the case study of Agnone (southern Italy)

Matteo Del Soldato ([a, b]), Diego Di Martire ([a]) & Roberto Tomàs ([c])

[(a)] Department of Earth Sciences, Environment and Resources, Federico II University of Napoli, Largo San Marcellino. E-mail: matteo.delsoldato@unina.it
[(b)] Department of Earth Sciences, University of Firenze, Via La Pira 4, 50121 Florence, Italy.
[(c)] Departamento de Ingeniería Civil, University of Alicante P.O. Box 99, E-03080 Alicante, Spain.

Document type: Short note.
Manuscript history: received 17 December 2015; received in revised form 24 February 2016; accepted 29 March 2016; editorial responsibility and handling by Margherita C. Spreafico.

ABSTRACT

Landslides constitute one of the most important geo-hazards affecting southern Italy. Particularly, in this area slope movements have over time caused relevant socio-economic losses and, in some cases, also casualties. Prevention, prediction and monitoring of landslide phenomena play a key-role to avoid or minimize their effects. In this work, damage suffered by facilities located within and surrounding a deep-seated landslide were classified through three different approaches. The investigated area is located in the municipality of Agnone (Molise region, central-south Italy), which is strongly affected by landslide processes. A main landslide event that occurred in 2003 is still active, exhibiting slow and intermittent movements. In this contribution, three different approaches for landslide-induced damage assessment are compared and their discrepancy discussed, highlighting the benefits and drawbacks of the different approaches. Finally, the future development of a new methodology and classification for infrastructures damage assessment is evaluated, merging the procedures used in this work.

KEY WORDS: Geo-hazards, Agnone, Damage assessment, Landslide.

INTRODUCTION

Landslides are considered the most frequent natural calamities and geological hazards in Italy, causing important human and socio-economic losses (Cotecchia & Melidoro, 1974). Mountainous and geologically complex territories, such as those in southern Italy, are frequently affected by landslides. Slope movements cause damage on buildings and other man-made structures with direct or indirect costs (Schuster & Fleming, 1986; Schuster 1996; Godt et al., 2000). The entity of the damage is based on several factors such as the dimension of the mass-movement, velocity, magnitude and type of mechanism, involved lithology, morphological features and the effects of human activity. In spite of the millennial knowledge of historically negative experience, the increasing of the population and the consequent expansion of the urban network (Rybar, 1997) motivated the construction of new infrastructures in unstable areas. As known, this process induces the alteration of the hillslope configuration and the remobilization of old landslides, previously accommodated and dormant (Chiocchio et al., 1997). Monitoring, prevention and mitigation of landslides play a key-role in natural hazard management by looking for cost-effective solutions to mitigate or minimize disastrous losses.

This paper is focused on the comparison of different field survey methodologies for the assessment of landslide-induced damage. The investigated structures are located within and close to an area affected by a slow-moving and intermittent deep-seated landslide in the municipality of Agnone (Molise region, southern Italy) (fig. 1), involving a Miocene-Pliocene formation composed by a predominance of clay and marls.

The last main event affected several facilities, mainly buildings, forcing the local administration to adopt restrictive legislative measures, e.g. the evacuation, occurred in January 2003. Currently, the landslide is still active. Recently, several man-made structures were examined in situ to evaluate their damage. The level of the damage was assessed by means of different existing methods based on: landslide displacements (Chiocchio et al., 1997); differential settlements and tilting (Burland 1977; Boscardin & Cording, 1989); scheme for post-seismic event of the Italian Department of the Civil Protection (DPC in the following) (Baggio et al., 2009). Then, the main benefits and drawbacks of each method, after comparing the results obtained in order to evaluate the most suitable approach for the facilities investigated within this area, were analyzed and discussed.

TEST SITE DESCRIPTION

The Molise region is the smallest one of southern Italy and, despite its limited extension, it is strongly affected by

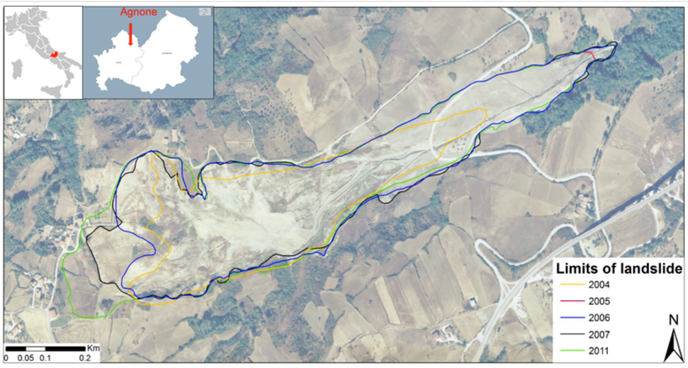

Fig. 1 - Boundaries of the CL-PO landslide from 2003 (major event) to 2011.

landslides and erosional processes. The studied slope-movement is located in the territory of the Agnone municipality, known as Colle Lapponi-Piano Ovetta (CL-PO landslide hereafter), in the catchment of Vallone San Nicola. This landslide consists of a large roto-translational slide evolving in earth-flow involving a low member of the structurally complex Agnone Flysch formation dated Upper Miocene (Vezzani et al., 2004). Thanks to several drilled boreholes, four horizons were recognized, from the top: a) a level of chaotic and plastic clay deposits, directly involved in the reactivation of the LC-PO landslide; b) a complex of gray clay, silty clay, sandy clay and silty sand; c) a stratum of scaly marly clay, marls and clayey marls. Thin depth of lithoid calcareous intercalations with high permeable beds were recognized. Weathering evidences, features of weak rock and scaly structures could be found (Calcaterra et al., 2008).
The main event occurred in January 2003 and consisted of the reactivation of a dormant historic landslide that completely altered the local hydrographic network. The same basin has been affected by several slope movements since March 1905 (Calcaterra et al., 2008). Historical and archival research on landslides (Guzzetti et al., 1994) reports that several slope movements occurred in the territory of Agnone in the period 1970-1988. In February 1994, other important landslides occurred in the study area causing the disruption of the country road (Calcaterra et al., 2008). After the main event in 2003, the landslide, was continuously enlarging its dimensions through a slow movement that generated damage to the facilities. The landslide has shown both advancing (2004-2006) and retrogressive (2006-2011) trends, which resulted in an overall increase of the unstable area, reaching an extension of about 280,000 m^2. From 2004 to 2011 the foot has progressed about 350 m and the crown has retrogressed about 270 m, reaching a total length of around 1500 m.

DAMAGE CLASSIFICATION APPROACHES

Skempton & McDonald (1956) classified building damage into three general categories: a) architectural damage affecting the appearance of structures with cracks in the walls, floors and finishes; b) functional damage ruining the use of the structure by tilting, jamming and extensive cracks; c) structural damage prejudicing the stability of the structure.

Field surveys have to be performed to evaluate damage affecting facilities and surfaces besides assessing the geomorphological impact. Operator and its experience play an important role in damage assessment studies. The field campaign is the best criteria to assess the damage, although practical difficulties to reach places (e.g. gates or stray animals), could arise during the realization of the works. Alexander (1986) published a scheme based on the structural damage recognizable on buildings elaborating the first landslide damage classification for urban areas with eight grades of damage: from 0 (no damage) to 7 (total collapse).

The first applied approach (fig. 2a) was the classification of Chiocchio et al. (1997). This approach was devised to improve some characteristics (e.g. the missing of the typology and the year of construction) of Alexander's methodology (1986) highlighted during the applications conducted in several villages in southern Italy (e.g. Crescenzi et al., 1994). Chiocchio et al. (1997) formulated a new landslide damage classification for urban areas through an interdisciplinary approach involving geologist, geomorphologists and civil

a) Classification according Chiocchio et al., 1997

Grade	Damage level	Load-bearing structures	Rigid settlement	Cracking	Immediate measures
0	None	Masonry	0	None	None
		Reinforced concrete frame	0	None	None
1	Negligible	Masonry	0	Hairline cracks of the plaster	None
		Reinforced concrete frame	0	Hairline cracks of the plaster	None
2	Light	Masonry	2 - 3 cm	Small cracks through walls and partitions	None
		Reinforced concrete frame	2 - 3 cm	Small cracks through walls and partitions	None
3	Moderate	Masonry	10 - 15 cm	Open cracks in walls; walls disjunction; little deformation; badly working casings	Evacuation suggested
		Reinforced concrete frame	10 - 15 cm	Significant cracking in the beams; partition walls deformed and crumbling; badly working casing	Evacuation suggested
4	Serious	Masonry	15 - 20 cm	Considerable disjunction of walls; space deformation; partition walls collapsed; unusable casing	Evacuation & shoring
		Reinforced concrete frame	15 - 20 cm	Perimetric and partition walls partly collapsed; deformed structures; spread cracking	Evacuation
5	Very serious	Masonry	>25 cm	Open cracks in floor; partition walls totally collapsed; seriously ruined lintels	Evacuation & cordoning
		Reinforced concrete frame	>20 cm	u.d.	Evacuation & cordoning
6	Partial collapse	Masonry	u.d.	u.d.	Cordoning
		Reinforced concrete frame	u.d.	u.d.	Cordoning
7	Total collapse	Masonry	u.d.	u.d.	Cordoning
		Reinforced concrete frame	u.d.	u.d.	Cordoning

u.d. = undefined datumw

b) Classification according Burland et al., 1977, slighty modified by Boscardin & Cording, 1989

Grades	Damage level	Crack width (CW in mm)	Description of damage
0	Negligible	< 0.1	Hairline cracks
1	Very Slight	< 1	Fine cracks and isolated generally restricted to internal walls finishes
2	Slight	< 5	Several slight fractures inside building; exterior cracks visible; doors and windows may stick slightly
3	Moderate	5 < CW < 15 or several > 3 mm	Several cracks; doors and windows sticking. Utility service may be interrupted; weathertightness often impaired
4	Severe	15 < CW < 25 depending on number of cracks	Windows and door frames distorted; floor sloping noticeably; Walls lean or bulge noticeably, some loss of bearing in beams; utility service disrupted
5	Very severe	> 25	Beams lose bearing; walls lean badly and require shoring; windows broken with distortion; danger of instability.

c) Classification according to DPC (Baggio et al., 2008)

Grades	Damage level	Crack width (CW in mm)	General description of the damage
D0	Nothing	None	None
D1	Weak	= 1	Damage don't change significantly the resistance of the structure; slightly cracks (= 1mm) in walls; limited separation of elements and dislocation (= 1mm); limited distortion without separation or structural failure
D2/D3	Moderate & Serious	< 10 or 15	Damage that could change significantly the resistance of the structures without the collapse of elements; cracks with big entity than D1 with possible expulsion of material (= 1cm or more close to the opening); symptom of crushing crack; important disjunctions; possible small collapse
D4/D5	Very Serious & Collapse	> 15	Damage that evidently modify the resistance of the structures; possible partial and total collapse

Fig. 1 - Classification of damage used in this work according to: a) Chiocchio et al., 1997; b) Burland et al., 1977; c) DPC (Baggio et al., 2009).

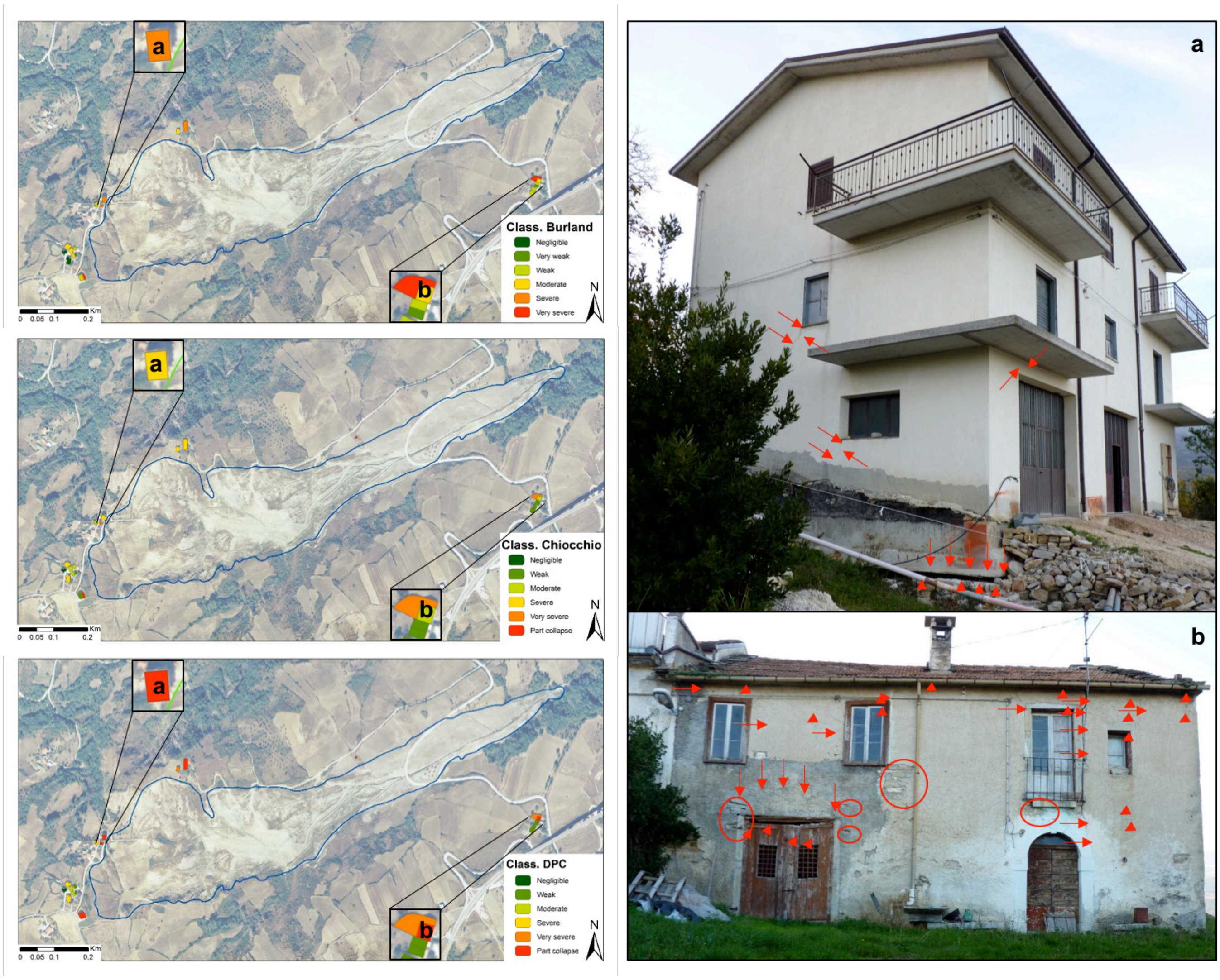

Fig. 3 - On the left, the results of the application of the three different classifications are shown: on the top the classification of Burland (1977); in the middle Chiocchio et al. (1989) approach; on the bottom the categorization derived from the Italian DPC methodology of survey (Baggio et al., 2009). On the right, two examples of damaged buildings within (a) and close (b) the landslide. The location of buildings a) and b) is marked in the figures on the left.

engineers. They extended the existing classification, proposed by Alexander (1986), adding some structural information concerning the building (i.e. the type of structure in masonry or reinforced concrete) and some quantitative reference values (e.g. cracking). These changes reduce the required experience and enhance the method, differencing the effect of the same apparent crack and minimizing the subjectivity of the survey. According to Alexander's proposal (1986), the damage can range from 0, no damage (intervention not needed), to 8, severe damage (requiring possible rebuilding in a safety area).

The second approach (fig. 2b), conceived by Burland et al. (1977) and later slightly modified by Boscardin & Cording (1989), is based on the evaluation of the ease of repair of the cracks, according to their width.

The third method (Baggio et al., 2009) is aimed to survey damage and first intervention in the post-seismic events and so it is focused on the civil facilities for the Italian DPC. It was conceived as a quick survey for a first classification of the magnitude of the damage and to assess the reliability of the structure to host safely its inhabitants. The scheme includes nine sections describing the localization, typology and opening of the cracks occurred in structural and non-structural elements, in addition to other information about external hazards affecting the building under survey. In this work, the methodology was applied using only a section of the damage for structural elements (fig. 2c). The application of this approach, which was devised for the classification of damage occurring in seismic events, is possible because also in this case damage are due to effect of shear stress. The peculiarity of this approach is the introduction of the extension of the damage. The construction is divided in three parts and for each one the level of damage must be evaluated. Obviously, the sum of the evaluated parts must give back 1, corresponding to the entire building (e.g. 2/3 of D4-D5 + 1/3 of D2/D3). To permit the comparison of this approach with the other two, the ten possible crossings of different importance of the extension of the damage, were classified in 6 categories of damage: from 0 (negligible, including no damage) to 6 (partial collapse).

RESULTS AND DISCUSSION

The three applied methodologies on the structures located on the landslide-prone areas of Agnone, gave back three different classifications of the level of damage. Originally, the classifications were made for the identification and categorization of the damage affecting only buildings, but in this work they were applied also to an electricity pole, two walls and three concrete squares, strongly affected by ruptures.

Two examples of buildings affected by damage and their respective classifications are shown in fig. 2. By a reciprocal comparison, it is possible to understand how the same two buildings were classified according to three different levels of damage. Pursuant to Burland et al., (1977), the buildings are principally classified with “low level of damage”. The methodology of Chiocchio et al. (1989) categorises the man-made structures homogeneously, mainly in the moderate and severe classes. Finally, the classification of the Italian DPC proved to be more severe and conservative, mainly categorising the construction in the high classes. The discrepancy among the classifications is mainly due to the different aim of each classification and the features considered for the evaluation of damage, e.g. Burland et al. (1977) methodology considers important ruptures (assessing them in centimeter instead of in millimeter) for low grades of damage. It is important to consider that in the classification of Burland et al. (1977), the evacuation of the building is suggested from the lower level of damage, e.g. *moderate* class. The approach used by the Italian DPC is more detailed regarding the identification of the cracks and it was devised to evaluate the practicability of buildings in the immediate aftermath of a seismic event. This could justify the severity of this approach that turns out to be more cautious.

FINAL REMARKS AND FUTURE TRENDS

The different approaches used in this work for landslide damage assessment revealed clearly some benefits and drawbacks. In the future, the proposal of a homogeneous and standard methodology for the assessment of landslide-induced damage by merging the different existing approaches could avoid the spotted problem. For example, providing a simpler evaluation of the width and extension of the cracks for the different typologies of the man-made structures. The improved methodology should include the possibility to apply it not only on the buildings, but also for damage occurring on other facilities (e.g. roads, bridges and channels).

REFERENCES

Alexander, D. (1986) - Landslide damage to buildings. Environ. Geol. and Water S., 8, 3, 147-151.

Baggio C., Bernardini A., Colozza R., Corazza L., Della Bella M., Di Pasquale G., Dolce M., Goretti A., Martinelli A., Orsini G., Papa F. & Zuccaro G. (2009) - Manuale per la compilazione della scheda di 1 livello di rilevamento danno, pronto intervento e agibilità per edifici ordinari nell'emergenza post-sismica. Editrice Italiani nel Mondo, Roma, pp 112. (In Italian)

Boscardin M.D. & Cording E.J. (1989) - Building response to excavation-induced settlement. J. Geotech. Eng., 115, 1, 1-21.

Burland, J.B., Broms B.B. & De Mello V.F. (1977). Behavior of foundations and structures on soft ground. In: Japanese Society of Soil Mechanics and Foundation Engineering (eds.), Proceeding of 9th International Conference on Soil Mechanics and Foundation Engineering, Tokyo, Japan, 2, 495-546.

Calcaterra D., Di Martire, D., Ramondini, M., Calò, F., & Parise, M. (2008). Geotechnical analysis of a complex slope movement in sedimentary successions of the southern Apennines (Molise, Italy). Landslides and Engineered Slopes, 299-305.

Chiocchio C., Iovine G. & Parise M. (1997) - A proposal for surveying and classifying landslide damage to buildings in urban areas. Engineering Geology and the Environment, 553-558.

Cotecchia V. & Melidoro G. (1974) - Some principal geological aspects of the landslides of southern Italy. Bulletin of the International Association of Engineering Geology, 9, 23-32.

Crescenzi E., Iovine G. & Parise M. (1994) - Analysis of landslide damage in a village in southern Italy: a preliminary report. In: Atti Convegno, Incontro Internazionale dei Giovani Ricercatori in Geologia Applicata, Lausanne Suisse, 68-72.

Godt J.W., Coe J.A. & Savage W.Z. (2000) - Relation between cost of damaging landslides and construction age, Alameda County, California, USA, El Niño winter storm season, 1997–98. In: Bromhead E., Dixon N. & Ibsen M.L. (eds.), Landslides, Proceedings of 8th international symposium on landslides, A.A. Balkema, 26-30.

Guzzetti F., Cardinali M. & Reichenbach P. (1994) - The AVI Project: a bibliographical and archive inventory of land-slides and floods in Italy. Environmental Management, 18, 4, 623-633.

Rybár J. (1997) - Increasing impact of anthropogenic activities upon natural slope stability. In: Marinos P, Koukis G.C., Tsiambaos G.C. & Stournaras G.C. (eds.), Proceedings of the International Symposium on Engineering Geology and the Environment, 23-27.

Schuster R.L. & Fleming R.W. (1986) - Economic losses and fatalities due to landslides. Bulletin of the Association of Engineering Geologists, 23, 1, 11-28.

Schuster R.L. (1996) - Socioeconomic significance of landslides. In: Landslides: Investigation and Mitigation. Washington (DC): National Academy Press. Transportation Research Board Special Report, 247, 12-35.

Skempton A.W. & MacDonald D.H. (1956) - The allowable settlements of buildings. In: Proceedings of the Institution of Civil Engineers, 5, 6, 727-768.

Vezzani L., Ghisetti F. & Festa A. (2004) - Carta Geologica del Molise. S.EL.CA, Florence, Scale 1:100,000.