# Slope failure process recognition based on mass-movement induced structures

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## 1. Introduction

Aim of the "2nd Conference on Slope Tectonics" are mass-wasting induced structures, fabrics and geomorphic features from local to regional scale, both in terrestrial and submarine environments, their structural and geotechnical analyses, and evolution modelling. Two thematic sessions are:

- Structure induced by slope deformations
- Modelling of mass-movement structures and dynamics

The slope failure process (the failure mechanism of a slope) is the origin of mass-movement induced structures and has to be the basis for geotechnical analyses as well as for modelling of mass-movement structures and dynamics and thus plays a key role when investigating mass-movements.

## 2. Importance of process recognition

Process recognition is the most important task when dealing with slope instabilities. A clear conception of the failure process must be the basis for

1. Monitoring and interpretation of monitoring results,
2. Modelling and analyses,
3. Risk assessment,
4. Design of measures for decreasing instability and for warning.

### 2.1 Monitoring

Figure 1 shows, that the installation of an extensometer in the upper part of a mass-movement makes much sense, if the failure mechanism is toppling, whereas it makes no sense, if the failure mechanism is a rotational failure. Only after recognition of the process (of the failure mechanism) it can be decided, which quantity has to be measured where in order to find out what is going on. The same applies to a monitoring system e.g. measuring the distance between the monitoring device and points of the slope. Not every mechanism can be controlled in such a way.

### 2.2 Modelling

Only a mechanism embedded in a model can be the result of an analysis. There is no model at present comprising all possible mechanisms.

Back calculation of the mass-movement "Weisse Wand" (South Tyrol, Italy) shows that the failure mechanism has decisive influence on the strength required for limit equilibrium. Vice versa, the failure mechanism has enormous influence on the factor of safety of a particular slope with a given rock or soil strength. Thus, process recognition has to precede geotechnical analyses and evolution modelling of mass-movements.

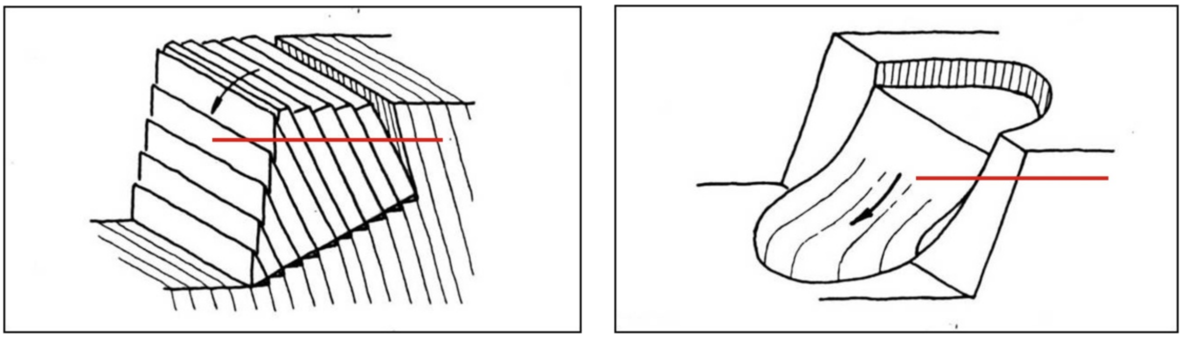

Figure 1: Extensometer for monitoring toppling and rotational failure

2.3 Risk assessment

The failure process as well as the run out triggered by it has influence on both, on the damage and on the occurrence probability. Thus, risk in a particular case can be assessed only after the failure process has been detected.

2.4 Design of measures for decreasing instability and for warning

Already Terzaghi (1950, 1960) pointed out that "the means for stopping a moving soil mass must be adapted to the process producing the landslide". A simple example for the influence of the failure mechanism on the design of mitigation measures is an embankment loading the toe of a mass-movement. Such an embankment makes sense in the case of a rotational failure; however, it makes less sense applied to a toppling slope.

When installing a warning system, the question, which quantity has to be measured where in order to recognize what is going on, is again very important (see "2.1 Monitoring").

## 3. Classifications of landslide mechanisms

3.1 Detachment mechanism - run out

Many classifications of landslide mechanisms do not distinguish between failure or detachment mechanism and the possible run out (e.g. rock fall, rock slide, rock avalanche, debris flow). As the failure mechanism influences the stability, the run out affects the danger for settlements etc. initiated by a failure. An ideal mechanical model, which is essential for investigations of slope instabilities, should therefore simulate both the failure mechanism (detachment of a mass) and the run out (propagation of the detached mass). There are only very few "ideal" models for very special cases. For most cases we have to separate into a model for the failure mechanism and a model for the run out.

As an example, Cruden and Varnes (1996) divided into falls, topples, slides, spreads and flows (Figure 2). The example they showed for a fall, however, was a slide (failure or detachment mechanism) turning into a fall in later phases (run out). The probability of a fall, therefore, is ruled by sliding of the block. Moreover, a monitoring system measuring the distance between the monitoring device and points of the slope could not be used as an alarm system, because very small areas would show changes of the distance.

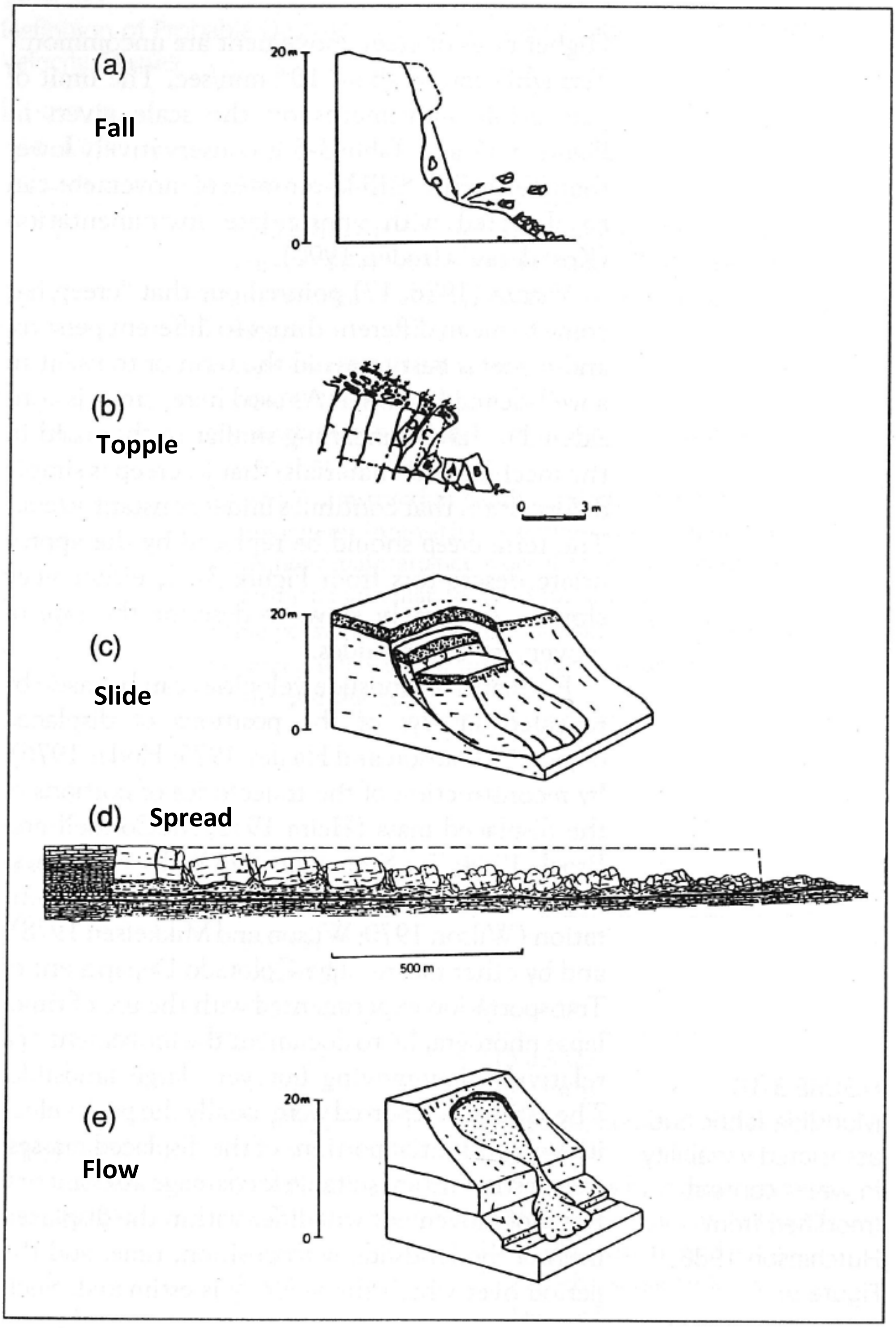


Figure 2: Types of landslides according to Cruden & Varnes, 1996

## 3.2 Sackung (sagging)

Sackung is a term known ubiquitously to geotechnical professionals practicing in alpine-type terrain. In 1932 Heim referred to Sackung as the slow, steep to vertical deformation of mountain slopes, wherein the internal structure is not changed considerably and displacement is concentrated on a distinct shear surface. Pioneering work by Zischinsky (1966) showed that displacements in many high slopes continuously decrease with depth, based on an assumption of Bingham rheology for the rock mass. Zischinsky referred to this slope deformation phenomenon as Sackung; however, the gentlydipping velocity isochrons indicated by Zischinsky are fundamentally inconsistent with the meaning of Sackung = sagging, which is a vertical movement, and with Heim's original descriptions.

Since Zischinsky's contribution the term has become common, but the underlying driving mechanism has remained obscure. Compounding the obscurity is the fact that many researchers and practitioners have subsequently applied the term Sackung to a broad spectrum of slope deformation styles (e.g. Hutchinson, 1988). More than 50 years have elapsed since Zischinsky's seminal contribution, and although during this time our understanding of rock mechanics and slope deformation processes has advanced substantially, comparatively meager advances have been made in the mechanical understanding of Sackung.

Poisel & Kieffer (2010) refuse classifications of mass movements, which do not define the mechanisms clearly. Thus they recommend that the term “Sackung” (“Sagging”) should no longer be used in order to avoid misunderstandings.

### 3.3 Catalogue of slope failure mechanisms

Thus a catalogue of slope failure mechanisms with a clear mechanical model (Figure 3; Poisel & Preh, 2004) is presented taking into account the geological setting and the geometry of the slope, the joint structure, the habitus of blocks, as well as the mechanical behaviour of the rocks or of the soil and of the rock or the soil mass (deformation and strength parameters). Its aim is to give geologists as well as engineers the opportunity to compare phenomena in the field and phenomena belonging to particular mechanisms and to find the mechanism occurring. Transitions from one mechanism into another mechanism e.g. according to changes of the material behaviour during the detachment process will be presented.

In order to classify and model a slope failure, close cooperation between geologist and engineer is therefore of paramount importance:

1. analysis of structures (observation and identifying of discontinuities and fractures) by the geologist, because the geologist is qualified for this work,
2. synthesis of a mechanism by both the geologist and the engineer,
3. modelling by the engineer, because the engineer is qualified for this work,
4. interpretation of results by both the geologist and the engineer,
5. back to analysis of structures?

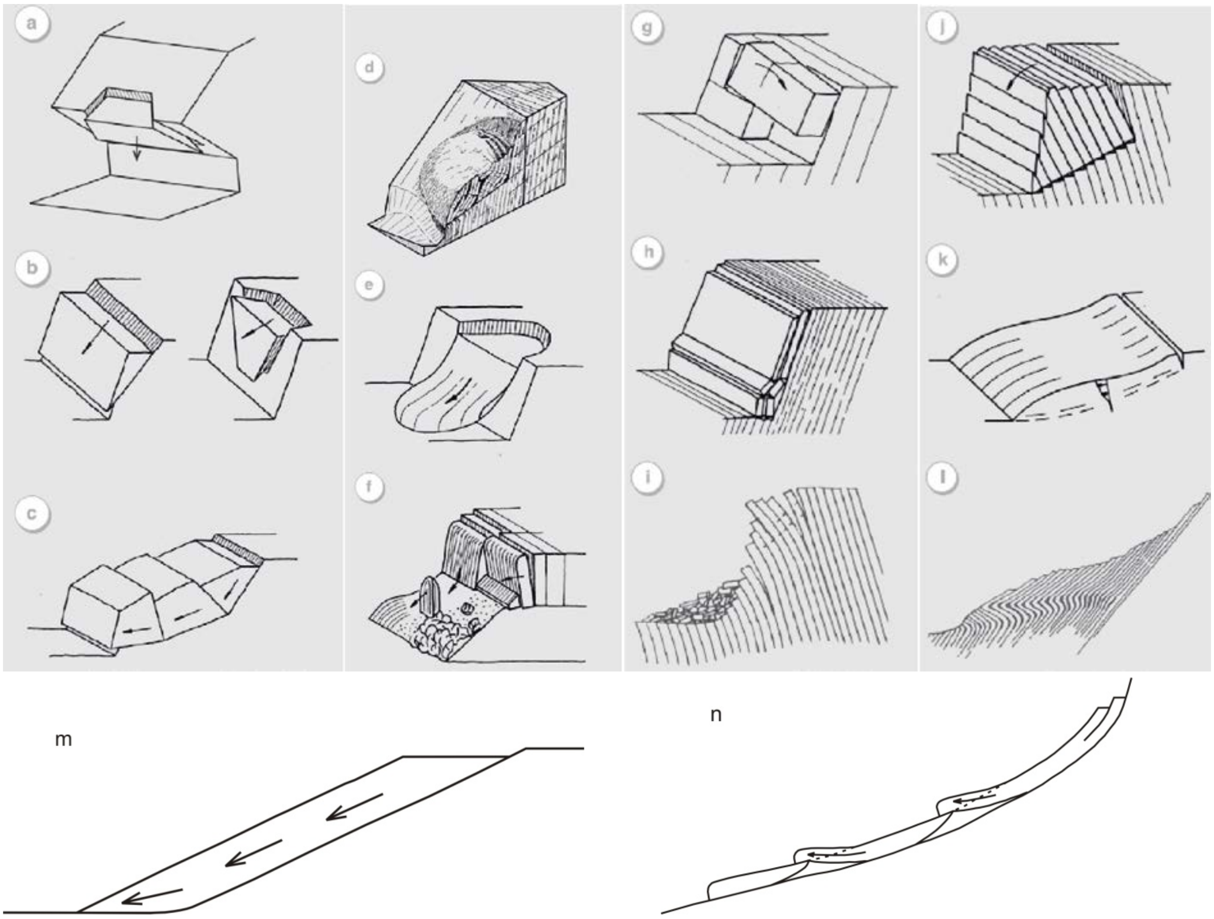


Figure 3: Slope failure mechanisms

a. falling,
b. translational sliding on a single or on two discontinuities,
c. sliding on a polygonal sliding plane,
d. slumping,
e. rotational failure,
f. hard on soft,
g. torsional failure,
h. buckling,
i. flexural toppling,
j. block toppling,
k. slope creep,
l. kink band slumping,
m. translational sliding parallel to the slope surface (“infinite slope”),
n. mudslide.

## 4. Examples of mass-movement induced structures indicating particular slope failure mechanisms

As described above, process or failure mechanism detection is extremely important when dealing with slope instabilities. Therefore, table 1 shows slope failure processes, the most prominent structures caused by them and cases, where those structures will be demonstrated.

Table 1: failure process, structures and cases

| **failure process** | **structures** | **cases** |
|---|---|---|
| Sliding of several blocks on a polygonal sliding plane | Antithetic fractures<br>“Graben”-like structure | Vajont<br>Veitsch |
| Rock slumping | A-shaped opening joints | Pardee dam |
| Rotational failure | Main scarp is a normal fault | Hope Slide |
| Toppling | saw tooth pattern of the slope surface | Afton Mine |
| slope creep | main scarp is a tension crack | Gartnerkofel |
| kink band slumping | Main scarps are normal faults<br>S-shaped deformation of rock lamellae | Bunzkögele |
| Mudslide | Thrust faults, Riedel-shears | Gschliefgraben |

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