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The Oselitzenbach landslide (Austria) – triggering, runout and risk evaluation

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1 Summary

In an international EU-Project "IMIRILAND" (Identification and Mitigation of Large Landslide Risks in Europe) several landlides in Europe have been investigated by different methods. The partners have been ARPA Torino, Politechnico di Torino, EPFL Lausanne, CSR Torino, TU Vienna, UPC Barcelona, LCPC Lyon.

Here the results of the Austrian Group is shortly presented. By the means of different numerical models the trigger influences and the runout bahaviour of three landslide scenarios have been calculated as well as the determination of hazard, vulnerability and finally, the risk.

2 introduction

2.1 History, climate and water condition

The annual precipitation is 2963mm/yr (the highest value measured in Austria). The groundwater conditions differ in the various parts of the area. The upper part shows a shallow infiltration, groundwater coming to daylight as springs in the middle part. In the lower part water losses are documented along deep rotational slide planes. The groundwater velocities in the upper part are about 0,2-5,0m/h (proved by a tracer test). Some lakes lie in a small depression, made up by secondary zones of movement. The greater lake is fed by 2 small tributaries and is dewatered by a small runoff river; the smaller lake has no tributary at the surface, but has a small runoff (3-5 l/s).

The catchment area of the Oselitzenbach torrent is considerably affected by two big sagging slopes. The main sliding process of these slopes took place between the last Ice ages (between 70.000y – 150.000y BP) documented by Würm age moraines partly overlaying the slide area.

The movements (measured since 1983) are very inhomogeneous, reaching from some cm/y up to some areas with deformations of more than 1m/y. Especially the toe zone of the Reppwandslide is still quite active and is responsible for debris generating slope failures and destruction of the Naßfeld-road. After sustained regional rainstorms in Sept. 1983 with numerous embankment failures extensive research was initiated along the Oselitzenbach torrent and the sagging slope above. A run-out of 60.000m^3 in volume took place (August 1987) and resulting intense settlements up to some metres occurred. Additionally a formation of new cracks up to 30m above the Naßfeld road was developed.

A construction programme started 1988: a 400m long new river channel was excavated in comparatively massive Hochwipfel formations as well as a deposition of landfill at the toe of the sagging mass provided by the excavated material (about 170.000m^3). Additional measures have been the drainage of the landslide – in order to prevent serious debris flow into the Oselitzenbach-torrent and in the receiving stream “Gail” and to prevent debris flow reaching and, possibly, destructing two villages below. This led to some lowering of the movements, but they are still going on with, however, reduced amounts.

2.2 Regional morphology and geology

The morphology of the mountain chain is dominated by Triassic and Devonian limestones in the highest peaks, the foothills and some less inclined slopes by shales and slates(partly sandy). During the ice ages the valleys have carved out, the V-shaped erosion valleys took place after the last Ice period, partly eroding the slope foot areas. The Variscian basement is represented by an epizonal tectonic unit (laminated limestones, marbles and phyllites) and the anchizonal Hochwipfel nappe. Due to the adjacent “Periadriatic lineament” the degree of tectonic influence is rather high, causing secondary faults and joints.

3 Hazard analysis

3.1 Geo-morphological and structural analysis

By the sagging mass of the Reppwandgleitung the valley floor became very narrow, the torrent eroded the toe of the mass. The lowest part of the Oselitzenbach is a steeply inclined valley to reach the deeper situated main valley of the Gail Valley, carved out after the last Ice Age since the last 20.000 years. Above the main scarp of the mass there are outcrops of massive limestones with steep slopes. Within the sagging mass there are many secondary scarps, forming different elements of the moved mass. Within the slide area itself the structural features are rotated and/or dislocated and therefore they do not represent the tectonical stress field.

The “rock menu” in the heavily disturbed sagging areas consists mainly of:

- Hochwipfel-schists: dark greyish sandy-siltstones, scarcely calcareous. Anchizonal light metamorphic rock, well bedded, with clayey interlayers. Mainly hard and brittle behaviour.
- Naßfeld-schists: Conglomerates, partly dark grey limestone beds, scarcely bedded. Sometimes thin interlayers of siltstone; heavily disturbed,
- Outside the landslide area: Triassic sediments (Trogkofelkalk: partly dolomitic limestones, lesser bedded, massive beds. Well jointed, loose rock with wide open fissures at the main scarp.

The geotechnical properties of rocks in the front area of the Reppwand-slide can be defined as following:

- Rock structure is disintegrated to a block-talus with a fine grained matrix (like a cohesive soil)
- Embankment (rock channel) with sandstones and schists, well jointed

3.2 Investigation and monitoring

As a consequence of intense movements in August 1987 an extensive construction and monitoring program has been started. Since October 1988 the toe zone of the landslide has been monitored by means of: 60 geodetic points, 1 inclinometer-probe type, 1 wire extensometer, 9 convergence scanlines, steel tape. Seven boreholes, one of them with an inclinometer. There has been a significant stabilisation after the finalisation of the construction measures in most areas. Period A (1988 - 1991, before the construction measures) and B (1991 - 2000, after the construction measures) show the following:

Homogeneous region	Per. A: 1988-1991	Per. B 1991-2000
“Seebach” above road	0,9cm/month	0,5cm/month
“Quellenbach”	1,3cm/month	0,65cm/month
Roadmaster hut	0,4cm/month	0,35cm/month

Table 1: Displacement rates

The refraction seismic section through the investigated area shows a three layer structure: The lowest layer does not show any displacements at the moment. The middle layer (15-30m thick) shows small displacements. The upper layer (10-15m thick) is heavily fractured and behaves therefore as a soil with low cohesion. This is the main reason for sustained displacements.

3.3 Danger identification

According to the results of the monitoring program and morphological studies (activity of landforms, cracks, etc.) three possible scenarios have been detected:

<u>Scenario 1: Failure and detachment of the area displacing most at present</u>

The measurements show that an area is moving with displacement rates of 7 cm per year at present. The theickness of the sliding mass is some 25 m. Thus, an unstable area of some 52.850m^2 and a moving mass of some 450.000m^3 can be assumed. The whole sliding surface is running through the fractured Reppwand sliding mass, there are no structural constraints. The run-out of the area displacing most at present was numerically modelled, showing that the ravine of the Oselitzenbach will be buried by 85.085m^3 of debris flowing over the debris cone of the Oselitzenbach burying 896.000m^2.

<u>Scenario 2: Bodensee slide</u>

The monitoring programme reveals that this area is moving with displacement rates of 5 cm per year at present. Due to the morphology an unstable area of some 536.000m^2 was assumed. The run-out of the Bodensee slide will bury the ravine of the Oselitzenbach with 3.375.000m^3 of debris flowing over the debris cone of the Oselitzenbach burying 200.000m^2.

Scenario 3: Reactivation of the old Reppwand slide

Geological investigations depicted an unstable area of some 2.911.000m^2. The run-out of the reactivated Reppwand slide will bury the ravine of the Oselitzenbach with 16.500.000m^3 of debris flowing over the debris cone of the Oselitzenbach burying the villages of Tröpolach and Watschig and 2.678.000m^2 of forest and rural areas and damming up the river Gail by 5m thus causing an inundated area of some 4.852.000m^2.

3.4 Geo-mechanical modelling

3.4.1 Mechanical “triggering” model

The Oselitzenbach site is studied by means of two 3D continuum models: the first model by means of the code FLAC^{3D} (Itasca Consulting Group) based on the finite difference technique, the second one using the finite element code DRAC (Prat et al., 1993). Only the Scenario 1 has been numerically investigated because of the highest occurrence probability.

Due to the geotechnical properties, only a continuum model has been analysed. The models, however, consider four different material properties. Based on the refraction seismic section a three layer model was generated. The density of the material is 2500kg/m^3. A Mohr-Coulomb constitutive model was investigated using the following material properties:

		E [GPa]	ν	φg[°]	c [kPa]
Naßfeld-schists	upper layer	2,5	0,2	18	14
	middle layer	3,7	0,2	25	20
	lowest layer	3,7	0,2	40	20
Hochwipfel-schists		9	0,1	40	1e3

Table 2: Material properties

The results are in good agreement with the results of the monitoring program. A characteristic profile was deduced, used for the two-dimensional run-out calculations. The distribution of the shear strain rate indicates a zone of maximum shear strain rate in a certain depth. Below this zone displacements and velocities are zero, above they have a value increasing to the surface. Thus the analyses using FLAC gave an area with continuously decreasing displacements with depth down to a certain depth ("sliding" zone, zone of maximum shear strain rate). This failure surface was used for the three-dimensional run-out analysis. Because of the more exact gradient the contour of the velocity of the FLAC^{3D} analysis was used to get the three-dimensional failure surface.

3.4.2 Mechanical "run-out" model

The computer programs PFC^{2D} and PFC^{3D} from Itasca have been used as an All Ball and a Ball Wall model and the computer code DAN and the rock fall program ROTOMAP (Geo& Soft International) have been used by Pirulli et. al (2003) in order to model the run-out behaviour of the Oselitzenbach landslide.

Generally PFC is not yet able to model the influence of water (e.g. pore pressure) on the run-out, whereas DAN needs an estimate of the detached rock mass and of the run-out direction. An estimation of the detached rock mass is also needed for the PFC Ball Wall model, which was provided by a FLAC^{3D} investigation. Thus the methods described should be used in combination, which makes a comprehensive assessment of the run-out close to reality possible.

PFC Ball Wall model In the PFC Ball Wall model the bedrock is simulated by linear (2D) and planar (3D) elements. In contrast to the All Ball model, where the relatively stationary bedrock is modelled by balls as well, in order to model also the failure mechanism of the slope and the detachment mechanism, in the Ball Wall model only the detached rock mass is modelled by balls. Therefore, in the Ball Wall model an estimate of the failure mechanism of the slope and of the detachment mechanism is needed as an input parameter. Consequently in the Ball Wall model the detached mass can be modelled with the help of more and smaller balls with the same computational effort. One goal of the investigations, therefore, has been to compare the two different approaches.

The PFC Ball Wall model offers the possibility to make use of the know-how related to run-out relevant resistances (factors of restitution, absorption, friction, et.) applied in rock fall programs and consequently makes a realistic calculation of the run-out possible (table 3a). The combination with FLAC allows a realistic estimate of the detached rock mass on the basis of already existing experiences. An interaction of detachment and run-out, however, is not possible.

Table 3a: Measurement lines and run-out distances Table 3b: Measurement lines and

Measurement line	**Distance [m]**		**Measurement line**	**Distance [m]**
D1	346		D1	330
D2 14m	397		D2	389
D3	573		D3	373
D4	556		D4	378
W2	377		W1	204
			W2	364

run-out distances

PFC All Ball model The PFC All Ball model allows the all in one calculation of failure mechanisms, detachment and run-out. For calculating, however, quite a demanding calibration of materials is necessary. When comparing the volume of the detached rock with FLAC both methods correspond closely, which verifies the All Ball model. The surface of the model is rather rough due to the modelling of the bedrock by balls, which has to be considered at the calibration of the run-out parameters. In the final state of the All Ball model, the run-out is described by the help of four horizontal measurement lines (D1-D4), the path width by the lines W1 and W2 (Table 3b).

Comparison Ball Wall model – All Ball model The area of the maximum displacement rates (light blue) in the All Ball model corresponds closely to the direction and width of the run-out in the Ball Wall model. The Ball Wall model however, indicates a far bigger travel distance. This is due to the collision of moving particles with stationary ones (bedrock) in the All Ball model, the moving particles losing energy additionally.

Rotomap und DAN-Code Since in the DAN method the run-out direction and the path width are assigned a priori, in the investigations have been determined with the aid of a 3D rockfall program called ROTOMAP. The comparison of the results of the PFC^{2D} Ball Wall model, which also needs an estimate of the run-out direction, and the results of the DAN model shows that two different run-out directions have been chosen and that these profile directions have a large influence on the results. The run-out directions determined by Rotomap corresponds very well to those of the 3D All Ball model in the West, whereas the run-out in the 3D All Ball model in the East indicates a smaller width. The same applies to the 3D Ball Wall model.

The comparison of the results of the methods (Table 4) show:

Method	PFC - Ball Wall	PFC - All Ball	Rotomap + DAN Code
detached rock volume [m^3]	450.000 (input from FLAC)	377.000 – 495.000	450.000 (input from FLAC) (244.300 - 571.300) depending o sumed)
travel distance [m]	573	389	597 (for a pore pressure of 0.1) 470-833 (depending on the pore pre
run-out width [m]	377	364	340
affected area [m^2]	127.000	97.537	134.494 (Rotomap)
maximum travel velocity [m/s]	29	4	21

- the FLAC^{3D} simulation as the basis of the DAN and of the 3D Ball Wall model give approximately the same detached rock volume as the All Ball model,
- the PFC – Ball Wall model and the DAN Code (depending on the pore pressure assumed) give the same travel distance of the run-out, whereas the PFC - All Ball model gives a much smaller value due to the rough surface of the bedrock caused by the bedrock built up by balls.
- the run-out widths and the affected areas obtained by the models correspond more or less and
- The maximum travel velocities of the run-out obtained by the models do not correspond. The slow travel velocity of the All Ball is caused by the rough surface of the bedrock built up by balls. These aspects should be considered at the calibration of the run-out parameters.

Table 4: Comparison of the results of the methods

Thus the combination of all three methods yielded

- a detached rock volume of some 450.000m^3,
- a travel distance of the run-out of 600m (due to the blocky nature of the Naßfeld-schists a zero or low pore pressure is assumed to develop in the run-out mass),
- a run-out width of 360m,

- an affected area of 130.000m^2, and
- a maximum travel velocity of the run-out of 20m/s.

These data mean that the Naßfeld road will be destroyed or buried with a maximum height of 7m respectively by the run-out in case of a slope failure over a length of 400m. The Oselitzenbach torrent will be dammed up as well over a length of 460m with a maximum height of 14m, thus endangering the villages of Tröpolach and Watschig including the adjoining agricultural and forest areas by debris flows.

4 QUANTITATIVE RISK ANALYSIS

In the chapters before 3 scenarios of the Oselitzenbach landslide evolution have been recognized. Each scenario is characterized by a failure, run-out areas (derived from the geo-morphological and geo-mechanical models) and by an occurrence probability (as a result of a historical analysis of recorded events). According to the proposed quantitative risk analysis, each element of the hazard scenario is used separately in the matrix calculus of risk evaluation. This process is applied on each recognized scenario.

4.1 Occurrence probability

Scenario	**Observation period (years)**	**Recorded events**	**Occurrence period (years)**	**Frequen (event/ye**
1	100	1983, 1987	50	1/50 = 0,
2	Historic times	non	1.000	1/1.000 =
3	70.000	non	70.000	1/70.000

Table 5: Definition of the occurrence probability through the historical approach

4.2 Elements at risk

The elements at risk are recognized through the definition of the involved area of each danger in the scenarios previously specified. These elements at risk are shown below.

Table 6: Definition of the elements at risk: scenario 1 (Detachment of the most active area at present)

Elements at risk	Name	Notes
Forests (private and public properties)		Involved area [km^2]: *by landslide: 0,* *by mudflow: 0,896* Involved persons:
Great traffic or strategic roads	National road B90	Involved length [m]: 400 Involved pe
Tourist accommodation		Involved persons: 1
Lifelines		Involved length [m]: 600 Involved tre

4.3 Vulnerability of the elements at risk

The vulnerability of the elements at risk was determined by an estimation of the effects on the elements at risk. The following Tables show the considered relative values of the elements at risk and the evaluated vulnerability for each scenario.

Considered values [VE]				
Elements at risk	*Physical*	*Economic*	*Environm.*	*Social*
Forests/Rural area (private and public properties)	1	1	3	1
Great traffic or strategic roads	3	4	1	2
Tourist accommodation - buildings	3	3	1	1
Lifeline	1	2	1	0

Table 7: Scenario 1: Considered values of the elements at risk

Vulnerability [V]				
	Physical	*Economic*	*Environm.*	*Social*
Vulnerability	0,25	0,5	0,25	0,25

Table 8: Scenario 1: Vulnerability

4.4 Expected impact

Crossing the values of the elements at risk (VE, see Table 8), and vulnerability percentage V (obtained as described in the previous section), the expected impact C is obtained as C = VE x V.

To state a precise quantitative damage evaluation for economic activities and assets, costs derived from economic analyses are essential (e.g. assets costs, reconstruction costs, turnover, profits loss, etc.). To assess environmental and social expected impacts (where an economic value is difficult to obtain), relative values indexes are used. In the quantitative risk analysis, arbitrary relative values indexes have been applied on each category. In Tables 9-10 expected impact values are shown.

Expected Impact [C=VExV]			
Elements at risk	*Physical consequ.*	*Economic consequ.*	*Environm. conseq*
Forests/Rural area (private and public properties)	0,25	0,5	0,75
Great traffic or strategic roads	0,75	2	0,25
Tourist accommodation - buildings	0,75	1,5	0,25
Lifeline	0,25	1	0,25

Table 9: Scenario 1: Expected impact

4.5 Risk assessment

The last phase of the quantitative risk analysis concerns the risk evaluation. This evaluation is obtained multiplying the expected impact values C (Tables 9) and the numeric values of the occurrence probability P related to each scenario (Table 10): R = C x P. The same results are also represented by a zoning shown in for scenario 1 and in for scenario 2 (for physical and social risk only). Due to the extremely small risk values of scenario 3, the physical, economical, environmental and social risk is not shown by a relative zoning of the values.

Risk assessment [R=CxP]				
Elements at risk	*Physical risk*	*Economic risk*	*Environm. risk*	*Social risk*
Forests/Rural area (private and public properties)	0,005	0,01	0,015	0,005
Great traffic or strategic roads	0,015	0,04	0,005	0,01
Tourist accommodation – buildings	0,015	0,03	0,005	0,005
Lifeline	0,005	0,02	0,005	0

Table10: Risk assessment for scenario 1: R1=C1 x 1/50

5 Regulation and risk mitigation measures already available

In order to prevent serious debris flow in the Oselitzenbach torrent and in the receiving stream Gail the following measures are possible:

- Linear measures: “Steps” in the stream bed and debris retention in the flood outlet areas
- Forestry measures to improve the outlet conditions
- Measures like draining and landfills to reduce the massive slope movements.

An extensive project of construction work and research was started in 1988 to prevent debris generating slope failures (especially at the toe zone of the Reppwand- Gleitung) and the destruction of the “Naßfeld-road”. These measures were necessary to prevent serious debris flow in the Oselitzenbach torrent and in the receiving stream Gail and to prevent debris flow reaching the villages Tröpolach and Watschig. For economic reasons the correction of all the debris sources from the very top downwards was not possible or necessary.

At present a risk management system according to the results of the IMIRILAND project is in preparation by the local authorities (e.g. WLV - National Authority for torrent and avalanche control) and the project members.

6 References

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