# Landslides
# Consequences – Restoration – Harmonization

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**Abstract**

In the last years the number of landslides and rockfalls is increasing not only in Germany but also worldwide. The causes are diversely. One of the causes is certainly the climatic change. Especially in the springtime of the year 2002 numerous landslides and rockfalls occurred in the German low mountain range for instance in the Rhenish Slate Mountains in SW-Germany.

The possibilities and the difficulties of risk assessment as well as the restoration of landslide and rockfall areas in the sense of securing and stabilization are shown by case studies.

Particularly applied modern protection methods are mentioned. A new method of the investigation of landslide areas with the help of electromagnetic impulse measurements is also introduced. Already achieved and further steps for the absolutely needed harmonization in the field of mass movements on slopes are discussed.

## 1. Introduction

The causes of landslides are of various natures. Landslides are frequently direct results of other natural disasters like earthquakes and floods.
In the last years the amount of landslides rose worldwide. The causes are on the one hand the increasing of human interference in the nature area and on the other hand climatic events like extreme precipitation, which arises increasingly.

For the improvement of the hazard evaluation and thus for the minimization of damage an interdisciplinary cooperation on the geotechnical sector of slope stabilities is necessary. A condition for such cooperation and for an international exchange of experience requires the harmonization of the technical terms, which includes a precise definition.

The prerequisite for a documentation of landslides, of the protection methods carried out and of the effectiveness of these methods is such a harmonization of terms.

The documentation, for which there are beginnings, should be the base for further research on the sector of slope stabilities in the sense of prognoses and protection methods.

An international disaster management concerning landslides is essential.

## 2. Consequences of landslide events

According to Cruden [1] a landslide is a movement of rock, earth or debris down a slope. The different landslide types are [2]:

- falling
- toppling
- sliding
- spreading
- flowing (fast movements)
- creeping (slow movements).

Results of landslides can be the blocking of traffic ways (Fig. 1) or the destroying of buildings. The consequence should be the execution of protection measures before a rockfall or landslide occurs. The problem of such protection measures is the prediction of the entry of the event.

If the danger of mass movements on slopes is in time recognized and the movements can be controlled, the assessment of the probability of the entry can be improved. A mapping of mountainous and hilly areas should be done in view of slope stabilities therefore.


Figure 1. Blocking of a road and a railway line due to a rockfall and destroying of a residential building caused by a landslide

The problem of prediction the time of occurrence and the risk assessment is touched in the case study of a rock slope in a lateral valley of the River Moselle in the Rhenish Slate Mountains (SW-Germany). A road was widened in the direction of the slope. The rock slope had to be cut therefore. After some weeks the slope reacted to the cut with deformation. Gaps opened up (Fig. 2). The road had been immediately closed as a result of that. A stabilization of the slope had been very difficult from the technical point of view because of its steepness. Therefore the road was removed down to the valley. By in such a way won distance between the foot of the rock slope and the roadside, the road users were protected from falling rocks or rock slides. The reason for the closing up of the road and finally their removal was the very high rate of movements, which reached 20 cm per day. The falling or sliding event could occur each moment after this extremely high rate of movements. But nothing happened. The mass movements stopped four weeks after the first opening of the gaps.

The rate of slope movements is normally the base for the prediction of a landslide event. This case study shows that every landslide has its own rules regarding the kinematics and the influence of the causing or triggering factors.

With immediate decisions, those to be frequently demanded, concerning slope stability and the risk, is decisive the experience. Then the causing factors will only qualitatively seized and valued. In that case the prediction and the risk assessment is only approximately possible. A quantification of the causing factors, to which generally long-term measurements of the movements as well as of the factors of influence and their correlation allows a more precise prediction of the behaviour of the instable slope. Permanent measurements of the slope deformation have substantial advantages in relation to episodical measurements as the following example Puenderich at the river Moselle shows. In a large slide area (1,6 Mio m³), which was already known with the building of the railway line at the end of the 19th century, but nevertheless had to be traversed, for the stabilization of the slope extensive drainage measures were implemented in that time. They were no more maintained in the last decades, so that it came again to slope deformations in the range of decimetres. The railway line was endangered therefore. The results of the episodical geodesic measurements of the slope deformation correlated well with the results of the measurements of precipitation, so that a direct connection was assumed. Therefore new drainage measures were considered uphill the railway line in order to lower the groundwater level and with that to minimize the rate of movement. The extensometers (Fig. 3), installed later, for securing the railway line permitted permanent measurements. The correlation to the rate of movements with the precipitation and the water level of the River Moselle shows the direct connection between the water level of the River and the mass movements. Therefore drainage measures uphill the railroad line would have had no crucial influence on the mass movements. A minimization of the rates of movement of the landslide is to be expected by drainage wells between the river Moselle and the railroad line so that the influence of the high waters of the Moselle, which cause the acceleration of the slope deformation, is eliminated and the groundwater level is lowered down. These two facts cause an increasing of the slope stability.

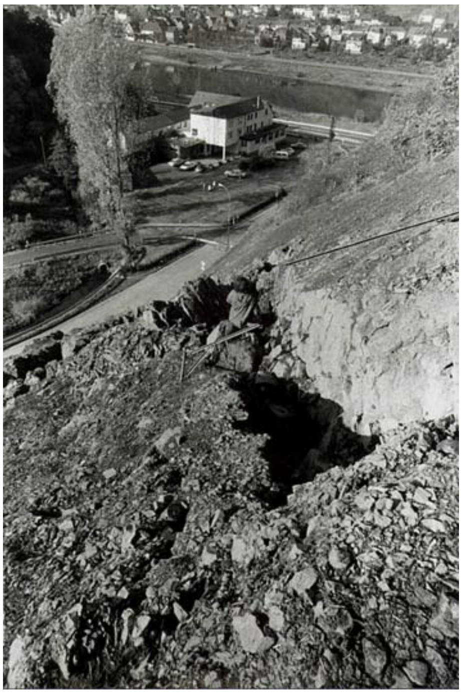

Figure 2. Opening of gaps on the rock slope

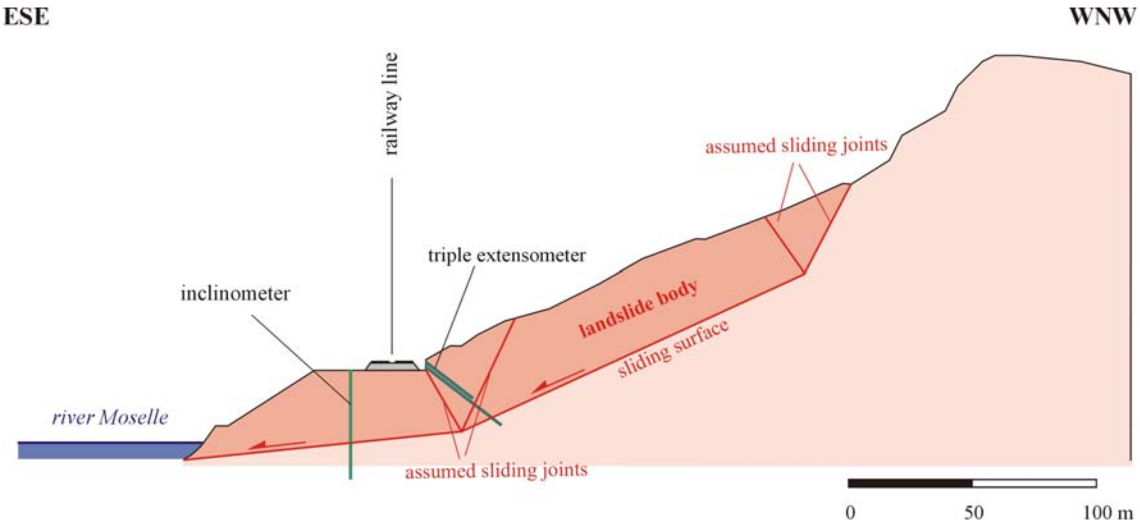

Figure 3. Cross-section of the sliding mass Puenderich with the installed extensometers for controlling the movements

In general you can say concerning drainage measures for reducing the movement of landslides that they are only so long effective as the working order is maintained. If maintenance will omit it exists the danger that it comes to additional slope irrigation, which leads to an acceleration of the slope movements.

These case studies show that the main prerequisite for risk assessment is theoretical knowledge and practical experience of the kinematics of landslides and causing factors. In addition only permanent measurements of the movements and of the direct influencing factors, like precipitation, groundwater level and the water level of the receiving stream, makes possible a quantification of the influence of these factors regarding the acceleration of movements. Permanent measures are the condition for a precise risk assessment and optimal protection measures.

In cases, where the rate of movements is known over a longer period (years) and a stabilization would be only possible with extreme technical methods controlling methods has been used.

Close to the city Landstuhl in Palatinate *(*SW-Germany) the embankment and the underlying bedrock (sandstone and claystone of the Rotliegendes, Perm) of a highway are sliding. The cemetery on the foot of the embankment and the road downslope is moving too. The rate of movement is two cm per year. The surface of the highway has to be repaired from time to time. But it is not to exclude that the movements accelerate due to extreme climate events and it could come to an endangering of the road-user.

Stabilization is very problematically from the technical point of view, because the surface of rupture is 35 m deep. Therefore the so-called GOCA System (Fig. 4) had been installed for permanent controlling the rate of movement [3]. It applies GPS for the real-time monitoring of movement processes at the earth surface. With the help of a specific filter system the accuracy of measurements in the horizontal direction reaches one to two mm and in the vertical direction two to three mm. An alarm will set off, when the limit value of four mm per day is exceeded. This new method is appropriated for absolute distance measurements and in forested areas, where other distance measuring methods cannot be used. To this method it has to be however remarked that the software for the evaluation of the measured data not yet matured at present and can be only done with high expenditure of time at the moment.

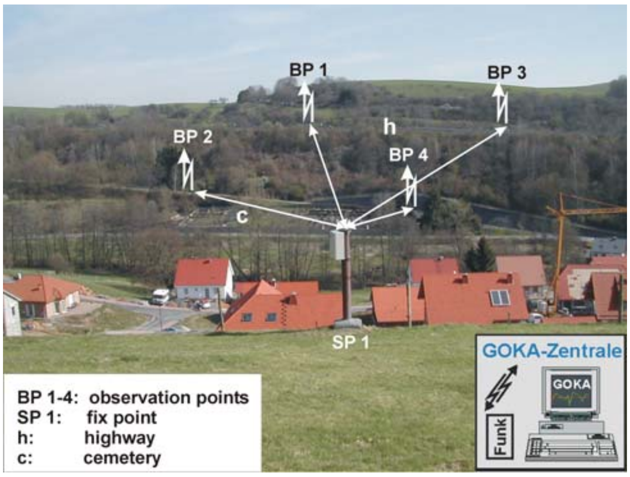


Figure 4. Landslide area

Concerning mapping and risk assessment in the case of urging data collecting a helicopter flying can be used. This is a faster and in steep slope areas a more precise (Fig. 5) as well as cost-saving method for risk assessment in comparison to conventional mapping [4]. In the springtime 2002 a large number of landslides and rockfalls in the Mittelrhein and Moselle area in SW-Germany effected closing of railway lines and setting up of slowdown sections in this area. This caused disturbances and delays in the whole railroad network of Europe. As the result of these events a systematic recording of the risk potential along the railway tracks was required. Urgent data collecting called for a helicopter survey.

Figure 5. An apparent stabile 30 m high rock slope (on the left). Only the view from the helicopter shows the instability of the slope. Gaps (arrow) separate the front of the rock from the solid rock (on the right)

The risk was assessed during the flight and the classification was checked with the help of film material, which was also taken during the flight, und directed ground checks later on.

The risk is defined as the product from hazard potential and vulnerability (Fig. 6). In that case vulnerability means the probability of hitting railway tracks or a train itself by sliding or falling rock masses. The risk was divided in four classes from “very high” to “low”. The rank “very high” means for instance:

- either to apply direct securing measures like closing up the railway line
- or to apply indirect securing measures like permanent surveillance by persons or measuring instruments and
- immediate planning and execution of securing or stabilization methods

and the rank “high” means:

- episodical surveillance and
- planning and execution of securing measures within the next two years.

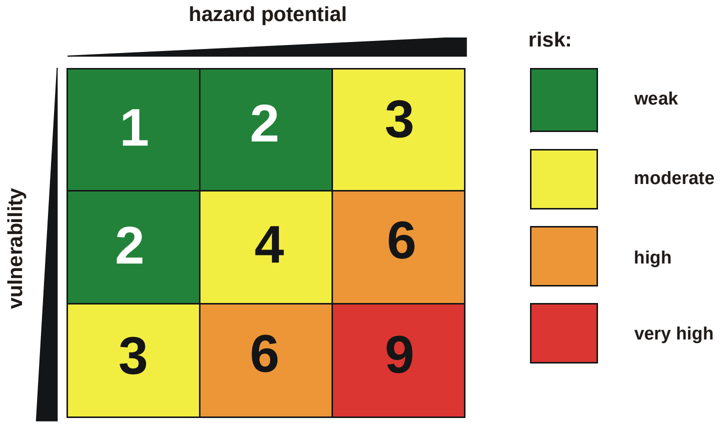


Figure 6. Classification of risk (risk = hazard potential x vulnerability)

A new method for the investigation of the extent of landslide areas is measurements of the natural electromagnetic pulse radiation [5]. It is possible to detect the borders of a sliding mass and in boreholes the depth of the surface of rupture with this new, in the meantime sufficiently tested, research method with a portable apparatus (Fig. 7). It is also possible to find out active faults and the horizontal stress field with this method.

The impulse rate per time is measured (Fig. 8) and stored. The data can be draw down to a PC.

Figure 7. The portable measuring apparatus

One is not able to avoid landslides and rockfalls with the introduced investigation and controlling methods but we can mitigate or avoid damages.

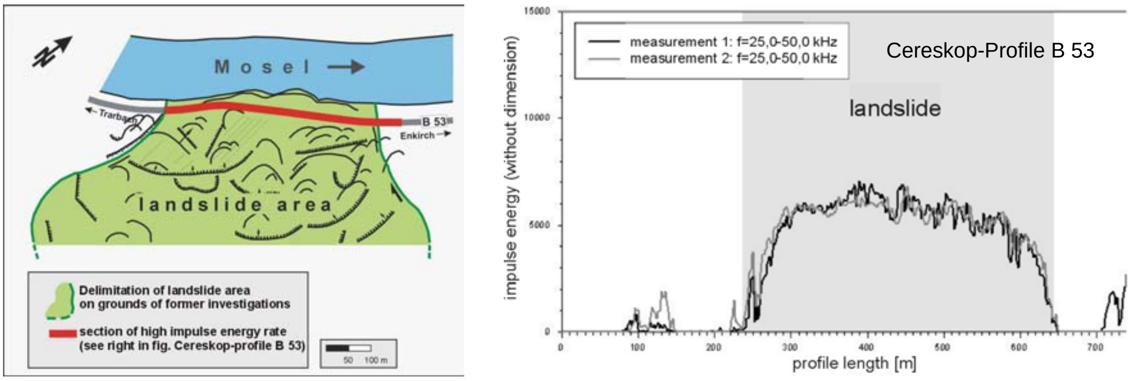

Figure 8. The results of electromagnetic impulse measurements in a landslide area at the River Moselle

## 3. Case studies for restoration

Two examples of environmental friendly and low-cost methods of restoration in the sense of stabilization, which hardly admits outside of Germany, are introduced. Landslides in rock and soil material up to the depth of the surface of rupture of about 10 m a three dimensional lattice ("Krismer-Gitter") of corrosion protected steel is fastened with a raster of nails on the surface of the landslide area. The length of the anchors depends on the depth of the surface of rupture. The lattice will be filled with edged gravel for superficial dewatering. After that the gravel will be covered with soil, which contains seed. After some months it is grown over (Fig. 9). This method has still the advantage of a fast and simple execution.


Figure 9. A rockslide before (on the left), which is partly covered with the lattice, and after (on the right) the stabilization with the "Krismer-Gitter" and the vegetation 3 months later

The second restoration method is the stabilization with strip-like supportive bodies made of earth-concrete [6]. With this in-situ-soil-improvement, made section by section, landslides reaching down to a depth of 10 m too, can be stabilized (Fig. 10).

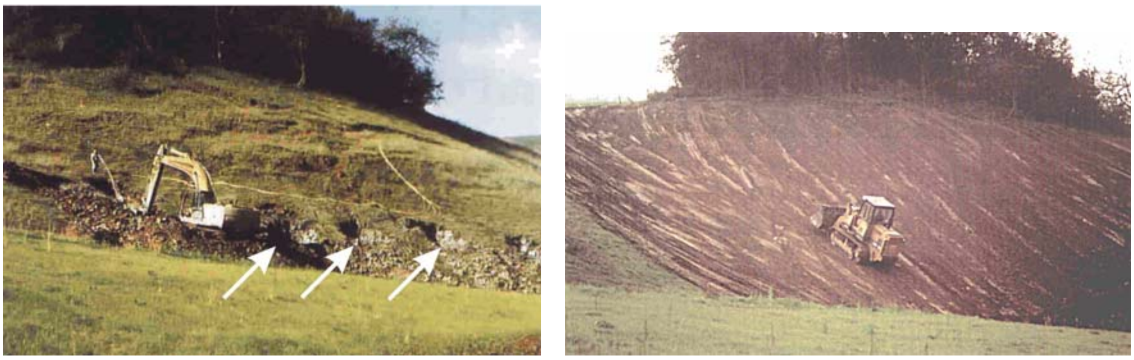

Figure 10. Stabilization of a landslide with strip-like supportive bodies. On the left hand side the digging of the ditches (arrows), which will be filled with so-called earth-concrete and the grading of the slope (on the right). The stabilized slope will be planted later on

Regarding technical, economical and scenic aspects, these two methods provide an intelligent solution especially if a fast stabilization is necessary, even of steep slopes.

**4. Harmonization**

A harmonization in the field of natural disasters, in these case landslides, should cover:

- bundling of knowledge and experience in order to find the best practice solution
- intensifying investigation of landslides regarding causing and triggering factors, monitoring and stabilization methods in the frame of common research projects.

The exact objectives have to be worked out mutually. All these works has to be done in an interdisciplinary cooperation. In the sense of harmonization an essential prerequisite is speaking a common language. This means we should use a uniform nomenclature for the landslide phenomena and processes. The Multilingual Landslide Glossary does a first step in this direction [2]. This glossary should be continued and the missing languages of the EU completed and further chapter added.

Another step of harmonization could be the continuation of the documentation of landslides in Europe. It exists already such a documentation of landslides in Europe from the year 328 A.C. up to 1986 [7, 8]. This documentation should also be continued. But at first the criteria of the documentation has to be new fixed.

Steps of documentation and evaluation of natural hazards are shown in Tab. 1. The three steps are the scientific part of harmonization. In the case of landslides it is the engineering-geological or geotechnical way.

Table 1. Step by step documentation and evaluation of gravitational natural hazards [9]

| **Step 1** | **Step 2** | **Step 3** |
|---|---|---|
| **Identification of natural hazards:**<br><br>**"What can happen and where?"**<br><br>documentation of phenomena in regard to the causes by:<br><br>• **basics**<br>maps<br>surveillance<br>measurements<br>• **documentation of occurrences**<br>• **map of phenomena** | **Hazard assessment:**<br><br>**"How often can it occur?"**<br><br>evaluation in regard of impact and area by:<br><br>• **hazard maps** | **Planning of measures:**<br><br>**"How can we protect ourselves?"**<br><br>conversions into the fields:<br><br>• **development of planning**<br>• **securing measures**<br>• **emergency planning** |

The harmonization in the sense of information and communication with the target of mitigation of natural hazards regarding the damages demands not only scientific work but also a common public relations work, which includes:

- Anchoring of instruments of the disaster prevention in other special fields and areas of politics
- Distribution of knowledge of the disaster prevention in all educational levels
- Converting of existing knowledge in politics, industry and administration
- Promotion and strengthening of the awareness of prevention in the society.

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