UDEC-application to the rock slope of "Sant' Andrea di Cadore" (Veneto Region, Italy)

(Kurzfassung der Diplomarbeit)

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Abstract

In times of increasing risks and damages caused by natural disasters it has become necessary to observe the traffic routes which are passing through the Alpine range. Also historic traffic routes have to be assessed with new scientific methods.

The applicability of rock mass classification systems to high rock slopes will be investigated. Therefore the rock slope of "Sant' Andrea di Cadore", situated in the Piave valley along the railway line Treviso – Calalzo, with an average height of 100 metres is taken as an example. The results will be confirmed by modelling and simulating the behaviour of the rock slope with the means of the Distinct Element Method (UDEC 3.1).

Zusammenfassung

In Zeiten von steigenden Risiken und Zerstörungen, die von Naturkatastrophen verursacht werden, wird es zusehends notwendig, die bestehenden Alpentransversalen erneut zu überprüfen und ständig zu beobachten. Auch historisch bestehende Verkehrswege müssen mit neuen wissenschaftlichen Methoden untersucht und beurteilt werden.

Die Anwendbarkeit und Eignung verschiedener Felsklassifikationssysteme auch für hohe Felsböschungen soll untersucht werden.

Hierfür wurde die Felsböschung „Sant' Andrea di Cadore", im Piavetal oberhalb der Eisenbahnlinie Treviso – Calalzo liegend, als Beispiel herangezogen. Die Felsböschung hat eine durchschnittliche Höhe von 100 m. Die Ergebnisse werden an Hand einer Simulation nach der Diskreten Element Methode (UDEC 3.1) verifiziert.

1 GEOLOGICAL SETTING

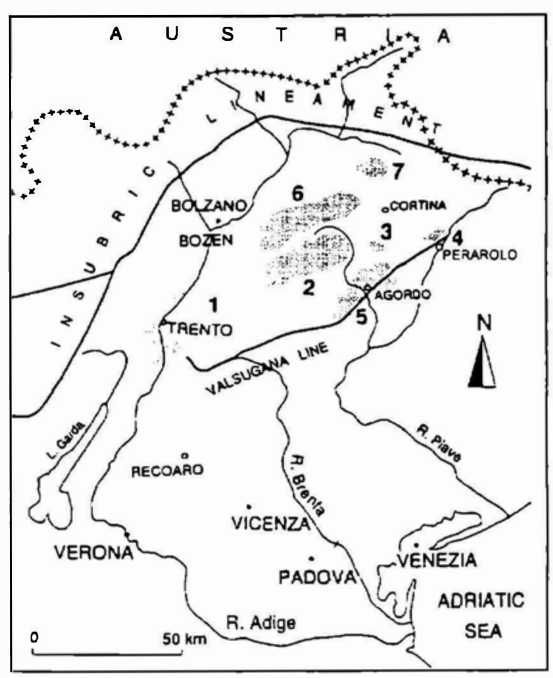

***Fig. 1** – Scheme of the Dolomite Region; DE ZANCHE et al. (1993) Legend: 1, Adige Valley; 2, SW Dolomites; 3, W Cadore; 4, eastern-central Cadore; 5, Agordo and Zoldo area; 6, NW Dolomites; 7, Braies area*

The area of this thesis submitted for a diploma is situated in the Eastern Dolomites at the confluence of the River Piave and the River Boite. The slope is exposed at S to WSW direction. The route of the railway line Belluno – Calalzo di Cadore and the old SS (Strada Statale) 51 "Alemagna", connecting Belluno, Longarone and Cortina d´Ampezzo are passing right through the landslide area. Above the railway line, at km 122+905,62 a rock slope of an average height of 100m menaces the line itself as well as the road and several houses (Case di St. Andrea).

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The rock slope consists in the lower part of the Cassian Formation (Carnian deposital sequence 2, DE ZANCHE, 1993) and in the upper part it is formed by the Dürrenstein Formation (Carnian deposital sequence 3). For about 100m along the railway line in direction Belluno, there is another endangered area. Placed in the Quaternary of the Valle del Boite (Boite Valley) a debris flow took place right underneath the railroad track. It occurred in December of the year 2000 after a heavy rainfall in the Cadore region. The debris flow phenomenon is situated in down slid big blocks of the Raibl Formation consisting of gypsum, red marls and gravel. Into this area during the past decades several boreholes were drilled to obtain more precise information on the debris flow. Thus, these two traffic lines, together with the village Perarolo di Cadore, are endangered by possible further slope movements.

According to stratigraphic units, the area is situated at the Lower Carnian age (Julian), consisting of the sequences Car 2 and Car 3. The Upper Carnian deposital sequence (Car 4) corresponds to the Raibl Formation. The Lower Norian deposital sequence (No 1) mainly consists of Dolomia Principale (DE ZANCHE, 1993).
This landslide area is situated inside the Valsugana line, south of the main thrust outcrops. The Valsugana line is one of the main tectonical thrusts in the Dolomites. South of the Valsugana line, an escorting minor thrust plane may separate the dolomites of the Cassian Formation from underlying Raibl beds with gypsum. These circumstances make the rock mass extremely disordered and faulted.

***Fig. 2** – The rock slope of "Sant' Andrea di Cadore". Picture taken from the opposite side of the Boite valley*

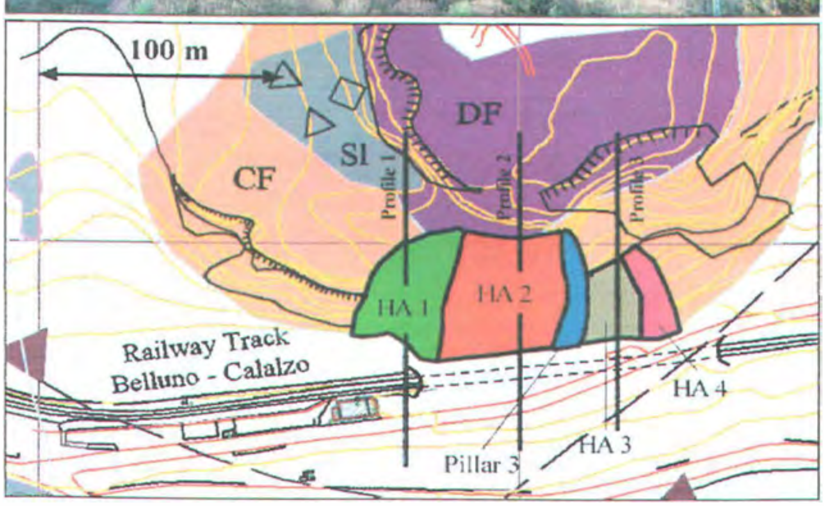

***Fig. 3** – Sketch of the rock slope and the "Homogeneous Areas" inside (HA1 – HA4).*

The profiles indicated are the three assumed profiles for UDEC-calculation.

Lithology:
CF *Cassian Formation*
DF *Dürrenstein Formation*
SI *Rockslide)*

2 THE SURVEY

The aim of the survey was to develop a Distinct-Element model of the rock slope, using the program UDEC 3.1 (Itasca, 2000). A Distinct-element model requires several input parameters, which are derived either by the means of field survey or by laboratory testing.
These input parameters are:
(using the Coulomb-Slip model)

- Joint normal stiffness
- Joint shear stiffness
- Friction angle
- Cohesion
- Tensile strength
- Dilation angle

and, of course

- Joint Orientation

It is, however, very difficult to obtain an appropriate number of undisturbed rock specimen for testing. Furthermore, tests are expensive and usually they take a lot of time.
Therefore the Rock Mass Classification Systems have been developed. These classification systems try to derive the parameters for calculation by a statistical approach. To create these systems, numerous rock slopes and debris flows all around the world were investigated, the failure mechanisms studied and the obtained data put into a classification system.
It is now possible to derive the required input parameters for distinct-element calculation from a visual survey of a rock slope, combined with the help of field tools like Clar´s compass, the Point-Load-Test tool and the Schmidt-Hammer.

The classification systems used in the survey were:

- Rock Mass Rating *RMR* (BIENIAWSKI, 1973, 1979, 1984, 1989)
- Slope Mass Rating *SMR* (ROMANA, 1985)
- Landslide Hazard Zonation *LHZ* (GUPTA and ANBALAGAN, 1995)
- Geological Strength Index *GSI* (HOEK, 1999)
- Slope Stability Probability Classification *SSPC* (HACK, 1998)

Parameters derived with the help of field tools:

- Discontinuity orientation (Clar´s compass)
- Joint Roughness Coefficient (JRC)
- Joint Compression Strength (JCS)
- Compressive Strength β_c , Friction Angle φ (Schmidt Hammer Index Test)
- Compressive and Tensile Strength β_c, β_t (Point Load Test)

All the 5 classification systems mentioned have been taken into consideration for the survey of the slope. The values are presented in the following chapter.
Joint orientations were measured by two means. On the one hand with the classical method of the Clar´s compass, and on the other hand by photogrammetric survey of the slope (with the ZEISS UMK 10/1318).

3 PERFORMANCE OF ANALYSIS OF THE ROCK SLOPE "SANT' ANDREA DI CADORE" USING UDEC 3.10

The following analysis of the rock slope was performed, taking account of the proposed solution scheme presented by the Itasca Consulting Group.

Load assumptions were applied due to the following scheme.

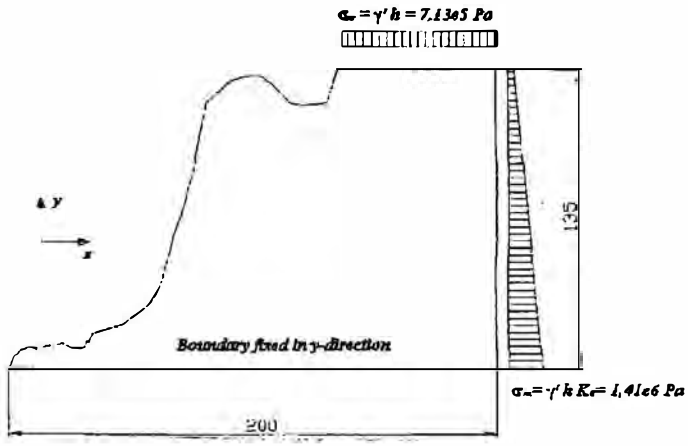

***Fig. 4** – Load assumption for Profile 1; Load assumption for Profile 2 is analogous to Profile 1*

Measure in metres

The rock parameters for the simulation were taken from Table 1.

SUMMARY OF PARAMETERS – TRIASSIC DOLOMITE (CASSIAN F.)		
Rock Parameters	Derived by classifications (**Rock Mass** Values)	by laboratory testing (**Solid Rock** Values)
Unit Weigth [kg/m³]		2850 kg/m³
Young's Modulus ***E*** [MPa]	$14 \cdot 10^3$	$60 \cdot 10^3$
Bulk Modulus ***K*** [MPa]	$15 \cdot 10^3$	$40 \cdot 10^3$
Shear Modulus ***G*** [MPa]	$5 \cdot 10^3$	$24 \cdot 10^3$
Friction Angle φ [°]		60
Cohesion ***c*** [MPa]		15
Uniaxial Tensile Strength σ_t [MPa]		5
Dilation Angle ψ [°]		0
Joint Parameters		
Friction Angle φ [°]	24 – 35	45
Cohesion ***c*** [MPa]	2	0,2
Uniaxial Tensile Strength σ_t [MPa]		0
jkn [Mpa/m]	$19 \cdot 10^3$	$6 - 18 \cdot 10^3$
jks [Mpa/m]	Senseless values	$9 - 30 \cdot 10^3$
Rock Mass Parameters		
E_d (for RMR<50) after Serafim+Pereira (1983) [MPa]	$5 \cdot 10^3$	
E_d (for RMR<50) after HOEK (1997) [MPa]	$4 \cdot 10^3$	
E_d (by GSI) after HOEK (1999) [MPa]	$4 \cdot 10^3$	

***Table 1** – Summary of parameters assumed for each model run. Parameters taken from field survey and derived from classification systems*

Assemble problem specific data, prepare detailed model runs

Material values for the blocks were taken from Table 1, according to the laboratory values for dolomite. As material model for the blocks was chosen the **Mohr-Coulomb model** *(cons=3),* for the joint system the **joint area contact** *(jcons=2)* model. These are the standard models assumed in stability calculation for rock slopes.

At the areas close to the right boundary of the system, the joint friction angle was set from 45° to 60° in order to assume a valid representation of undisturbed rock mass inside the slope. This higher friction angle was changed for a range up to 50m left of the right border.

Close to the surface of the slope a lower friction angle of 25 – 35° was applied. These values were obtained by the means of the classifications. It shall represent weakening and weathering of joints next to the surface.

These sudden changes of friction angles will cause discontinuities in the stress picture of the system. Therefore, the model was chosen big enough. As a rule of thumb it can be said, that a model should be 5 times as large as the survey area in order to avoid disturbances from the borders.

Perform the model calculations

First of all, after applying boundary conditions and gravitational loads, the models were calculated into a primary equilibrium stage. This is necessary to be able to continue with further load application and calculation.

16 model runs have been performed, assuming different orientations of failure planes. By observing the resulting movements of the system, the most realistic failure plane can be determined, or, by further variation of joint parameters, the most realistic model can be found.

Profile 1

A discontinuity system with a dip of 20° with the slope and 45° against the slope was chosen to be the most realistic. The model was brought to initial equilibrium and afterwards stresses were applied.

In a second stage of the simulation, **dynamic loading** was simulated. The assumed velocity of oscillation was v_x*=5cm/s* in the x-direction. As a result, the slope becomes unstable and UDEC stops the calculation due to contact overlap. This indicates that highly weathered parts of the wall could fail due to an earthquake.

Profile 2

The same discontinuity sets as in Profile 1 were chosen, only the set with the dip angle of 70° was skipped. After bringing the model into initial equilibrium, static stresses were applied (*Fig.5*). The values for cohesion and friction angle were determined by conceptual models with big block size (about 30 m). These are $\varphi=35°$ and *c=0,2MPa*, because Area 2 seems less weathered. For this detailed calculation, a block size of 2-*4m* was assumed inside the slope and a block size of approximately *2m* at the surface. During the stress calculation small block failure occurred in the upper part of the slope. This is a realistic result for the zone and corresponds to the observations made during the field survey.

The **dynamic response** of the system was stable. A velocity of oscillation of v_x*=5cm/s* in the x-direction was applied. Only a simple dynamic analysis was performed and viscous boundaries were applied at the borders.

The result for the assumed values is satisfying. Being subject to dynamic loading, the slope remains stable at a friction angle of *φ=35°* and a cohesion of *c=200000Pa*. Displacements remain in the order of 0,2mm.

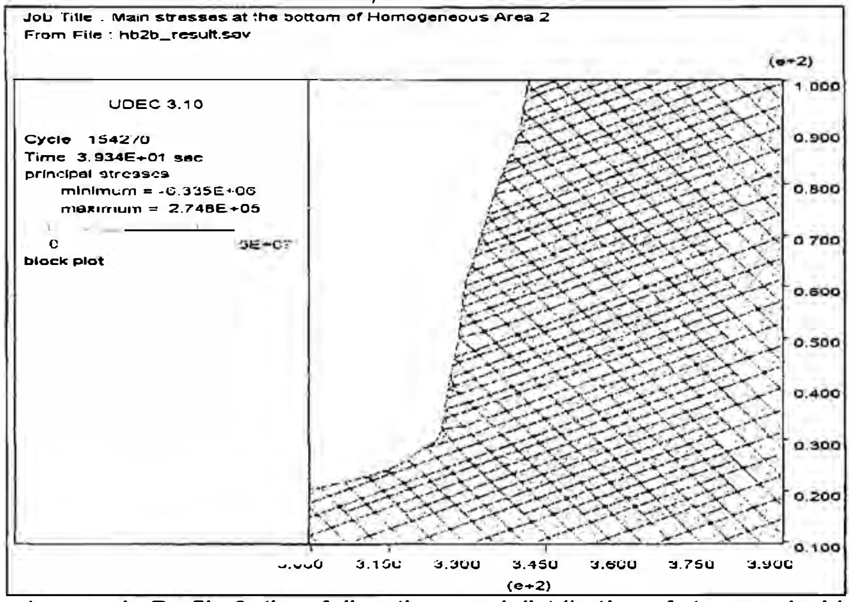

***Fig. 5** – Main stresses in Profile 2, they follow the usual distribution of stresses inside a rock slope*

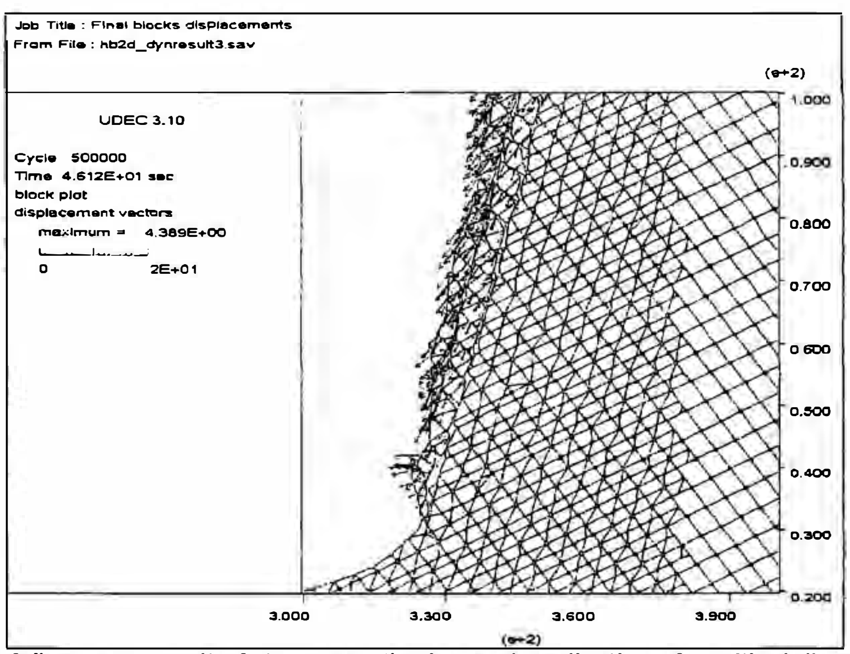

***Fig. 6** – Slope failure as a result of strong weathering and application of a critical discontinuity plane. Displacements are in the range of 4m now. This situation does not correspond to reality.*

Result and comment on stability

The rock slope can be assumed stable in most of its parts. Only highly weathered areas are likely to fail if dynamic loading occurs. Still, if an enlargement of the passing traffic routes is planned, measures have to be taken to ensure further stability in the case of extraordinary loading (earthquake, high precipitation). The slope is menacing several houses and the railway line before it enters the tunnel.

However, the more critical area considering the traffic routes is the underneath debris flow in the gypsum outcrop. It causes direct danger for the railway as well as for the Boite River.

4 CONCLUSIONS

Summing up, UDEC is a powerful tool in rock engineering, but it has its weaknesses. It would be a mistake to believe that numerical modelling can replace a detailed field survey. As the example of the slope of "Sant' Andrea di Cadore" shows, by changing only one single parameter it is possible to obtain almost any result. Therefore, care has to taken to adjust or assume the parameters in a realistic way. The interpreter should try to avoid constructing the model according to the expected behaviour. Therefore, the engineering geologist can never be replaced in his task of revealing the relevant parameters.

Classifications in this respect provide a rather objective evaluation system for rock slope engineering. Especially the SSPC method tries to filter out the observer's expectations.

The combination of both, the classification systems on the one hand and the numerical model on the other hand, leads to considerable results and helps to predict the behaviour of rock mass and provides a suitable design tool for rock engineering.

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