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THE FUERWAG-LANDSLIDE NORTH OF SALZBURG / AUSTRIA
Process and Countermeasures

Die RUTSCHUNG FÜRWAG im Norden von SALZBURG / ÖSTERREICH
Prozess and Maßnahmen

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ABSTRACT

The FUERWAG-Landslide is situated approximately 15 km of the state capital Salzburg of the Austrian Union State Salzburg. The bedrock layer is the FLYSCH formation covered by moraine. The Landslide is well known and processes are reported since the last century. In the eighties and the early nineties new sliding activities were observed. During 1992 to 1996 preventive countermeasures with drainage system and stabilised open channels were done by the Austrian Forest Engineering Service in Avalanche, Torrent and Erosion Control. In summer 1998 a new thrust starts the sliding and went in the headwater during 5 month 80 m. This meant large danger for the downslope and footstep infrastructure, a first grade road, a local railway track, electricity circuit and gas pipelines. In the early 1999 the concerning agency of the Forest Engineering Service started immediately countermeasures. During one and a half month a drainage system with 12,8 km polyethylene-pipes, diameter 90 mm, 45 collecting wells of steel and emergency campaign a Master Plan was developed. The implementation starts as soon as possible and were finished at the end of 1999. The basic idea of the project was to deliver the collected runoff and drained water without loss to the food of the landslide. This was done by a steel pipe, diameter 630 mm, with a length of 1,0 km, with 2 inflow facilities, 5 control wells and an outflow well. To complete the emergency campaign, 2,5 km drains were added to the system. An afforestation with Black Alder (Alnus glutinosa) rounds up the measures. The development 2000 showed first during the winter a decrease of the movement. After the snow disappearance phase and the thawing up season the process of landsliding was accelerated again in the summer and decreased in the late autumn. At the end of 2000 a large block fell from the Flysch rock and activated the southern part of the landslide again. This disaster destroyed also the drainage system which was installed 1992 to 1996.
KEYWORDS: Landslide Fuerwag, Salzburg/Austria, landslide process, countermeasures.

INTRODUCTION

In the most southern section of the Haunsberg, north of the city of Salzburg (Fig.1), exists a large scale landslide area. Observations during the year 1999 have shown up irregular landsliding and gliding processes occur on various sites. After a phase of several years with smaller activities in the headwater, a larger deformation was recognised at the footstep of the landslide transfers a spacious distortion to the gas pipeline. This was seen in the context with a headwater landslide, recognised Fuerwag North. To the recording of possible contexts, a geological-hydro-geological and morphological examination started. The complex geologic, hydro-geological model of the landslide slope was seen.

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Also it appeared in this geologic, hydro-geologic examination that the springs and sources at the headwater were decisive for the landslide Fuerwag North. In the headwater also deeper water-tables were infiltrating the landslide and increasing the movement..

Consultants and experts of the responsible catastrophe-service of the district government, Salzburg-surroundings demanded the clarification of these complex underground-circumstances for a long-term redevelopment of the landslide Fuerwag. They stimulated another examination of these geological-hydro-geological contexts. With the foresttechnical service for torrent - and avalanche control a project for monitoring was developed. Aim of the monitoring is it, to explain the processes moving the slide-masses to define their reasons.

After complementary discussions in the spring 2000, the proposed programme of monitoring started for the recording of geological-hydro-geological data at the Haunsberg, Salzburg, in December 2000. Albeit the examination in the proposed schedule could not be executed, in the last

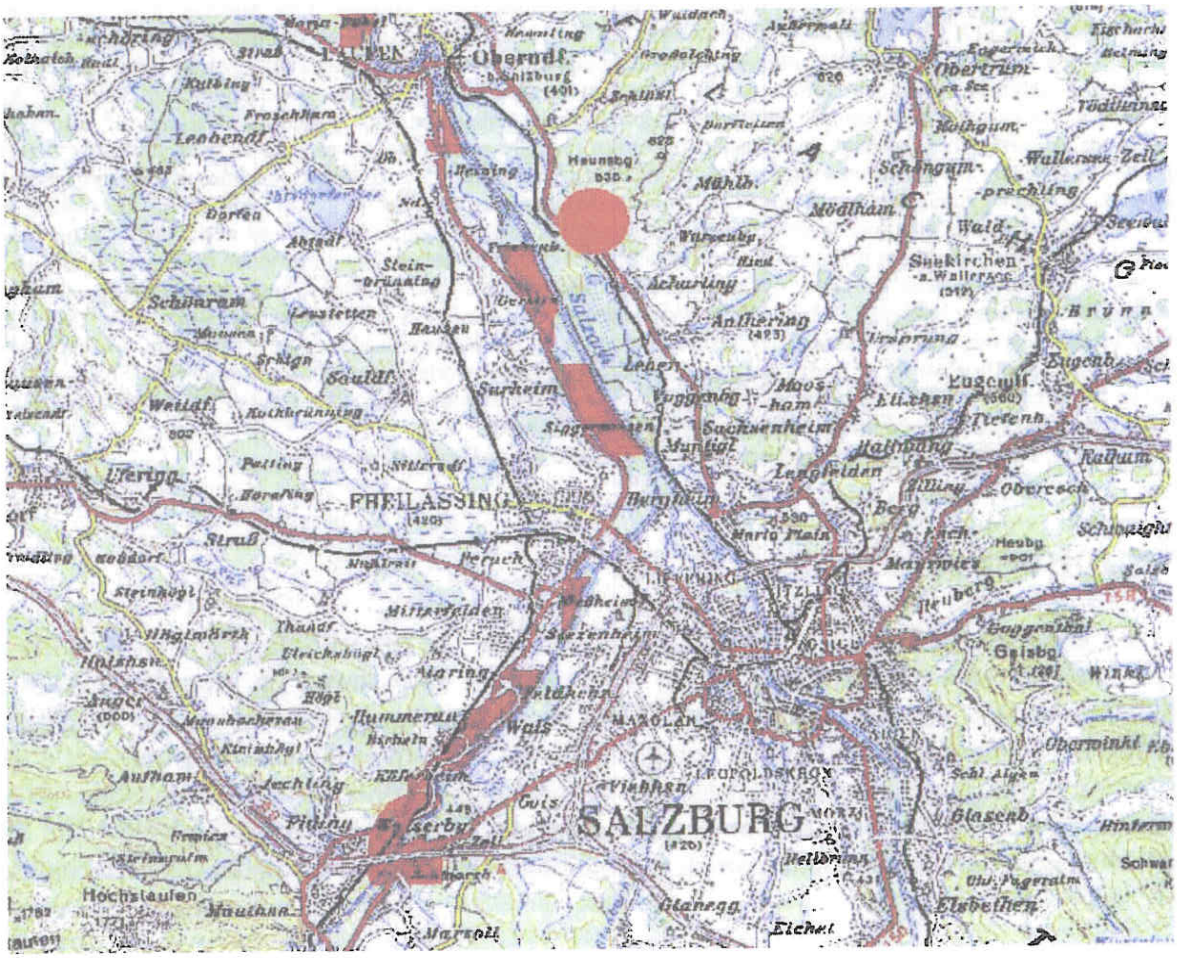

Fig. 1: Site of the landslide area FUERWAG (red circle)in the north of the city of Salzburg.
Abbildung 1: Lage des Rutschgebietes FÜRWAG (roter Kreis)im Norden der Stadt Salzburg.

months different data were elaborated, which are partly presented in the present work.

METHODS of INVESTIGATION

Aim of the investigation programme was in particular:

- the supervision of the hillside-movements in the different parts of the landslide
- the collection of hydro-geological and geological data to the investigate the causing factors for the different parts of the landslide
- to compare the effect of different countermeasures, to optimise the further measures.

With the activation of the Landslide Fuerwag south in the late-autumn 2000, the main focus of the controls was put on the southern area of the Fuerwag landslide. To compare with the executed investigations, the proposed research-framework at the beginning of that in the January 2001 is formulated again shortly and the executed investigation-methodology will be shown afterwards:

- Geologic-hydro geologic observation and mapping: the headwater movements starting in the late-autumn at the landslide Fuerwag South shall be mapped out and elaborated. The terrain-changes should be grasped continuously by mapping so that a continuous assessment of the hazard situation is possible.
- Graphic preparation of the terrain-observations and surveyings. The data raised in the terrain as well as the geodesic data, which are measured by the geological service approximately 2 - until 3 times per week- should be prepared in layouts continuously, so that a swiftly recognising and assessing of the youngest activities become possible.
- Periodic hydro-geological measurements: with measurements of the discharge of springs as well as the water-tables as well as the water-temperature and -conductivity and the confrontation with data of precipitation-events, an assessing of precipitation-events and their consequence should become possible to evaluate the landslide process.
- Chemical examinations of the source - and groundwater. the different sources, the water of the springs and groundwater-levels shall proved and analysed chemically.
- Marking-attempt: About to get informations on possible contexts between the known water-systems, between surface as well as subsurface water in the gliding area and the tensed deep water in the valley floor, a marking-attempt had been proposed by means of several Tracers.
- Exploitation by boreholes - geotechnic examination of the slide-area at the landslide headwater, one should open the soil topsoil and/or bedrock conditions and the possible gliding levels by two boreholes, with whatever soil-mechanic and clay-mineralogical investigations of the creeping area were planned.
- Geophysical investigations: lens-like remains of gravel-horizons with tense water tables, which are covered by older slide-masses and are interpreted as one of the most essential causes for the instabilities in the subslope, should be localised by geoelectric measurements.
- Data-collection and evaluation: the different hydro-geological investigations and surveying data as well as inclinometer measurements should appraise elaborate and prepare in reference to the geological conditions as well as the possible creeping areas. Comparisons with precipitation-data should examine possible contexts with precipitation-events.

PERFORMED INVESTIGATIONS

The considerable reactivation of the sliding mass and expansion of the sliding in May 2001 led to a concentration of the investigations on the Landslide Fuerwag South. Nevertheless, the data-collection and -preparation included the entire area of the landslide Fuerwag, North and South, with what following investigation-methods went into action:

- Geological-hydro-geological observation and mapping: the morphological phenomenons of the Landslide Fuerwag South were recorded like the hydro-geological realities in geological terrain-reception to different times as well: the results were held on in geological plans in each case.
- Graphic preparation of the survey: The geological service conveyed continuously following geodesic measurements to the analysis and graphic representation; the situation of the plots and

the area of the southern landslide was mapped. The determined deformations were prepared graphically and recorded in maps.

- Periodic hydro-geological measurements: since December 2000, the discharge of springs was recorded as well as the water-tables as well as the water-temperature and the electric conductivity at selected plots in 10 round-ups. The plots are at the release edge of the northern landslide and the „Adelsberger"-branch, just as to the north and to the south of the landslide Fuerwag South and is shown in maps

- Digital duration-measurement of the groundwater-stand: in the gauges KG 1/99, KG 2/99, KG 5/99 and KG 9/01 through data-loggers for the duration of 1 to 3 months.

-Precipitation-data: the measurements the rain gauge „Nussdorf"-village were appraised continuously and were worked in the level-stands as well as discharges of springs as well as the distortion into the measurements; present stand of these data is end of December 2001.

- Chemical examination of the water of springs and groundwater: eight groundwater-gauges, seven spring-gauges, the Reitbach and the well of the street-administration were proved at the 17.7.2001 and 6.11.2001. The samples were sent to the federal bacteriologic-serologic investigation-institute Linz for the chemical-physical analysis, the samples to the isotope checking to the research-centre for environment and health, Munich, for analysing.

- Exploitation through drilling - geotechnique examinations of the slide-area: still in May 2001 a drilling was sunk near the farmhouse „Rocherl" at the southern edge of the landslide Fuerwag South and was developed to a gauge. The soil-mechanic treatment started with the inclusion of a consultant in September 2001.

- Geophysical investigations: the current control-measurements at KB 02/99 pointed on one to strong surface-influence in the relationship to the permeability in the water-leading layers, so that an inadequate gauge-construction was suspected. To the control of the construction of the gauge, geophysical examinations were implemented in form of boring-log with measurement of the natural gamma-radiation, the temperature, the conductivity as well as measurements with smooth-water-table and under pump-use.

- Data-collection and evaluation / project- information: the results of the different investigations were co-ordinated continuously in approximately monthly discussions with the district government Salzburg-surroundings, the geological service, the Foresttechnical Service in Avalanche, Torrent and Erosion Control and its geological survey; in the context with the vocal reports over the internal-results was relayed also maps as well as diagrams over the investigation. The discussions are documented in protocols by the district government Salzburg-surroundings.

RESULTS OF INVESTIGATION - DATA-COLLECTION

Subsequently the data determined and appraised in the previous investigation-course are illustrated and shortly are written a commentary on.

Geological Mapping

The landslide Fuerwag south became geological-morphological to different times and maps out hydro-geologically. The results were documented in several plans.

Separation-surface-analysis

After from several sides as causing element for the landslide Fuerwag South a small rockfall (Fig.2) with approximately 300 to 500 m³ was described, exact statements are on the basis of the found condition at the time of mapping not possible, a mapping of the geological structure-was enforced.

Fig. 2 Rockfall area activating the landslide Fuerwag South in the late-autumn 2000.
Abbildung 2 Abrissfläche, die im Spätherbst 2000 die Rutschung Süd aktivierte.

Geodesic surveying

The results of the control-measurements at the plots 24 to 26, the 110 kV-line and the new row of prewarning at the hillside-foot is documented in the excerpt landslide south, for the time period of the 02.05.2001 to 30.10.2001. Figure 3 shows the dislocation-vectors and settling in dependence on the time.
The drama of the landslide Fuerwag South becomes recognisable at the acceleration from June 2001(Fig.3). While altogether admittedly in the past time between August 2000 and June 2001 irregular, however over several weeks approximately constant distortion was recorded, the daily distortion-amount changed itself in the summer 2001 strikingly without a context with stronger pre-

cipitation-events or other reasons being recognisable. This unforeseen acceleration of the slide-masses at the Haunsberg was to observe also in the landslide North, independently from the different hydro-geological conditions -

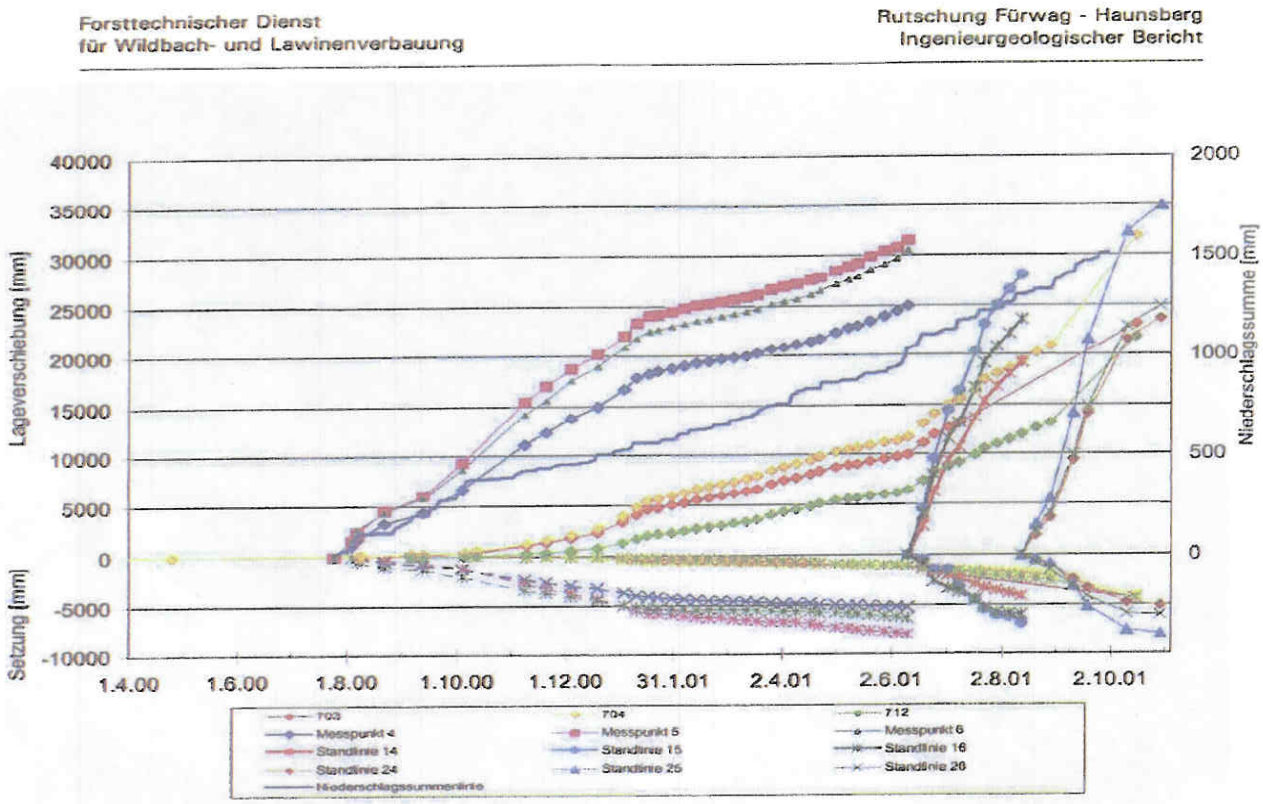

Fig. 3 Dislocation and settling movements diagramm Fuerwag South (Bechtold 2001)
Abbildung 3 Verschiebungs- und Setzungskurven Fürwag Süd (Bechthold 2001)

From the evaluation of the daily distortion-amounts the acceleration is clarified of the slope distortion after the 19.06.2001, averaged over the time period of two measurements. In the method-section of the landslide, the daily distortions reached tops of over 90 cm per day, (plot 25), while was measured in the same time period at the 110 kV-line 5 to 10 cm per day approximately.

So albeit the distortion-amounts vary in the different reaches of the landslide it is remarkable that the distortion approximately simultaneously accelerates or is braked, independently from the situation of the respective plots. Obviously the load-entry transmits itself in direction of the valley after causing the landslide not undulating from above downward but is available a synchronised, conse quently very fast reaction and breaklike movements in the entire slide-mass. This reaction is interpreted as a hint on a deep situated gliding area as well as on pore-water-overpressure into the gliding line.

To investigate the influence of the precipitation on the slope movements - and consequently on the basis of the lacking sources in the area of the landslide Fuerwag south of the surface-water -the distortions were compared with the sum of the daily rainfall in the period of June until end of Octobers 2001. An immediate context of acceleration with starting of the precipitation as well as with heavy-precipitation's is not given, but also cannot be excluded however that the unrhythmic rates of distortion – displaced about some weeks – stands in connection with -prolonged precipitation

periods in June and end September as well as the decrease of the rates of distortion after rainless periods

GROUNDWATER-CONTROL-MEASUREMENTS

Groundwater gauges were established for recognising possible groundwater-influences. Following characteristics were investigated,

- Groundwater hydrographs
- Daily fluctuations of the groundwater table
- Electric conductivity
- Groundwater temperature
- Discharge of springs
- Runoff and discharge measurements
- Chemical-physical analyses
  - Hart-Ca-Mg; Ammonium-oxides; iron-manganese; chloride; sulphate; PH,
  - Isotope analysis; Tritium;

DATA-ANALYSIS

Subsequently one tries to interpret the preliminary results of the investigation performed since the spring 2001.

Groundwater-hydrograph

Observing the groundwater hydrograph it is shown particularly that - independently from the opening of an aquifer - the water-level is partial subservient to synchronous fluctuations. The core drilling KB 1/99 shows similar water-level-fluctuations like the gauges KB 4/99 and KG 5/99 developed in grits. This refers on a context of the groundwater developed in the gauges as well as on an interrelated groundwater-body within as well as at the border area of the slidemass to the understoring sediments. In a next following step through complementary investigations (for example pump research), this would be a hint.

Chemical - physical investigations

The gauges KB4/99, KB5/99 and KB9/01 are filtering and percolating in grits show differently high concentration at total-nitrogen, that is reduced to a big part from nitrate to nitrite and ammonium, on an indication of low oxygen-activity and low percolation. The scattering chemical parameters have altogether showed up very strong local influence into the single gauges.

The springs at the headwater and the discharge of the drainage system differs in the chemical parameters from the water in the groundwater-gauges. That is another noticeable index on very low runoff influencing the water into the gauges at the foot of the slope.

Concluding it is determined that hints are available with the measurements of the groundwater table and the chemical data in connection with the waters in the underground of the slide-mass. The indications of the very low surface influence are already very clearly recognisable so that assuming an deeper seated influx of water exists into the foot of the landslide.

Results of the geodesic control

It is emphasised that only with the knowledge of the distortion-speed an assessment of the hazard potency is possible, independent from the monitoring.

For a possible stabilisation of the landslide one has to take care in particular that the activities of the landslide concurring in conformity over the entire landslide (Fig. 3). This distortion is only possible by a hydraulic process, consequently by swimming on a water film (gliding horizon) under high pressure of standing water-film.

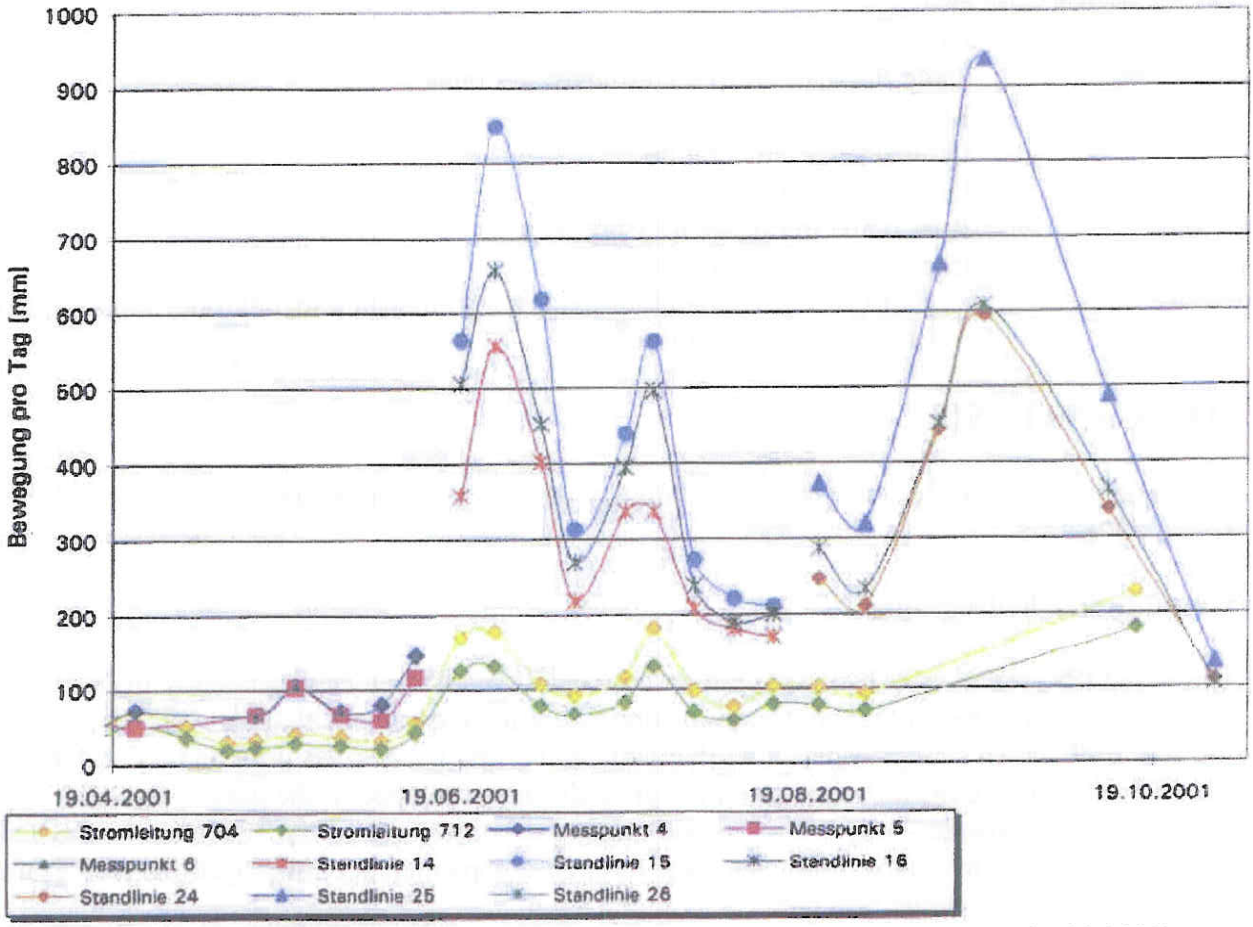

Fig. 4 Daily rate of deformation landslide Fuerwag South APR-OCT 2001 (Bechtold 2001)
Abbildung 4 Tägliche Verformungsraten der Rutschung Fürwag Süd 2001 (Bechtold 2001)

In connection with the continuos distortion of the slide mass it is of importance when the infrastructure-facilities are impacted by the landslide. Undoubtedly, this can be answered only hypothetically, however is existing sufficiently data, to employ on concrete data based prognosis, about a coarse, however.

- Plot 806: this was already activated in March 2001, during which the downslope plot 905 was still without movement, however the landslide reached this point in September with the same speed as in plot 806. The two surveying-points lie removed approximately 100 m of each other and the interval of the rate of the movement amounts to 150 days (Fig. 4). It calculates itself a velocity of the landslide movement of 0,66 m per day.

- Plot 811: between next to the last and last measurement this plot shows the same development in speed like plot 905 (Fig. 5). That means a propagation of acceleration of the activation of the landslide about 0,7 m per day.

Considering that the national highway is situated approximately 250 m in fall-line in the centre of plots 813 and 818 which moved ready clearly in July. Under the assumption, that the landslide

moves with an approximately constant speed of 0,66 m downhill one has to calculate with an activation of the area of the national highway end of March 2002. However geodesic measurable distortions should enter already essentially earlier.

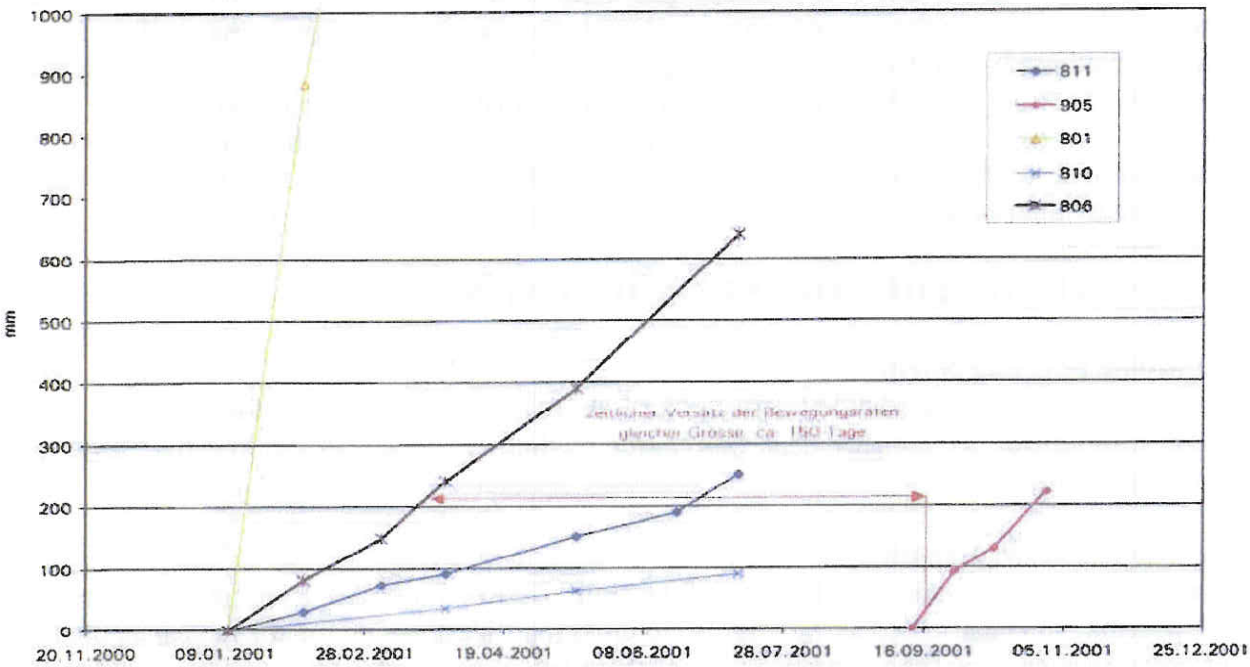

Fig. 5 Dislocation of selected points of measurements of the south landslide (Bechtold 2001)
Abbildung 5 Zeitliche Verschiebung ausgewählter Messpunkte der Rutschung Süd.

Compare the dislocation of northern and southern landslides

Finally, one should shortly describe the differences between the two slide-masses. From the view of the preliminary results of the investigations, the two landslide Fuerwag North and Fuerwag South show partially clearly different circumstances:

- Fuerwag North: with the hydro-geological survey, numerous springs were mapped in the demolition-area of the landslide, the irrigation of the slide-mass consequently already took place directly below the ridge of the Haunsberg.. The mechanism of the landslide was visible. That should already reach by deviation and drainage of water in the release-area of the landslide a broad stabilisation.
- Fuerwag South: the landslide neither was caused by surface-water or by springs in the release area nor as well as was forced. Rather, a relatively small rockfall was triggering the distortions with few m³ mass in August 2000. The considerable expansion of the landslide in the demolition-area in May 2001 cannot be explained with precipitations or with springs neither since no sources were existing and also the weather-circumstances were with poor precipitation. The distortion of the landslide and the considerable speed are explicable with the pre-determined inclination circumstances only by gliding on a water film glide surface.

OUTLOOK

A long-term improvement of the situation can be reached in the entire Fuerwag-slope only by accordingly lasting reduction of the presumably deep-set water-influx into the three slide-branches. This measure necessitates an elaborate investigation of all parameters, that can contribute to the clarification of this water-body. Considerable data, that deliver some indications of hydro-geological contexts, were already composed with the monitoring project, that had to be moved away something by the Rutschung Fuerwag South of the original goal. The redevelopment of the landslide Fuerwag South, but however still long-range analyses necessitate also the entire Fuerwag-slope as well as more from the soil-mechanic than also geological-hydro-geological side. Let us hope that with continuance of the activities in the landslide also the necessity these - for landslides undoubtedly unorthodox - examinations are recognised.

MEASURES OF THE FORESTTECHNICAL SERVICE

Landslide Fuerwag North

The movements of the landslide Fuerwag North decreased and stopped until some local, in the size rather insignificant movements. This was caused by drainage-measures and loss-free deviation into the recipient Reitbach.

Landslide Fuerwag South

The swift movements and the plasticity of the slide-mass first allowed no counter-measures. It was not possible, to embarrassed as well as also to cross the slide-mass on foot or with an appliance too. In order to come from one landslide side to the other, it was necessary to walk around the entire movement-zone.

After more or less gone wrong attempts, to bring the movements with drainage's and wells to fading away, as this succeeded in the landslide north, following method was enforced:

- Open ditches, which let dry up the surface of the landsliding area
- Collection these waters in wells at the edge as well as outside the moving masses
- Loss-free deriving the caught waters into the recipient by hoses
- Prevention of the penetration of watering into the landslide in the headwater by horse-shoe drainages and deep seated drains,
- Construction of a filter-dam at the smallest part (only 15 m wide) of the landslide

These measures were implemented by October 2001 until February 2002. This arduous work challenged again and again the implementing crew. The open ditches had to be updated daily. Breaks and postponements occurred up to 3,5 m within a night. Some wells grew out from the lateral shear-surfaces during the night, like fungus. At the end of the headwater the smallest part of the landslide (15 m wide) despite at all attempts in the end to deviate water from the landslide, still movements approximate 10 m daily were measured casually. After the smallest part, the movements slowed down since the cross-section of the landslide expanded to the 5 until 8-time width. An improvement of the movement-situation was coming up only as in the middle of December a cold-period appeared, that lasted until the end of January. The water reason for the sliding could now be drained from the landslide. Under the strong frost-effect (-15 to -20°C), the surface of the landslide stopped. The surface of the landslide was enterable again and with it also machinable. The ditches worked in their draining task. Immediately the implementation -crew worked forward to the smallest part of the landslide and tried there, to grasp the water causing the movement. In 5 m depth, they reached the Flysch formation and the landslide promoting water on it. These water was grasped in drainages and deviated loss-free. After the end of the cold-period, a filter-dam, a barrier from permeable gravel-material, was erected at the smallest part of the landslide above the drainage. Into that construction 4.000 tons coarse-buffs (, 70 - 150 mm) were installed. The imple-

mentation of the construction lasted 5 weeks since the delivering of the material was impeded after end of the cold-period again.

CONCLUSION

Now, beginning of March, can be said, that the measures of the Foresttechnical Service in Avalanche Torrent and Erosion Control were target oriented and that the endangering of the infrastructure was bottomed at present. By the drainage at the smallest part and the downslope ditches system up to 400 m³ water are sucked out daily from the slide-mass. The water is as well hindered to infiltrate the landslide.
After stabilising the actual situation of the landslide by immediate measure, the definite stabilisation by drainage-measures will start in the spring 2002.

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