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Observed rock mass degradation and resulting slope instability

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ABSTRACT: After excavation of a road cut, weathering and erosion processes will start acting upon the newly exposed slope material. Field observations show that the resulting degradation caused by stress release, weathering and erosion may have significant effects well before the envisaged end of the engineering lifetime of the road cut. Since 1990 a road cut in Upper Muschelkalk limestone was monitored to study these effects. The classifications and laboratory test results show that degradation of the rock material and rock mass has progressively continued throughout this period, and threatens the stability of the current slope by causing a notable decrease of the bedding plane's friction angle. The test results also show the limited usefulness of shear box testing for slope stability assessment. The small size of shear box samples can lead to both a serious over- and underestimate of the in-situ shear resistance.

1 INTRODUCTION

In 1991, a road cut located close to the town of Falset in northeast Spain partially failed due to block sliding over the bedding plane. This slope was studied before and after the failure by ITC and the Delft University of Technology. With the road cut being excavated in what on first appearance seem to be competent dolomites, weathering would perhaps not have been thought to be an issue during the engineering lifetime of the cut. However, as observations taken since the time of failure show, the rock mass exposed in the road cut has degraded considerably as a result of weathering on the bedding plain, leading to a decrease in geotechnical strength. This is a process that affects all rock masses (e.g. Huisman & Hack, 2002), but in this particular slope, the relatively high rate of degradation of the bedding planes combined with their unfavourable orientation has caused a considerable decrease of the slope stability. This paper also shows the difficulty of obtaining strength values for slope stability assessment on the basis of small samples.

2 SITE CHARACTERISATION

The studied road cut is located along a minor double lane road near Falset, and was excavated around 1960 using gunpowder blasting which caused little damage in the remaining rock mass. Initially the slope was excavated at an angle of 85°, but this steep angle only remains in the left-hand part of the slope. The right-hand part has probably caused problems already at the time of excavation and in that part the bedding planes are now slope-forming, with several steep steps from one bedding plane to another. The overall slope height is approximately 10m.

The slope is excavated in Triassic carbonates of the Upper Muschelkalk. At the study site, these consist of medium to thickly bedded dolomites; dolomitisation has occurred through various processes (López-Gómez, Mas & Arche, 1993). The slope aspect is 165°. The bedding spacing is on average 0.80 m with a range of orientations from 160°/37° to 175°/30°. Two joint sets are present. One set is vertical (265/85) and strikes approximately perpendicular to the road cut. This vertical jointing contains some clay infill, which is likely topsoil flushed in from the terrain surface, and some karstic solution was observed. A second joint set (337/48) is striking parallel to the slope face and bedding and approximately perpendicular to the bedding plane. The spacing of this second discontinuity set is approximately 15 m. However, this discontinuity set showed a far smaller spacing of about 5 m in parts of the slope directly below the part that had slid and in parts directly adjacent to the sliding plane. This is likely due to the slope geometry that caused existing joints to open and new cracks to form because of tensile stresses.

It is obvious that the bedding planes are unfavourably orientated with respect to block sliding, and depending on assumptions on bedding plane roughness and water conditions the factor of safety of the slope with respect to sliding is close to unity. From the slope profile it seems likely that small blocks did already slide down during excavation, although no records on this exist. In 1991 however, a well-documented slide failure occurred affecting the right-hand part of the slope, with a volume of rock included in the slide estimated at 50 m^3. In 1991 and 1992 samples were taken for laboratory strength testing. Since the 1991 slide a number of rock mass classifications has been made and in 2002 and 2003 further samples were collected to determine if any weakening of the rock mass had taken place, since this would have a direct effect on slope stability with the slope being close to limiting equilibrium.

In 1991, the bedding planes were found to contain some clay infill (Cindarto, 1992). This was at the time no more than a thin dusting on the bedding plane surface, and thought to result from weathering as the bedding planes often contain some minor contents of clay. In 2002 parts of the outcropping bedding planes, and especially the bedding plane which acted as sliding plane in 1991, were found to contain a significantly thicker slightly plastic layer of approximately 8mm (see Figure 1).

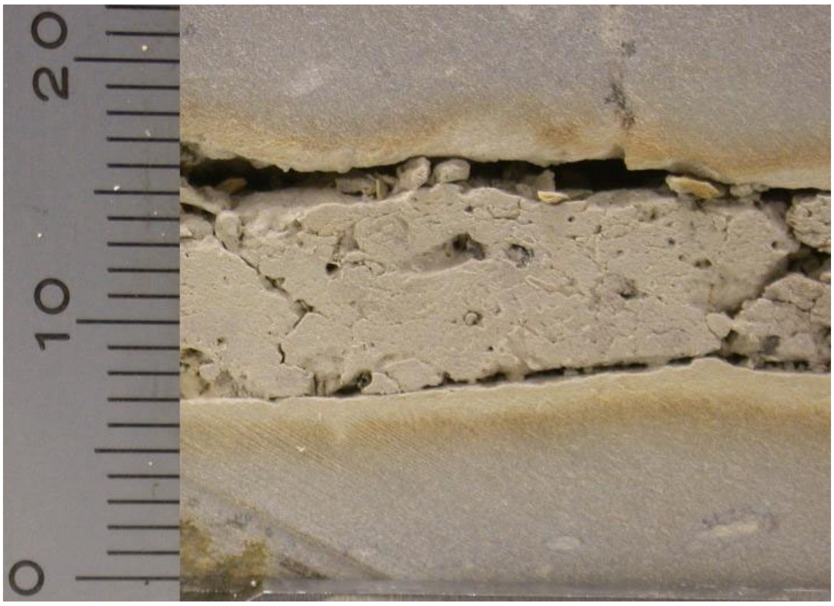

Figure 1 - The plastic layer developed on the bedding plane in cross-section (shear box sample, 2003; scale in mm)

Material analysis using XRF/XRD testing indicated a montmorillonite content in this layer of approximately 3% by volume, which explains the plastic behaviour. Furthermore, the presence of even such small amounts of montmorillonite suggests that the layer is vulnerable to further weathering and weakening (Kühnel, 2002). The total clay content including non-swelling clays is approximately 14%. Apart from the plastic layer, the discontinuity walls were weathered to a depth of about 1mm (see Figure 1). Block samples incorporating this plastic layer were taken for shear box testing in 2003, to compare with the results of the 1991 tests.

3 LABORATORY STRENGTH MEASUREMENTS

In 1991 and 1992 shear box tests have been done on the bedding planes. Samples had been obtained from the debris of the failed slope and have been sawn out of still standing parts of the road cut. Only samples could be tested which did not contain steps. No significant differences were found between tests on the bedding planes and on the other discontinuities. The shear box friction angle from these tests is 45°, with no (apparent) cohesion. The clay infill on the bedding surface as observed in the field was not present on the surfaces of the samples for testing. For the debris samples this is obvious but also for the sawn samples the infill (which was very thin; 1-2 mm) was lost during the sawing and sample preparation.

The samples taken in 2003 contained the recently developed plastic layer (see Figure 1) and were taken adjacent to sample locations of 1992 in the remaining part of the road cut. Care was taken not to disturb the weak plastic layer. The samples were tested in the shear box with the plastic layer as the slide plane. The average friction angle was now 27°. The test results show some non-linearity in the shear stress – normal stress diagram near the origin, up to normal loads of approximately 100 kPa. Because of this, a small apparent cohesion was found of 14 kPa.

4 SLOPE STABILITY

Over the last 14 years a number of SSPC classifications (Hack, 1998 and Hack, Price & Rengers, 2003) has been done on the slope. The exposure characterization done in 1990 before the slope failed and the resulting slope calculation shows that for a slope dip (road cut) of 90° the stability probability for sliding along the bedding plane was 55% before the slide actually happened. This indicates that the safety factor for slope stability against sliding was almost unity[1], and a very slight decrease of the condition of the bedding plane due to weathering would have been sufficient to cause failure. The fact that tension cracks already had developed also indicates that the slid block was not fully supported by shear strength along the lower parts of the bedding plane.

If the friction angles measured in the 2003 shear box tests are used, the safety factor of the remaining part of the slope in dry conditions would be 0.88 if the cohesion is considered to be apparent only. Should the plastic layer extend underneath the potential sliding blocks in the thickness found in the outcrop, the SSPC indicates that the stability with respect to sliding would be in the order of 2% only. From both the safety factor and this probability value, it is clear that the layer cannot be persistent throughout the rock mass; otherwise, the slope would have failed.

5 LABORATORY DATA VS. FIELD OBSERVATIONS

A discrepancy was found between the laboratory test results and classifications made in the field already in 1992. The laboratory shear box friction values for the bedding plane obtained in 1991 and 1992 are representative for a rough planar surface without infill and a large-scale roughness

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[1] Correspondingly, with the friction angle values obtained from the tests and classifications, the safety factor with respect to block sliding for the part that actually failed would have been 1.3 with the 45° friction angle found in the shear box tests, and 0.93 with the 35° found with the classification (both in dry conditions).

equal to straight. This results in a friction angle of about 43° according to the 'sliding criterion' (Hack, 1998 and Hack, Price & Rengers, 2003). The description of the bedding plane in the field is, however, straight, rough stepped with fine soft sheared infill and equivalent to about a ‘sliding angle’ of 35° along the plane. The value from the laboratory shear box test of 45° is thus in agreement with the sliding criterion for the sample tested, but is not representative for the bedding plane in reality. That the difference between the test result and reality is not larger is pure coincidence: the absence of steps on the surface of the samples is compensated by the absence of the infill material in the laboratory tests. This illustrates the limited usefulness of shear box testing, even for discontinuities that have no large-scale roughness.

In the 1991 and 1992 tests, the laboratory values overestimate the shear resistance. On the other hand, the friction angle found in the 2003 tests is apparently smaller than for the average in-situ conditions. It is clear that if the plastic layer encountered at the fringes of the bedding planes, where they intersect with the slope face, continued underneath the hanging blocks in the slope for the full length of the bedding plane, the slope would be unstable even in a dry situation (see section 4). Since the slope is, however, still standing, the conclusion is valid that the plastic layer only extends into the rock mass along the bedding planes over a limited depth. Numerical analysis of the sliding potential in this situation was done using the distinct element code UDEC (De Jong, 2003). Results indicate that if about 30-50% of the bedding plane is affected, the slope will reach limiting equilibrium. It does not seem unlikely that this will happen in the near future.

6 CONCLUSIONS

The study of the slope described in this paper shows that even in, at first sight, competent rock formations, weathering may play an important role in the decrease of slope stability on engineering timescales. In this particular case, the effects of weathering are critical for the slope stability, because of the unfavourable orientation of the bedding planes on which weathering occurs. Clear as this effect may be, it remains difficult to quantify the exact effects on the rock mass strength and the resulting slope stability. Shear samples taken from the slope without and with significantly weathered bedding planes result in friction angles and shear strength values that differ from values derived in the field from classifications. Extrapolation of the shear box test results to a slope scale should be avoided in cases such as this, where a discontinuity is weakened by penetration of weathering into the rock mass and the shear resistance varies over the discontinuity surface. Classifications made on the in-situ rock mass are more appropriate in such cases.

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