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Study and modelling of a heterogeneous debris slide

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ABSTRACT

The paper describes a new approach to the study of heterogeneous debris slides. For this purpose, an investigation was carried out in the field as well as the laboratory. The two-dimensional computation techniques of Distinct Element Method were applied for the prediction of the displacements in the landslide. The predictions accord well with the results of inclinometer measurements in the landslide. This technique can be applied with some modifications to many soils that can be treated as heterogeneous debris (silty-clayey matrix with big boulders), such as those found along the Alpine arc. The study also demonstrates that it is possible to adapt the mathematical models implemented in the up-to-date calculation programs for particular needs, even if this is to the validity limits of the theory.

INTRODUCTION

The determination of the geotechnical properties of heterogeneous debris is quite difficult because of its complex nature. For instance, the presence of big boulders in the silty-clay matrix complicates its behaviour significantly. The general laboratory tests allow us to analyse in a complete way only the matrix, and hence it is insufficient for comprehending the real mechanism of failure.

This explains the interest to investigate this problem in detail, trying to follow new investigation techniques in order to understand these phenomena. For this purpose, we chose a landslide (Plate 1) that has reactivated from time to time since the beginning of the 19th century. It is situated on the left flank of the Luserna Valley, a branch of the Pellice Valley in Piedmont, Italy. Owing to its rather small dimensions, it was possible to carry out the detailed investigations, which lasted for more than a year.

Plate 1: View of the landslide at Luserna, Italy

PHYSIOGRAPHY

The Pellice Valley lies in the Western Alps of Northwest Italy, about 60 km away from Turin in the Piedmont (Fig. 1).

GEOLOGICAL SETTING

The area falls in the Massif of Dora-Maira, as shown on the 1:100,000 scale geological map of Italy. This Massif extends more-or-less between the Susa Valley in the north and the Maira Valley in the south, and its genesis is rather disputed. It is known, together with the Gran Paradiso and Monte Rosa, as one of the crystalline Massifs that are inside the Western Alps.

The Massif of Dora-Maira extends for about 1,000 km^2 from the Susa Valley to the Maira Valley, and is delimited in the north and west by the Piedmont zone, and in the east by the Quaternary deposits of the Po Plain. Together with the

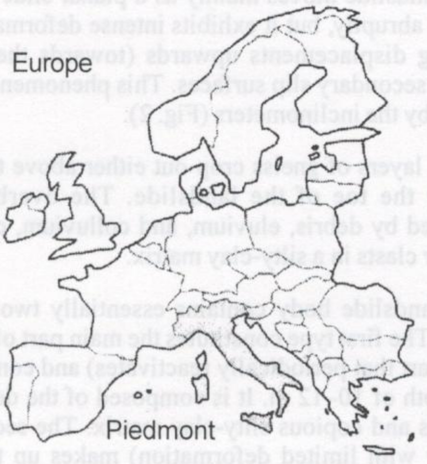

Fig. 1: Location map of the Piedmont

Nappes of Monte Rosa and Gran Paradiso, the Dora Maira represents a portion of continental crust belonging to the units of the upper Pennidic Zone. The Dora Maira Massif is made up essentially of a pre-Carboniferous polymetamorphic base and a Carboniferous-Permian monometamorphic cover (Cadoppi 1990).

The area comprises a group of gneissic rocks consisting of alternating gneiss with large lenses of quartz, and leucocratic tourmaline gneiss and mica schists. In particular, in the study area, the rocks are made up of schistose gneiss that have got fine grains, at times highly foliated, known in the literature as the Luserna Gneiss. The rocks generally crop out in sub-horizontal (up-to 20°) layers, which are up to 10 m thick and dip due west. Under the microscope, the gneiss shows a planar schistosity and a microcrystalline texture, and contains mainly feldspars (40–50%), quartz (30–40%), and muscovite (5–10%).

The rocks are frequently ramified by east-west trending sub-vertical joint systems and some faults (trending due N 20°E and E-W) accompanied by cataclastic belts with a thickness varying from some decimetres to a few metres.

Landslide history

The slide has been moving slowly but periodically since the beginning of the 19th century (1840–1948). During the extreme climatic events, it reactivates from time to time with sudden displacements of a considerable magnitude. The value of these displacements is not known with certainty, but undoubtedly there were significant movements that caused the collapse of a school building and serious damage to the country road running along the crown of the landslide.

In the following years, the movements continued with strong reactivation, and were recorded in the municipal documents as well as by the local Waldensian Church (we have data of some movements in 1881, 1949, 1977, 1989). To date, the landslide is moving at a steady rate of a few centimetres per year.

Morphology and evolution of the landslide

The landslide moves mainly as a planar slide and does not move abruptly, but it exhibits intense deformation with increasing displacements upwards (towards the ground) along the secondary slip surfaces. This phenomenon is well recorded by the inclinometers (Fig. 2).

Thick layers of gneiss crop out either above the crown or below the toe of the landslide. The overburden is represented by debris, eluvium, and colluvium, composed of angular clasts in a silty-clay matrix.

The landslide body contains essentially two kinds of material. The first type constitutes the main part of the slide (i.e. the part that periodically reactivates) and continues up to the depth of 10–12 m. It is composed of the debris with big blocks and copious silty-clay matrix. The second type (probably with limited deformation) makes up the upper portion of the rocky sub-layer and contains muscovite gneiss, which is strongly fractured and moderately weathered up to the first 4–5 m, but below 15–20 m, the gneiss appears to be fesh and blue-grey in colour (i.e. the typical colour of the Luserna Gneiss).

The inclinometer measurements permitted to reconstruct the displacement direction of the landslide in the vicinity of the residential area located at the northeastern edge of the slide. After monitoring for more than a year, a slow (about 1 cm/year) and steady movement towards the southwest was recorded. It had a negative impact on the stability of the residential area.

METHODOLOGY OF STUDY

The study was based (Barisone and Bottino 1990) on the following information (Fig. 3 and 4):

- landslide history and rainfall data;
- topographical survey, geomorphological survey, and seismic survey;
- geotechnical investigations (core drilling, soil penetration test, Schmidt hammer tests as well as inclinometer, extensometer, and tiltmeter measurements and elastic waves speed measurements);
- groundwater study (measurement of temperature, pH, chemical analysis, water table fluctuation, piezometric measurements); and

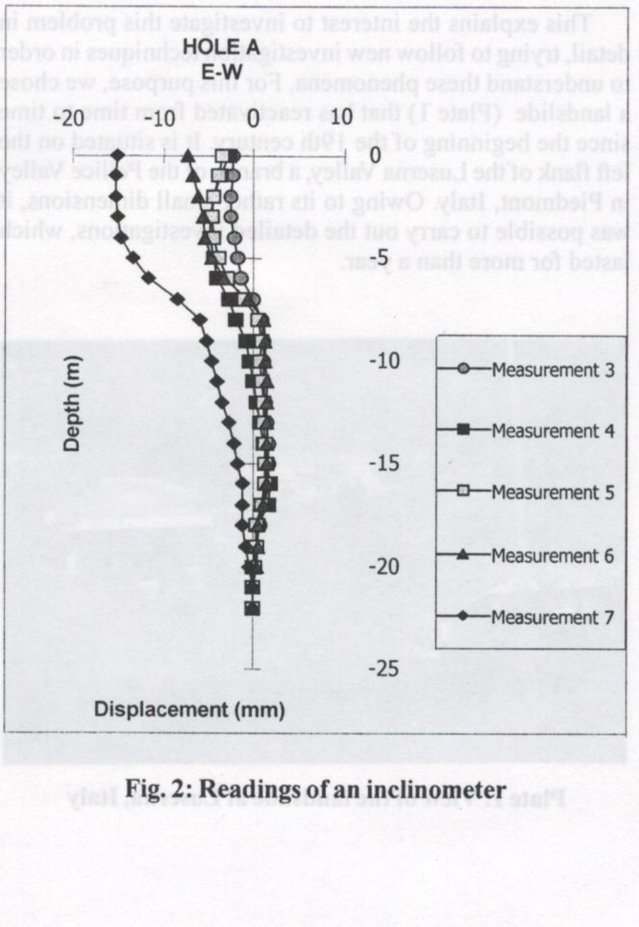

Fig. 2: Readings of an inclinometer

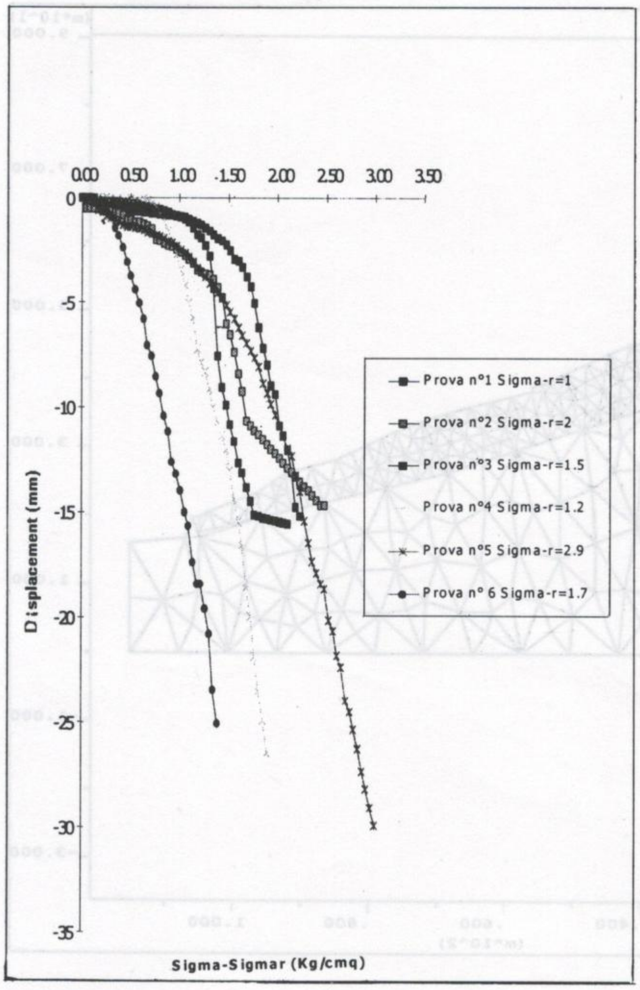

Fig. 3: Results of triaxial compression test

general and special laboratory tests (uniaxial compression, triaxial compression, shear test, granulometry, Atterberg limits, clay mineralogy, study of thin sections).

The in situ investigations provided the important information on the composition of the landslide, the position of perched water tables within the landslide, the location of slip surface, the amount and direction of displacement, and the elastic-dynamic modulus of the layers involved in the movement. From the measurements and simultaneous analysis of the soil profile, we deduced the presence of two perched water tables with different sources, and consequently their seasonal trends, chemical composition, and temperatures. After the determination of various layers in the landslide, the laboratory tests permitted to determine their geotechnical and mechanical properties.

We also studied the geometry of the landslide, its water table characteristics as well as c and j values. These parameters were used for the stability analysis of the slide using one of the classical methods (i.e., the Janbu Method). In addition, a copious series of supplementary parameters (e.g., the elastic modulus, normal and tangential stiffness of the sliding surface, cohesive strength, and permeability of the discontinuities) was also obtained for carrying out further detailed analysis.

The Distinct Element Method of modelling

The choice of a Distinct Element Method (DEM), instead of the most classical and widely used Finite Element Method (Swoboda 1988), is due to the fact that the phenomenon we are studying is not exactly a continuous medium, at least for two reasons: firstly, there is well-defined slip surfaces and secondly, there are big boulders that are significantly different from the matrix.

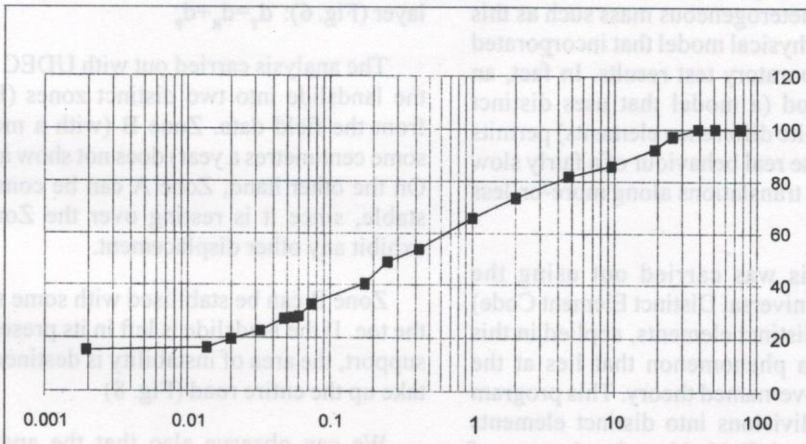

Fig. 4: Granulometry of the matrix

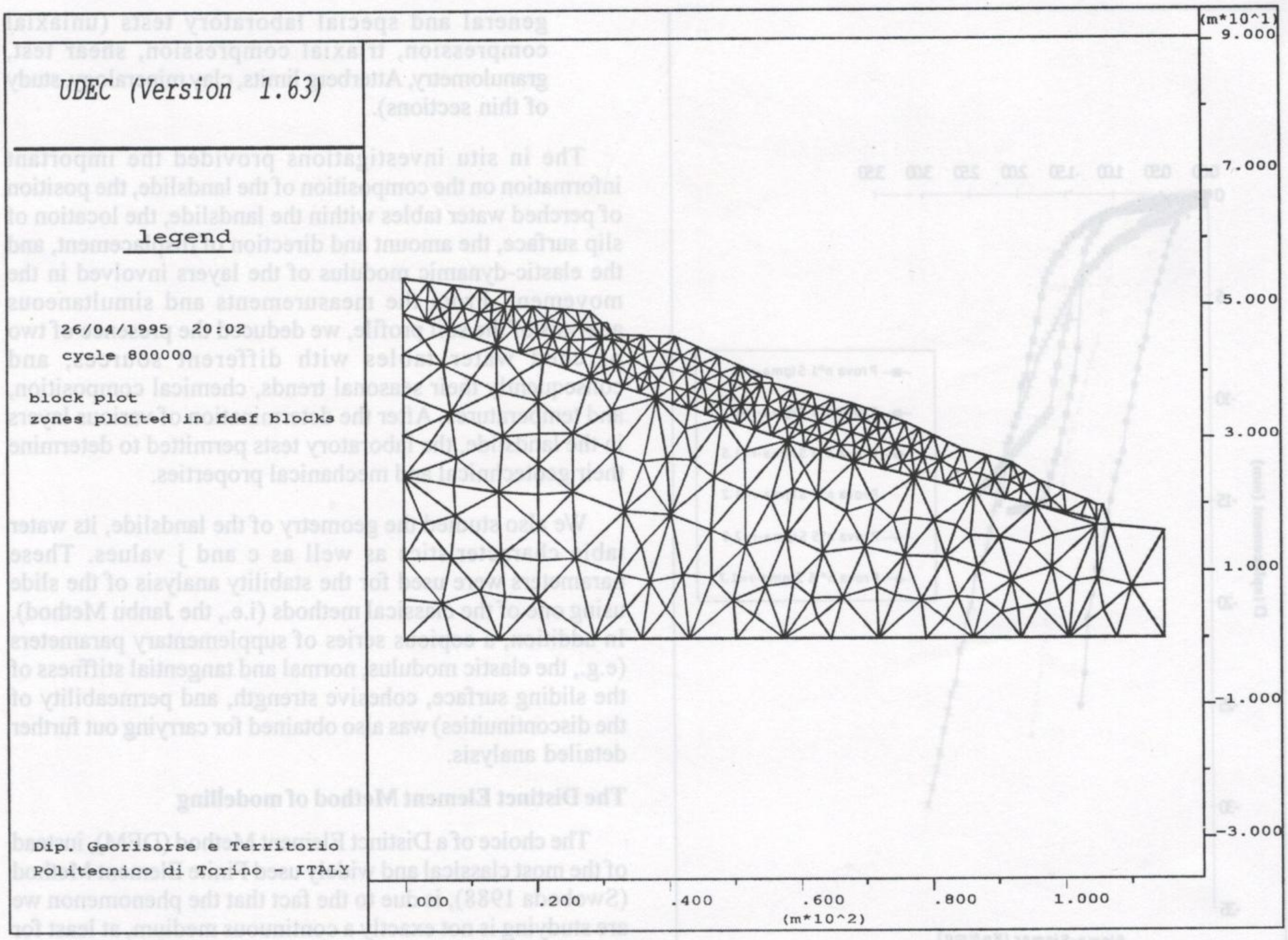

Fig. 5: FLAC grid on a UDEC model

For the purpose of estimating the geotechnical and geomechanical properties of a heterogeneous mass such as this landslide, we formulated a physical model that incorporated the field data as well as laboratory test results. In fact, an integrated numerical method (a model that uses distinct elements subdivided into finite difference elements) permits to simulate in the best way the real behaviour of a fairly slow deformation, involving also translations along more-or-less definite surfaces.

The numerical analysis was carried out using the calculation model UDEC (Universal Distinct Element Code) based on the theory of the distinct elements, applied in this context in order to study a phenomenon that lies at the application limits of the above-named theory. This program (Fig. 5) combines the subdivisions into distinct elements (block units) that are further subdivided into the elements of finite differences (for instance FLAC, Fast Lagrangian Analysis of Continuum). In this way, the resultant of displacement vectors is obtained by adding the two components: 1) due to the plastic deformation of the mass and 2) due to the stiff sliding of the mass on the rocky sublayer (Fig. 6): $d_T=d_R+d_P$

The analysis carried out with UDEC permitted to divide the landslide into two distinct zones (Fig. 7), as deduced from the field data. Zone B (with a movement quite fast: some centimetres a year) does not show any signs of stability. On the other hand, Zone A can be considered temporarily stable, since it is resting over the Zone B and does not exhibit any other displacement.

Zone B can be stabilised with some support measures at the toe. If the landslide is left in its present state without any support, the area of instability is destined to grow wider and take up the entire road (Fig. 8)

We can observe also that the analysis shows that a lowering of the water table by 0.5 m increases the stability conditions significantly. This points out that it is possible to intervene not only with works like retaining walls, diaphragms, and the like, but simply and cheaply with sub-

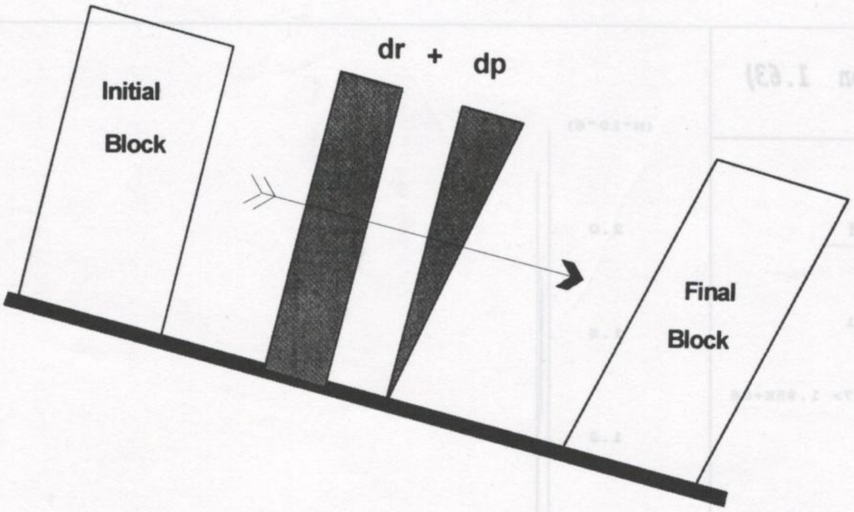

Fig. 6: The displacement vector is produced by adding two components: dr – translational component and dp – rotational component.

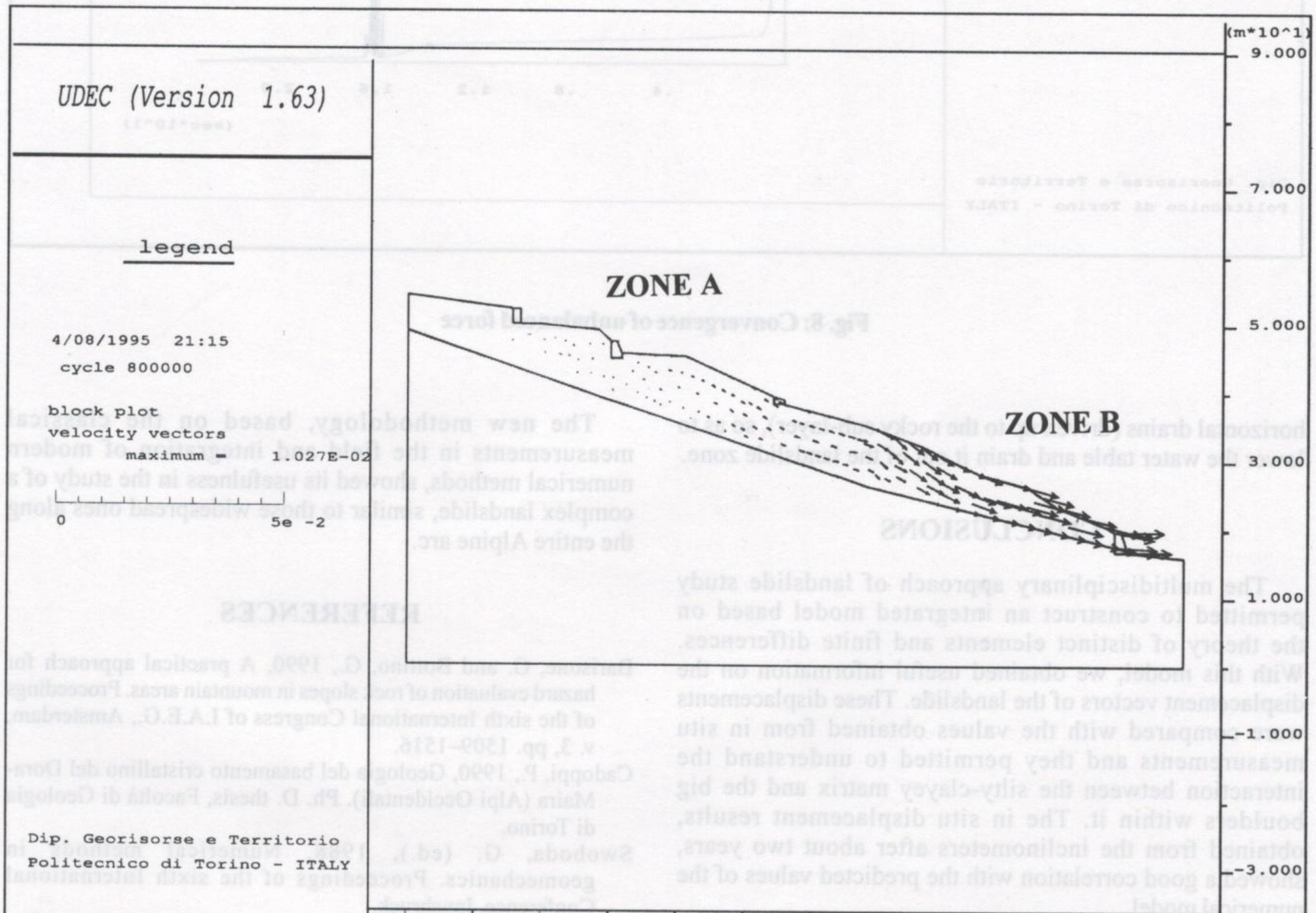

Fig. 7: Displacement vectors is produced by the addition of two components.

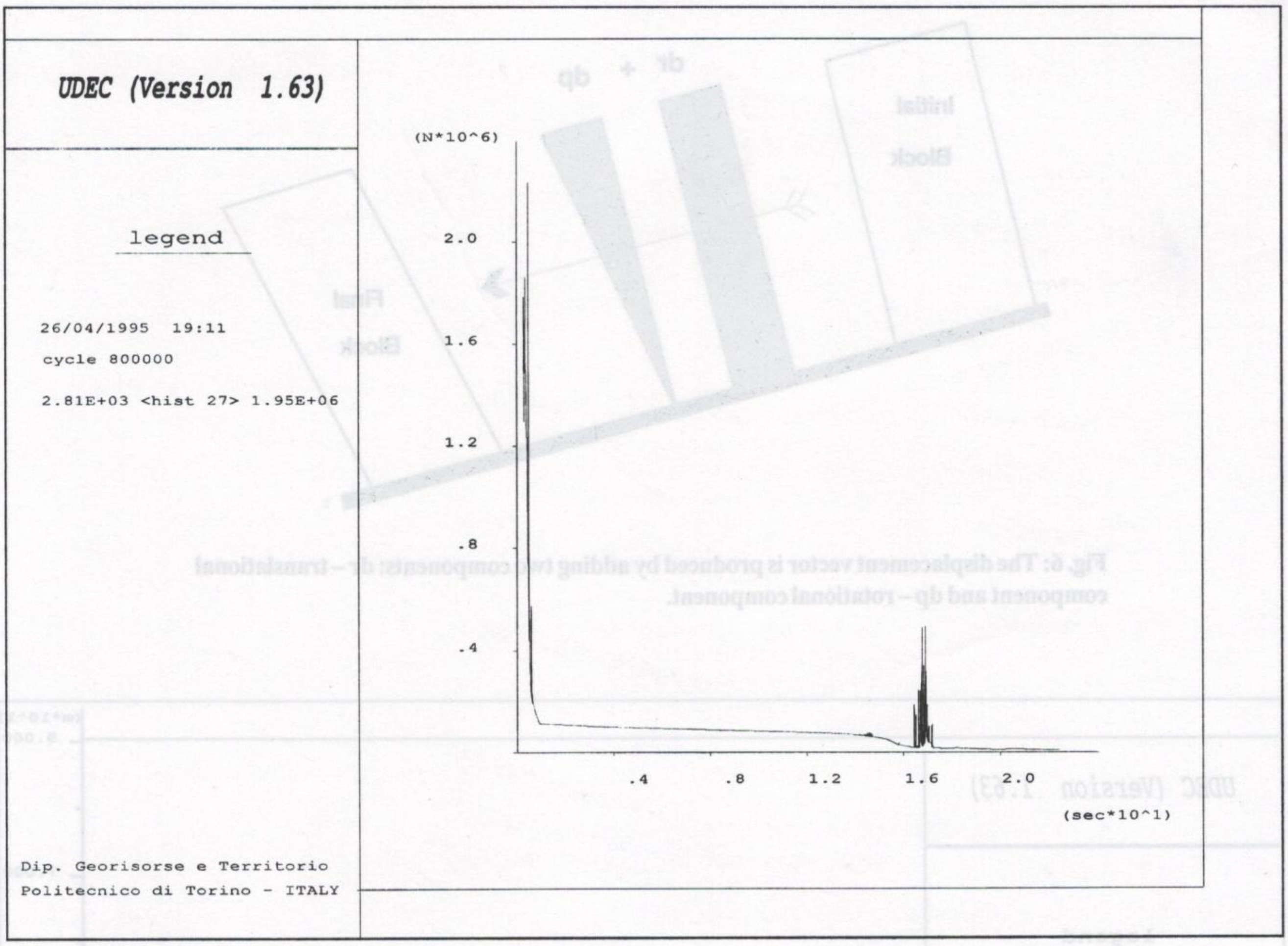

Fig. 8: Convergence of unbalanced force

horizontal drains (driven up to the rocky sub-layer), so as to lower the water table and drain it out of the landslide zone.

CONCLUSIONS

The multidisciplinary approach of landslide study permitted to construct an integrated model based on the theory of distinct elements and finite differences. With this model, we obtained useful information on the displacement vectors of the landslide. These displacements were compared with the values obtained from in situ measurements and they permitted to understand the interaction between the silty-clayey matrix and the big boulders within it. The in situ displacement results, obtained from the inclinometers after about two years, showed a good correlation with the predicted values of the numerical model.

The new methodology, based on the classical measurements in the field and integration of modern numerical methods, showed its usefulness in the study of a complex landslide, similar to those widespread ones along the entire Alpine arc.

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