

A FLOOD RETENTION BASIN IN AN ABANDONED STONE QUARRY - EVALUATING THE STABILITY OF A SUBMERGED ROCK SLOPE

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ABSTRACT

Flood mitigation measures are currently being projected for two Styrian communities threatened by frequent floods caused by the creek Lammerbach. A stone quarry scheduled for shut-down could serve as a flood retention basin. Quarrying activities have left a steep rock slope with an inclination of 60°. This slope's foot would be submerged when the flood retention basin is filled. Geotechnical investigations aimed to prove, that the stability of the rock slope during submersion would match the required factor of safety. Four possible failure mechanisms were derived based on the joint system and the rock blocks. The stability calculations assumed limit equilibrium of the rock slope in the actual state (factor of safety = 1.0). Friction angle and cohesion in the actual state were back calculated for each joint plane using limit equilibrium equations. For each failure mechanism the stability of the rock slope in the final state (submersion) was calculated and compared with the required safety factor. Three necessary measures were determined to provide the required stability of the sidewall under submersion.

Key Words: Flood retention, Geotechnical modeling, Failure mechanism

INTRODUCTION

The town of Kindberg and the community of St. Lorenzen in the Austrian province of Styria are partly threatened by frequent floods caused by the creek Lammerbach. Floods occur almost annually, several residential buildings are located in the „Red Hazard Zone“. Two damage-causing floods were observed within the year 2009.

The Lammerbach is a right-hand tributary to the river Mürz. Its catchment area amounts to 3.2 km² and reaches from 540 m to 1230 m a.s.l.

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Fig.1 Lammerbach flood event July 15th, 2009

The catchment's geological conditions show paragneisses, central-alpine sediments, augengneisses and fine-grained orthogneisses.

Preliminary hydrological investigations revealed that a retention reservoir of app. 63.000 m³ is necessary to reduce the maximum dimensioning-discharge (HQ150) from 22 m³/s to an amount that can flow through an existent highway-bridge located at the lower reaches of the creek.

The Federal Service for Torrent and Avalanche Control is currently projecting mitigation measures aiming primarily at flood retention. Additionally a debris-retention basin will be located upstream of the flood-retention basin. Riverbank and bed stabilization measures will protect the riverbed along the stretch between the retention basin and the mouth of Lammerbach into the receiving water course Mürz.

A stone quarry located upstream of the alluvial cone next to the left bank of the torrent is scheduled for shut-down by 2011. The basin of this quarry was thought to be an ideal location to construct a flood retention basin matching the required volume.

The quarrying activities have left a steep rock slope with an inclination of 60°. The slope's foot is located at 609 m a.s.l. The slope would be submerged up to 622 m a.s.l. for several days when the flood retention basin is filled. Extensive geological and geotechnical investigations and simulations were realized to prove the stability of this slope during submersion.

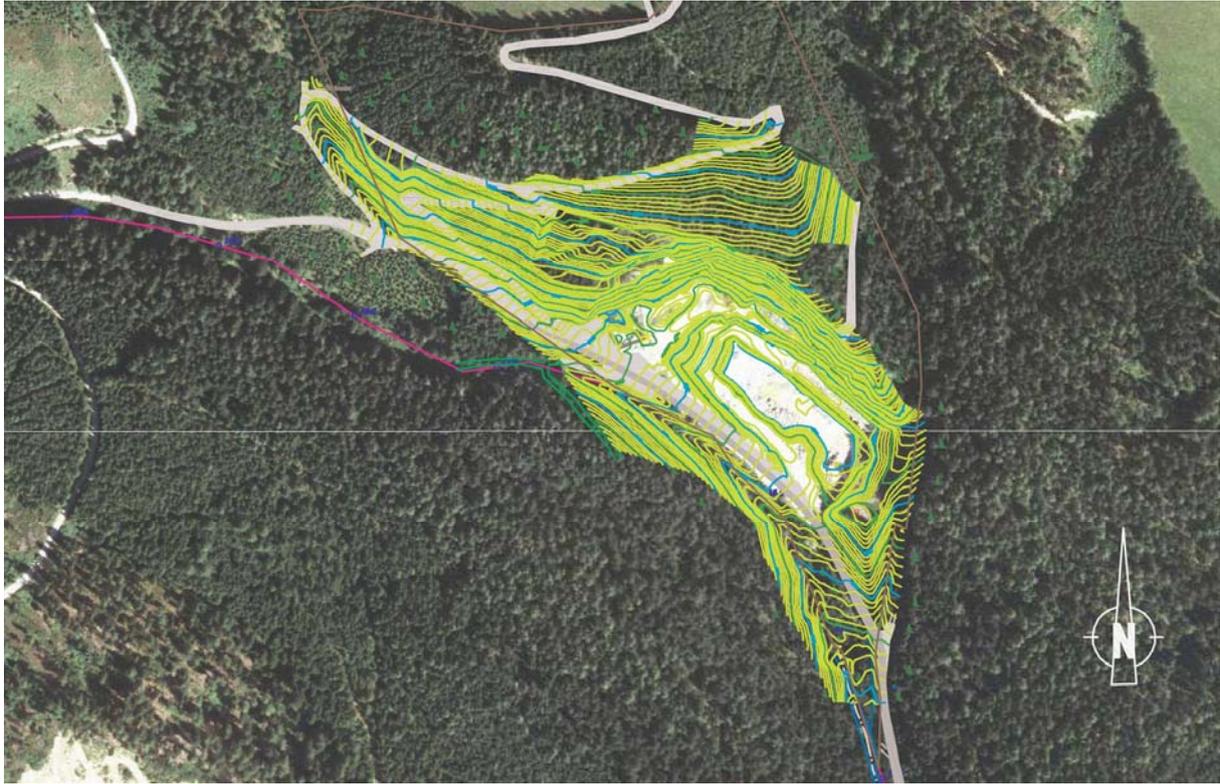


Fig.2 Orthofoto of the stone quarry with 1m-contour lines



Fig.3 Stone quarry next to the left bank of Lammerbach (viewing direction northwest)

METHODS

Geodetic mapping and monitoring of the rock slope

Seven benchmarks were attached to the base of the wall and monitored precisely.



Fig.4 Location of benchmarks at the base of the rockwall

High accuracy measurements of the benchmarks were repeated periodically for 2 years, especially during thawing periods and after blasting operations in the quarry. It could be verified by these measures, that no significant deformations occurred during the monitoring-period.

Geotechnical investigation of the rock slope

The rock slope was mapped geotechnically and the orientation as well as the conditions of the joints (e.g. roughness) were determined by means of statistical measurements of structural elements (joints and faults) and a photogrammetric analysis using digital pictures of the rock-face (ShapeMetrix). 1 foliation plane, 2 joint sets and 2 faults were identified.

Table 1 (above): Joint system of the rock slope

		dip direction	dip
1	foliation plane	210? 225?	20? 35?
2	joint set 1	155?	75? 80?
3	joint set 2	235? 242?	61? 82?
4	fault 1	145?	26?
5	fault 2	310-330?	43? 55?

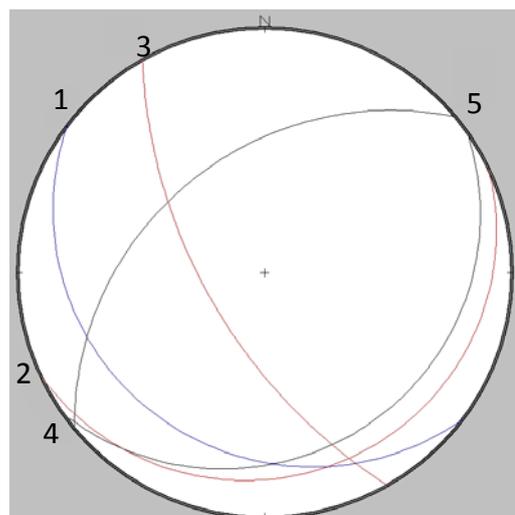


Fig.5 (right) Stereonet with great circles of foliation (1, blue), relevant joints (2 and 3, red) and faults (4 and 5, black)

Derivation of Failure Mechanisms

Based on the joint system and the rock blocks the following possible failure mechanisms were derived:

1. Rock slumping
2. Wedge slumping
3. Large rock blocks sliding on foliation planes
4. Large rock wedges sliding on two large faults

Failure scenario 1: Rock slumping

Like a ladder leant too flat against a wall, rocks with heights of 10 to 15 m and thicknesses of max. 2 m slump on faults with inclinations of 35 to 40°. The rocks are isolated from the wall by joint system 2.



Fig.6 Isolated rocks prone to slump

Failure scenario 2: Wedge slumping

Columns are isolated from the rock wall by the two joint systems. These columns or wedges slump on steeper foliation planes sliding along the joint systems.



Fig.7 (left) Missing (already slumped) wedges in the upper part of the rock slope
Fig.8 (right) Isolated wedge

Failure scenario 3: Large block sliding

Large rock blocks, isolated by the two joint sets, slide on foliation planes with clayey-sandy fillings.

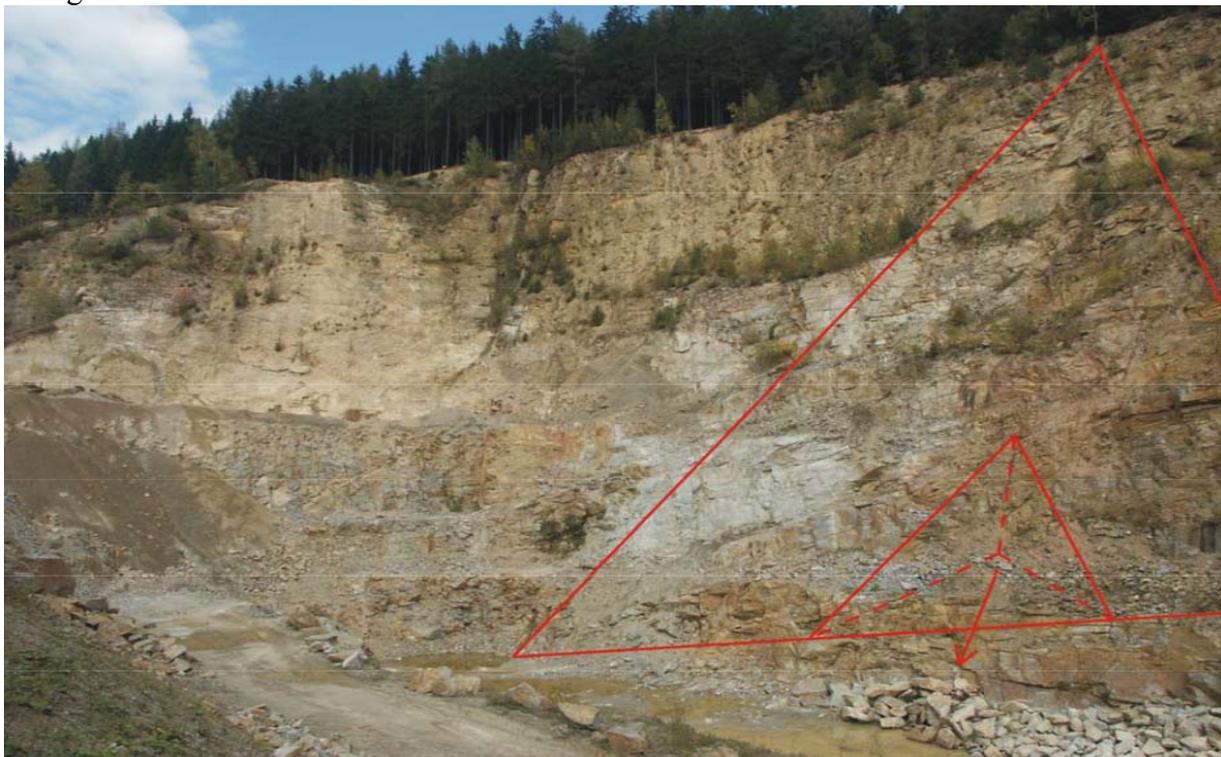


Fig.9 Schematic picture of large blocks isolated by joint systems sliding on foliation planes

Due to the planned reduction of the height of the berms of the new design-slope this failure mechanism would change from slumping to sliding.

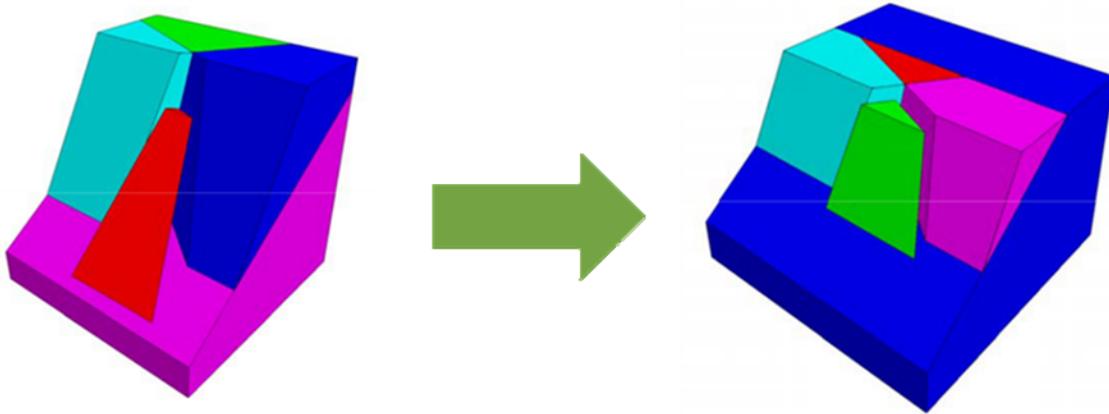


Fig.10 The planned reduction of berms to heights of 6 m would cause large rock blocks to slide instead of slumping

Failure scenario 4: joint-bordered rock block sliding on faults

A wedge-shaped joint-bordered rock block slides on fault 1 and 2.

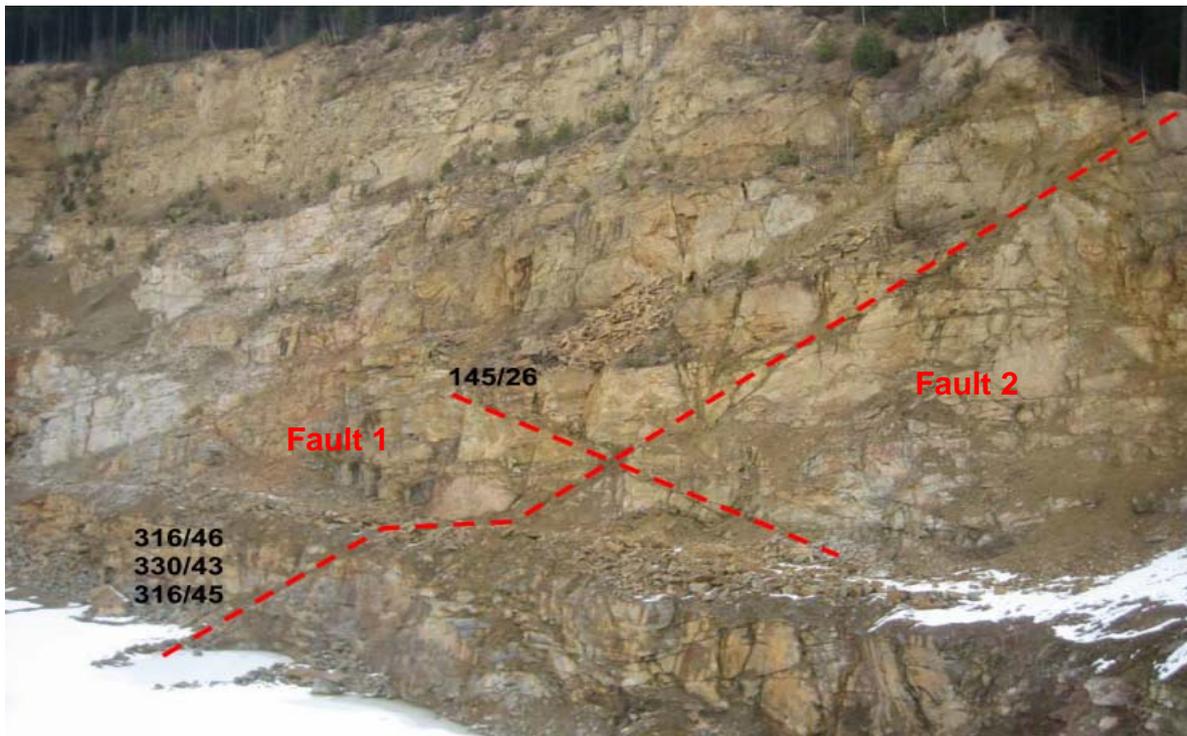


Fig.11 Two large faults serving as sliding planes for joint-bordered rock blocks

Back-calculation of the actual state

For each failure mechanism the stability in the actual state was calculated. It had to be assumed, that the system is actually in limit equilibrium (safety factor = 1.0). Under this assumption the friction angle and the cohesion in the actual state were back calculated for each joint plane using limit equilibrium equations and the distinct element code 3DEC (Itasca Consulting Group), because laboratory tests of these parameters would have provided results not coinciding with nature due to scale effects etc.

Definition of the final state

It was proposed that in the final state (after realization of the retention basin and the backcutting of the slope including the installation of terraces) the slope dip angle of the sidewall is reduced from 60° to 40°. The dimensioning basis under full load can be described as follows:

- Submersion of the rock wall from the basis (609 m a.s.l.) to 622 m a.s.l.
- Low draw down velocity so that the difference between the reservoir water level and the ground water does not exceed 2 m. Thus the ground water drag is regarded as negligible.

Safety class and required safety factor

For each failure mechanism the possible consequences of a failure were described. Considering this scenario the relevant safety class (1, 2 or 3) according to the applicable National Standard ÖNORM B4433 was determined. Depending on the safety class this National Standard requires a certain safety factor.

Proof of the sidewall's stability under submersion

For each failure mechanism the stability of the rock slope in the final state (submersion) was calculated (using Block-Theory). Taking into account the above mentioned stabilizing and destabilizing factors, the provided safety factor in the final state was calculated and compared with the safety factor required.

Evidence was provided, when the safety factor in the final state was higher than the safety factor required by the above mentioned standard.

RESULTS

Table 2 Failure Mechanism 1

Failure mechanism 1 Rock slumping		
Safety class	2	No endangerment of human lifes, no serious economic consequences
Required factor of safety	1.15	
Provided factor of safety	1.16	
Proof of stability	1.16 > 1.15	Evidence provided ✓

Table 3 Failure Mechanism 2

Failure mechanism 2 Wedge slumping		
Safety class	2	No endangerment of human lifes, no serious economic consequences
Required factor of safety	1.15	
Provided factor of safety	1.04	
Proof of stability	1.04 < 1.15	✗ Evidence not provided → Wedges prone to sliding must be removed

Table 4 Failure Mechanism 3

Failure mechanism 3 Large block sliding on foliation planes		
Safety class	3	Endangerment of numerous human lives, serious economic consequences
Required factor of safety	1.3	
Provided factor of safety	1.307	
Proof of stability	1.307 > 1.3	Evidence provided ✓

Table 5 Failure Mechanism 4

Failure mechanism 4 Large, joint-bordered rock blocks sliding on faults		
Safety class	3	Endangerment of numerous human lives, serious economic consequences
Required factor of safety	1.3	
Provided factor of safety	>> 1.3	
Proof of stability		Evidence provided ✓ Failure mechanism not relevant

Earthquake safety

The probability of an earthquake co-occurring with a full submersion of the rock-wall is extremely low ($p = 0.0014\%$).

According to the Austrian Central Institute for Meteorology and Geodynamics the referring horizontal earthquake acceleration for Hadersdorf is 1.05 m/s^2 .

For exceptional load cases like this (safety class = 3) the Austrian national standard ÖNORM B4433 requires a factor of safety of 1.1.

The critical failure mechanism is „large block sliding on foliation planes” (Scenario 3)

Assuming the worst case scenario (earthquake acceleration acts parallel to the sliding surface), the following safety factors were calculated:

- Earthquake without submersion of rock wall: safety factor = 1.11 → o.k.
- Earthquake co-occurring with submersion of rock wall: safety factor = 1.10 → o.k.

Required measures

To provide the required stability of the sidewall under submersion the following measures were determined to be necessary:

- Reduction of the slope angle of the sidewall from 60° to 40° .
- Removal of small scale rock wedges prone to sliding (especially below maximum water level, but also above).
- The draw down velocity has to be controlled in order to keep the difference between the reservoir water level and the ground water to a maximum of 2 m.
- Continuation of the geodetic monitoring of the sidewall (differential survey).

CONCLUSION AND OUTLOOK

Geotechnical investigations have revealed that stability of the sidewall can be achieved, when the above mentioned measures are realized.

100000 m³ of rock material will arise from slope angle reduction of the sidewall. According to a preliminary estimate by the quarry operator approx. 70000 m³ of this material will be unsalable.

The exact location of the retention dam will be determined considering

- optimum dam-height/retention-volume ratio
- underground conditions (by means of core drillings and seepage resistance measurements)
- usage of the unsalable quarrying material to raise the retention dam with a concrete sealing core

REFERENCES

- 3G Software & Measurement GmbH (2009). *ShapeMetriX^{3D}*. Software Code and User Manual.
- Austrian Federal Forest-Technical Service for Torrent and Avalanche Control (2007). *Vorprojekt Lammerbach*. Unpublished
- Austrian Standards Institute (1987) *ÖNORM B 4433 Geotechnical engineering (foundation engineering); analysis of base and slope failure*. Austrian Standards plus GmbH.
- Becke, M. (2000). *Ingenieurgeologisches Gutachten – Beurteilung der Bruchwaende im Tagbau Hadersdorf*. Unpublished.
- ITASCA (2007). *Three Dimensional Distinct Element Code 3DEC*. Software Code and User Manual.
- Lenhardt, W. (2008): *Horizontale Referenzbodenbeschleunigung im Bereich Hadersdorf*. Unpublished
- Poisel R. (2008). *Bericht über Standsicherheitsuntersuchungen der Abbauwand im Nordosten des Steinbruches Hadersdorf bei Errichtung des geplanten HWR-Standesortes Lammerbach*. Unpublished.