

Numerical Modelling to Calibrate the Geotechnical Model of a Deep-Seated Landslide in Weathered Crystalline Rocks: Acri (Calabria, Italy)

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Abstract

Crystalline rocks are often subjected to several types of mass movements, depending on their weathering grade. These rocks are present in the European area along the Italian and French Alps, in the North-East area of Portugal, in the Sierra Nevada Massif (Spain) and in Greece. In particular, crystalline rocks are also widespread in Calabria and a high percentage of these rocks is present in the Sila, Serre and Aspromonte Massifs. Fresh or weathered crystalline rocks, highly fractured, may be affected by deep-seated landslides due to the presence of tectonic structures, which may predispose and control the landslide mechanisms. The Serra di Buda landslide, near the town of Acri (Cosenza), can be included among the deep-seated landslides which affect weathered crystalline rocks. Starting from the geological model, the analysis of the geotechnical data (digital terrain model, borehole logs, piezometer levels, superficial and deep displacements, geomaterial characteristics, etc.) allows to detect the uncertainties inherent the elements that concur to define the geotechnical model. To reduce some of these uncertainties a calibration by means of numerical modelling is carried out, and the results obtained show the usefulness of this approach.

Keywords

Deep-seated landslide • Weathered gneiss • Numerical modelling

223.1 Introduction

Deep-seated slides are phenomena that develop a failure zone/surface at depths greater than 30 m, and they may often be characterised by a catastrophic evolution, which may cause significant damages, also in term of loss of lives.

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The knowledge of a geotechnical model of this type of landslides, capable of summarise their fundamental elements, may lead to a correct management of risk. However, the definition of the geotechnical model is not easy, because it includes uncertainties which increase with the size of the landslide volume. These uncertainties are linked to the difficulty to individuate, for such a great volume:

- the stratigraphic and structural conditions;
- the pore pressure regime, related to the hydraulic features of the slope;
- the representative geotechnical parameters of the geomaterials involved into the landslide.

All these elements justify the study of deep-seated landslides, with the aim to progressively improve the capacity to act in terms of risk reduction and mitigation.

In this paper, the deep-seated Serra di Buda landslide will be analysed, by means of numerical modelling. After illustrating the elements which characterise the geo-environmental context of the case study, and on the basis of the

geological model, the elements which contribute to the definition of the geotechnical scheme will be described, highlighting the uncertainties level and the calibration procedure required to optimise the available elements.

223.2 The Case Study: Serra di Buda Landslide

The Serra di Buda landslide, located near the town of Acri (Cosenza), on the western side of the Sila Massif, is part of a wide Sackung-type Deep-seated Gravitational Slope Deformation (Sorriso-Valvo et al. 2005) (Fig. 223.1). The landslide involves high-grade metamorphic rocks, composed by biotite–garnet and sillimanite gneiss, which are intensely fractured and weathered (Borrelli et al. 2012). The slope involved in the landslide is characterised by a high structural complexity, due to the presence of several fault systems. In particular, an important role in the predisposition to the instability is played by the presence of degraded zones, with a soil-like consistency and local argillified levels, associated to thrust planes which daylight on the lower part of the slope.

The results of the geological-structural and geomorphological studies, supported by monitoring and geotechnical investigations, allowed to define the geological model of the Serra di Buda landslide. The geological model is characterised by a complex weathering profile, strongly controlled by tectonics (Borrelli and Gullà 2012).

Starting from the geological model, with reference to a section representative of the landslide from a kinematic point of view (Gullà et al. 2004), a preliminary geotechnical scheme of the landslide was defined (see Fig. 223.2a in the

next section). The geotechnical scheme is composed of two zone: the upper zone named C_rock, that reaches a maximum depth of 150 m, includes rocks from moderately to intensely fractured, and colluvial and detrital soils which are passively involved by the deep-seated landslide; the lower zone named “Bedrock”, at depth more than 150 m, is constituted by fractured fresh rock.

In the C_rock zone two bands of completely degraded rock were considered to schematise the tectonic structures detected in the Serra di Buda slope (C_soil_1, the upper, and C_soil_2, the lower). Relatively to the uncertainties previously defined, this paper focuses on the uncertainties related to the geometry of tectonic structures and the pore pressure regime.

223.3 Calibration of the Geotechnical Model

To reduce the uncertainties detected in the geotechnical scheme, a calibration of the geotechnical model, by means of numerical modelling, was carried out. The calibration consisted in two stages:

- (1) in the first stage the geometry of tectonic structures was specified;
- (2) in the second stage the groundwater levels, which are able to cause instability conditions into the slope, were specified.

The calibration was carried out comparing, step by step, the calculated and measured displacements.

With the aim to run the numerical analysis, the FLAC code (Cundall 2008), which implement the Finite Difference Method, was used.

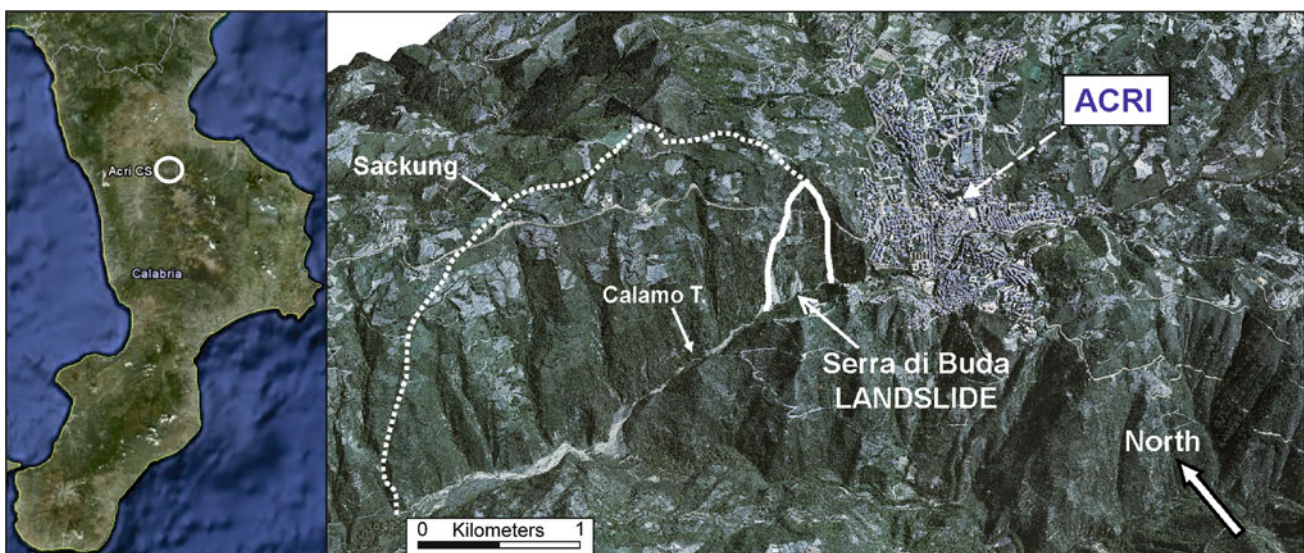


Fig. 223.1 The Serra di Buda landslide and the Sackung involving the slope near the town of Acri (Cosenza)

Fig. 223.2 Initial (a) and final (b) geometric configurations used in the first stage of the calibration, and comparison between the S3 measured and calculated inclinometer displacements

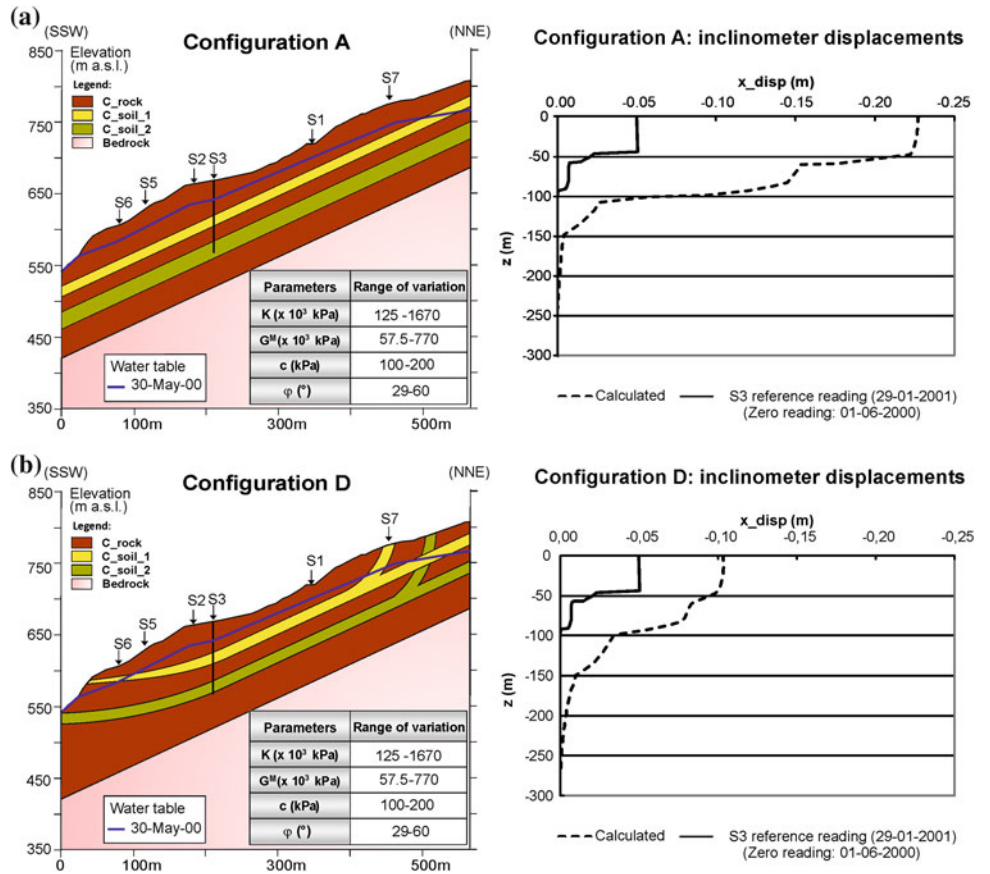
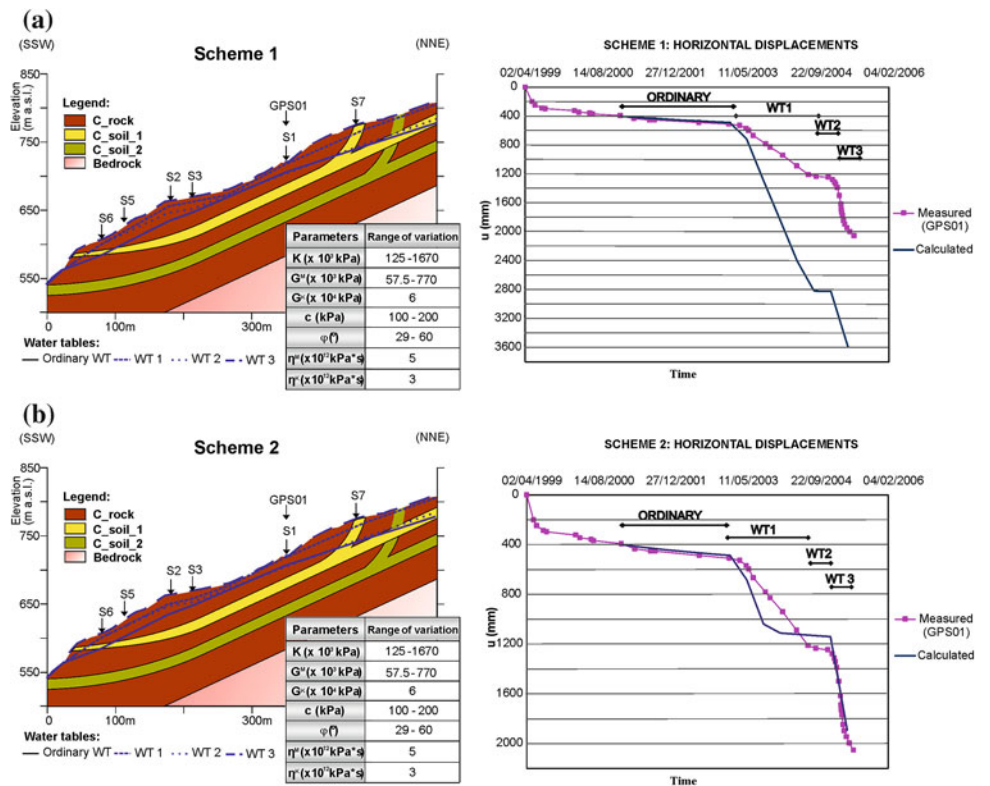


Fig. 223.3 Schemes, (a) and (b) (characterised by different water tables), used in the second stage of the calibration, and comparison between the measured and calculated horizontal displacements, with reference to the GPS01 point of the GPS monitoring network



The calculation schemes were characterised by a 5×5 grid. Roller boundary conditions were imposed at vertical border of the schemes, while at the scheme bottom fixed condition were applied. Moreover, the constitutive laws assumed for the materials characterising the calculation schemes were: in the first stage of the calibration, an elastic behaviour for the Bedrock and an elastic-plastic behaviour (Mohr-Coulomb model) for the other materials; in the second stage, a viscous-elastic-plastic behaviour (CVISC model) for the C_soil_1 zone was introduced.

Starting from the available data, the first stage of the calibration consisted in the specification of the geometry of tectonic structures, with reference to the shape and the position of the bands C_soil_1 and C_soil_2 (Fig. 223.2). The numerical modelling was carried out, by fixing, each time, both the water tables (reconstructed from the available piezometer measures) and physical-mechanical parameters (resulting from the integration of geotechnical tests results and literature data) and by varying the C_soil_1 and C_soil_2 bands geometry. For the sake of brevity, in Fig. 223.2 are shown the initial and final calculation schemes for this stage. Figure 223.2 also shows the results obtained from the numerical analysis, compared with the measured inclinometer displacements along a reference borehole. The results obtained suggest that, in the final scheme, the position, the shape and the thickness of the C_soil bands are adequate to simulate the failure zones detected from the inclinometer measures.

The second stage of the calibration consisted in the specification of the pore pressure regime able to cause, over time, instability conditions. In the calculation schemes, the pore pressure regime was schematised by means of a water table reconstructed from the available piezometer measures. The numerical modelling was carried out, by fixing, each time, both the physical-mechanical parameters and the bands geometry (as defined at the end of the first stage) and moving the water table with reference to defined positions. In Fig. 223.3, with reference to a representative point, are shown the results obtained from the analysis, compared with the data of monitoring (Maiorano 2013).

223.4 Conclusions

The results obtained from the numerical modelling allow to specify the shape, the position and the thickness of the zones associated to the tectonic structures, with reference to the inclinometer measures.

Due to the complexity of the pore pressure regime, typical of weathered and degraded crystalline rock mass, the individuation of representative piezometric levels is not easy. However, the calibration lead to define some characteristics of the pore pressure regime (schematised by means of a piezometric line) which are able to reproduce adequately the time-displacements curve (Fig. 223.3). In particular the analysis shows that high levels in the middle-lower part of the slope, may cause an increase in displacements, allowing to reproduce adequately the time-displacements curve.

In conclusion, the present paper shows the usefulness of stress-strain numerical analysis in the study of deep-seated landslides. In particular, already at this level of study, the numerical modelling carried out, mainly supported by displacements monitoring, allowed to reduce the uncertainties of the geotechnical model and to improve significantly its forecasting capabilities. The importance of superficial displacements monitoring, through GPS, must be highlighted. In fact, as regards the case study, the data obtained through GPS monitoring can be assimilated to the results of a full-scale test. So, for further developments of the study and always through the comparison between measured and calculated displacements, the GPS data can be used to calibrate also the mechanical parameters of the geotechnical model (Maiorano 2013). Given the complexity and the time consuming costs required by the definition of the geotechnical model of deep-seated landslides, it would be advisable to use the results obtained as reference to planning the study of other similar cases.

References

- Borrelli L, Gullà G (2012) Modello geologico-tecnico della frana di Serra di Buda (Acri - Cs). *Rend Online Soc Geol It* 21:525–527
- Borrelli L, Perri F, Critelli S, Gullà G (2012) Minero-petrographical features of weathering profiles in Calabria. *Southern Italy Catena* 92:196–207
- Cundall P (2008) *FLAC user's manual*. Itasca Consulting Group, Minneapolis
- Gullà G et al (2004) Landslides: evaluation and stabilization. In: Lacerda WA, Ehrlich M, Fontoura SAB, Sayão ASF (eds) 9th international symposium on landslides, Rio de Janeiro, June-July 2004. Failure and post failure conditions of a landslide involving weathered and degraded rocks, vol 1 (A.A. Balkema Publishers, London, 2004), p 1241
- Maiorano SC (2013) Ph.D. Thesis, Università degli Studi Mediterranea di Reggio Calabria
- Sorriso-Valvo M, Gabriele S, Gullà G, Antronico, L, Tansi C, Greco R, Fantucci R (2005) Studio geologico-geomorfologico-geotecnico e monitoraggio della frana di Serra di Buda (Acri) (Rubettino Industrie Grafiche ed Editoriali, Catanzaro)