A numerical model simulation of an instability phenomenon: the Gardiola case (Germanasca Valley – Italy)

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Abstract

A water course obstruction caused by a landslide is a phenomenon that may cause high risky situations for anthropic sites located both up and down the natural dam. Following the intense raining period of last 13-16 October 2000 in the North West Piedmont and Aosta Valley, a lot of instability cases were reported to the authorities of all Turin Province; in particular, the CNR-IRPI of Turin has been in charge to check the cracks phenomenon that destroyed part of the road that connect Pinerolo to the Germanasca Valley (West Piedmont) with particular regard to the landslide interference with the Germanasca stream.

Immediately after the first report, a topographic monitoring system was installed in the area and the relationship between the landslide and the raining phenomena was clear. A numerical model of the system was then developed to assume possible scenarios caused by an eventual collapse of the natural dam, assess the risk of stability and to design appropriate defensive handmade.

1 Introduction

The area where the landslide reactivated, is on the left side of the Middle Germanasca Valley, North West of Gardiola, Salza di Pinerolo municipality. In the Gardiola area the valley is very steep and narrow, with a valley floor 30m wide. On the right side, the valley’s original glacial profile is deformed with a pronounced gravitational spur.

The surface reactivated by the landslide occupies a morphologically well defined hollow along the slope, characterized by scarps and counterslopes features which witness repeated reactivations. Geomorphological evidences of
the reactivation of the landslide are some earth cracks at an altitude of about 1300 m a.s.l., and deformation of Germanasca river's low flow bed at the landslide's toe. The landslide's right side corresponds to a small cut that runs immediately on the outer side of a curve on the S.P. 169; the left side, about 200m NE, is limited by a cut with a high waterflow and by a slope welt; the landslide's surface is about 40 000m².

Bedrock geology of the area is characterized by micaschists (Complesso del Dora Maira), with subordinated lenses of marble with silicates and matabasites. Superficial formations are mainly colluvial and landslide deposits. On the right side, just in front of the reactivated landslide, the presence of a relict landslide, which is now stabilized, deforms with a pronounced spur the valley's regular profile created by glacial activity. The study of the aerial photographs from 1980 (C.G.R.A Parma) and 1999 (Alifoto, Torino) flights evidenced on the slope a km-wide deep seated gravitational deformation.

2 Pluviometric analysis

Rainfalls precipitation are one of the most events that causes activation of a landslide phenomenon.

Data archived by a weather station installed in Praly (TO), 3 km SW from the investigation area, underlines a strong pluviometric trend signed by the flood event of October 2000 and by a subsequent collapse of fluid precipitation (Fig. 1), caused by the progressive diminution of temperature who support snow precipitation.
One of the most important characteristic of these pluviometric-data is the time duration of maximum precipitation intensity in October 2000 was represented by a raising of water-bearing stratus for long time. These phenomenon had caused the reactivation of landslide who returned in his static stability after diminution of raining flow.

3 Topographic measurements

After ascertained the high-risk situation, it was projected the installation of a topographic system to monitoring the movements. After the high-movements caused by the alluvial event, it was possible to install a new topographic monitoring system equipped with a robotized total-station. The daily measurement-database is stored and send by a GSM connection to a workstation located at CNR – IRPI offices. In the landslide zone there are 16 retro-reflection-prisms acquired by the monitoring system every 3 hours.

The monitoring system has permitted defining with great precision the unstable area, controlling the goodness of the structural projects carried out after the event and, especially, making hypotheses about future scenery of the phenomenon by using numerical models. The situation-graph shows how in the month of March there was an incremented movement caused by snow melting, and in the month of May caused by an increment of the rainfall: in this situation a new little collapse occurred in the lower area of the slope.

Figure 2: Recorded displacements of prisms situated on the landslide, immediately after the alluvial event
4 Correlation between rainfalls and displacements

It is very interesting, after the observed results, to find a relationship between pluviometric regime and displacements. It is possible making hypotheses about the future scenery and define suitable project of intervention reducing the risk.

A first comparison, between the total daily rainfalls and the movement’s velocity of the landslide area, was made. It is evident, from obtained results, the rainfalls influence on the stability of the slope, and some explanations seem appropriate:

- The slope answer, in consequence of rainfalls, is only evident with rainfalls of particular entity (rainfalls below 30 mm/d, do not produce any displacements);
- A little delay is observed between rainfalls peak and displacements velocity peak and, moreover, exhaustion velocity curve seems to decrease slowly: it is possible thinking that there is a great influence of the underground stratum on the restoring phenomenon.

Figure 3: Comparison between daily rainfall and recorded displacements velocity

5 Using a numerical model to look for possible scenery of risk

The use of a numerical model is due to the necessity of simulate, at least qualitatively, the slope behaviour with different water table levels. It is certain, in fact, that the most important causes of movements are the high rainfalls occurred...
between 13 and 16 October 2000 which had caused an increasing in the water level (the same phenomenon can be caused by snow melt during spring).

After a preliminary valuation, carried out with topographic monitoring and with the results of the preliminary investigations executed immediately after the alluvial event, a volume of 800,000 m$^3$, in temporary stability situation, was estimated. Such volume of material, in case of full collapse, could generate a 60 m high dam, large 120 m and length 200 m at the top. The upstream basin created will submerge an area of 100,000 m$^2$, until 1240 m and will contain about 700,000 m$^3$ of water.

5.1 Common features of numerical models

The solution of a geomechanical problem needs to be satisfied the equilibrium and congruence conditions and the constitutive ties of materials. Since many terrain have a multiphase system, it is very difficult to define initially the right parameters. For these problems, it is necessary introduce some simplifications to become to solutions with some practical utility and, when it is possible, verify results with direct in situ measurements. In this case, the possibility to control the results of movements obtained from modelling and movements measured by the topographic control grid, has been of great importance; this fact has allowed to modify the parameters of the simulation by using a back analysis method. The calculation model used in this case is the FLAC (Fast Lagrangian Analysis of Continua). The model applying to a defined grid the motion equations and the constitutive laws for solid body, allows to know the tensional situation, movements and break mechanism inside the slope.

![Cross section of the unstable slope at Gardiola site (Germanasca Valley)](image)

Figure 4: Landslide slope discretization. The continuos line shows the substratum-covering contact.
The solid body, in this case the slope section, is divided in a grid formed by elements of quadrilateral shape, internally divided in four triangular elements laid upon in pair.

5.2 Evaluation of slope stability conditions

As evident from topographic measurements, the water table influences slope stability conditions very much. For these reasons, it has been executed, firstly, an analysis with the water table located about 100 m under surface, at the top of the represented slope (Analysis without water table). In these conditions the slope is considered substantially steady and so it is possible to verify the accuracy of deformability and strength parameters. Geotechnical parameters have been found from literature, because there were not data obtained from direct experiments on slope material (for logistic problems to operate on landslide area and for the particular characteristics of the same materials) and then they have been calibrated with a back analysis process.

Table 1: Final parameters from back analysis

<table>
<thead>
<tr>
<th>Material</th>
<th>$\gamma_a$ [kg/m$^3$]</th>
<th>$\phi$ [Kpa]</th>
<th>C [MPa]</th>
<th>E [MPa]</th>
<th>$\nu$</th>
<th>K [MPa]</th>
<th>G [MPa]</th>
<th>T [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substratum</td>
<td>2600</td>
<td>45</td>
<td>600</td>
<td>15000</td>
<td>0.25</td>
<td>1000</td>
<td>600</td>
<td>1</td>
</tr>
<tr>
<td>Covering</td>
<td>2000</td>
<td>42</td>
<td>6.4</td>
<td>385</td>
<td>0.29</td>
<td>330</td>
<td>200</td>
<td>0</td>
</tr>
</tbody>
</table>

The definition of the rock substratum position has been very complex, in fact direct surveys, which can give some information on his correct position, don't exist and moreover geological data are very contradictors. After these considerations, it was decided to introduce the substratum-covering contact surface at a such depth (about 110 m at the top of the slope) to do not influence the unstable mass behaviour. In the lower area of the slope, near the river, the surface contact was positioned with precision, thanks to the observation of some outcrop areas.

5.3 Analysis with changing water level

A lot of analysis have been carried out by increasing progressively the water level, until a position critical for slope stability conditions has been found.
Figure 5: Landslide displacements area. Prisms for topographic monitoring and the water table are represented

It was impossible to verify the correspondence between the estimated critical water level, situated about at the depth of 51 m (at the top of the represented slope) and the real water level position, which has caused the movements. Geophysical surveys, executed 20 days later the alluvial event on the slope near prism 10, have shown a possible water level 20 m under the surface; in the same point, the water level derived from the simulation is about at the depth of 17 m.

The model, with the water level at the estimated altitude, didn’t reach the convergence for the great movements at the foot of the slope. In this situation it is possible to guess a probable breakage and falling down phenomenon at the foot of the slope, as really happened in the month of May (Fig 2, prism 5).

Table 2: Comparison between values of the real displacements and the simulated displacements during springing rainfalls of May

<table>
<thead>
<tr>
<th>Prism n.</th>
<th>Displacements detected by motorized total station (m)</th>
<th>displacements predicted by FLAC (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>1.4</td>
<td>2.2 ± 2.4</td>
</tr>
<tr>
<td>10</td>
<td>1.8</td>
<td>2.2 ± 2.4</td>
</tr>
<tr>
<td>5</td>
<td>2.2</td>
<td>2.4 ± 2.6</td>
</tr>
<tr>
<td>3</td>
<td>2.6</td>
<td>2.2 ± 2.4</td>
</tr>
</tbody>
</table>

It has been possible found the zone of the slope in which there is plasticization; this area locates the potential sliding surface (Fig. 6).
The upstream zones of plasticization are not significant because these are very near at the boundary of the model and because they don’t represent a continuous line of plasticization, starting and ending from surface.

The good correspondence between reality and the results of simulation is also given by the position of tension cracks, that shows the crack at the crown of the slope (Fig. 6). This is situated about at 1265 m by the model, while it is really at 1275 m.

The results of electric tomography have indicated a potential sliding surface about at the depth of 20 m from surface; the numerical model find the sliding surface between 15 m and 20 m, showing, in this case, a good agreement with geophysical surveys.

The previous analysis simulate slope behaviour with swings of the water level; the critical level of these one, probably reached during the days following the alluvial event of October and during rainfalls of may, has caused the slope instabilisation, in all two situations; in particular during the springing period the collapse of the area at the foot of the slope has been recorded.

5.4 Hypothetical scenery

The reload of the underground stratum, following snow melt and rainfalls of may, has caused the general restoring of the instability phenomenon and the collapse of the area at the foot of the slope.

Considering the new morphology of the slope, some further simulations have been carried out to find hypothetical future scenery of the crumbling event.
In particular, starting from the critical water level previously defined, it was tried to understand if the critical water level could determine new slope instability situations.

The model converges and it is believable, from obtained results, that a further reaching of the critical water level doesn’t generate a new collapse with the new slope morphology. This critical level can generate slope readjustment with total movements of about 2 m (maximum cumulated movements of about 4.5 m).

Finally the simulation tried to find a new critical water table, from which a collapse of slope could start. After different simulations, with an increasing water level, a second critical level has been found; it is situated about at the depth of 40 m from surface (at the top of the represented slope) and it causes a total and general falling down of the slope, consequently to the great movements recorded. The critical water table level, near prism 10, is higher than precedent situation; it is about at the depth of 14 m – 15 m.
Figure 8: Area interested by the instability phenomenon with the new critical water table level (The displacements are cumulated from the previously situation)

6 Conclusions

The numerical simulation with FLAC has allowed to define the critical conditions that probably have generated the restoring of the crumbling phenomenon, in consequence of the alluvial event of 13-16 October 2000 and during springing rainfalls of May 2001.

The amount of May instability phenomenon and the results of the topographic monitoring have been fundamental to define the characteristic geotechnical parameters of the slope, because values of geotechnical parameters coming from laboratory or in situ tests didn’t exist. From these information, the calibration of the model was carried out with a back analysis methodology.

With the numerical model a critical water table level, which produces displacements inside the slope, has been found using hydrogeological and topographic monitoring information. It has been impossible to verify the real position of the water level, because there isn’t a system of piezometer on the slope.

Some new simulations after the collapse of a slope zone in consequence of springing rainfalls, have been made do define some possible future scenery of the phenomenon. The critical water level initially defined can generate further displacements on the slope, without yet causing a collapse. A new increasing on water level, instead, can generate an extended falling down phenomenon on the slope.

A general falling down of the slope, as predicted from the last scenery, can obstruct the Germanasca river. This situation can produce a great basin, and
therefore the upstream zones can be submerged; an instantaneous collapse of the dam can induce a catastrophic flood wave involving down-valley villages.

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References