Engineering Geological Models: Some Examples of Use for Landslide Assessments

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Abstract
The Commission C25 of the International Association for Engineering Geology and the Environment is currently working on "The use of engineering geological models". This article presents examples of engineering geological models for landslides using both a conceptual and an observational approach. Generally speaking, the conceptual model forms the basis for the development of the observational model. However, there are cases where the relationship between the conceptual model and the observational model is not so unidirectional. The experience gained in developing the observational model in these cases can facilitate considerably the development of future conceptual models in the same type of engineering geological conditions.

Keywords
Landslides • Engineering geological model • Conceptual • Observational

2.1 Introduction

This paper constitutes a contribution to the discussion currently taking place within the Commission C25 of the International Association for Engineering Geology and the Environment, which is currently working on a paper entitled "The use of Engineering Geological Models" (Parry et al. 2014). The C25 considers two different methodologies for developing the models:

The *conceptual approach*, according to Parry et al. (in press), is based on understanding the relationships between engineering geological units, their likely geometry and anticipated distribution. This approach, and the models formed, are based on concepts formulated from knowledge and experience and are not related to real three-dimensional (3D) space or time. Importantly, the model is largely based on consideration of *geological concepts* such as age, stratigraphy, rock type, unconformity and weathering.

The *observational approach* is based on the observed and measured distribution of engineering geological units and processes. These data are related to actual space or time and are constrained by surface or sub-surface observations.

To illustrate these concepts, the article will present several examples from Cretaceous sedimentary regions of the Czech Republic.

2.2 Conceptual Models of a Slope Structure Comprising a Rigid Layer Above a Plastic Layer

In the Czech Republic, slope movements relatively often occur in a rock structure characterized by an upper layer (No. 1 on Fig. 2.1) consisting of rigid (competent) rock broken into blocks by the Tertiary tectonics, and by a thick

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lower layer (No. 2 on Fig. 2.1) consisting of plastic (incompetent) rock. Typically, the upper layer is composed of massive sandstone and the lower layer of plastic claystone.

Figure 2.1 represents a conceptual model of a long-term evolution of a slope with this structure, as seen in various stages of development (Rybář and Nemčok 1968). In Fig. 2.1a erosion processes start to cut through the rigid layer. Figure 2.1b demonstrates that a narrow valley is prone to bulging (Varnes 1978). Further deepening and widening of the valley (Fig. 2.1c) leads to cambering—block-type movement on plastic underlying rock (Varnes 1978; Nemčok et al. 1972) in the upper part of the valley and to landslides of plastic rocks and derived soils in the lower part of the valley. Figure 2.1d represents a denudated slope prone to landslides triggered by river erosion at its base.

In Czech Cretaceous sediments, the most common slope state corresponds to the model stage "c" (Fig. 2.1c), which can be encountered also in Prague. Using archival research data, the general conceptual model can be further developed into a site-specific conceptual model for a particular location. Common features of site-specific models for the stage "c" comprise: (1) upper slope consisting of sandstone, often affected by block movements; (2) groundwater horizon developed in the sandstone above the impermeable clay, often drained ahead of the sandstone blocks on slopes consisting of fine grained soils; (3) ahead of the sandstone blocks, potential occurrence of landslides in the slope composed of fine grained soils.

An example of a site specific conceptual model is given in Fig. 2.2. In the village of Hrubá Skála, located in the NE of the Czech Republic, family houses were built on a seemingly favourable flat terrain which in reality consisted of unrecognized old landslides. A correct use of the principle of engineering geological models would have easily prevented damage to the houses (Novotný 2009).

A similar site specific conceptual model in Fig. 2.3 characterizes the Prosek district in the north of Prague (Pašek 2000 in Novotný 2009), affected not only by slope movements but also by historical undermining (Cílek 1999 in Novotný 2009), which should be taken into account when determining the scope of site investigation works needed for the correct development of the observational model. Houses constructed near the slope edge with disregard of the model were damaged by fissures and one of them had to be demolished (Lešner 2004 in Novotný 2009).

Generally speaking, all site investigation works should aim to answer questions raised by the conceptual model, and thus to elaborate the observational model. At the same time, the conceptual model itself can be used to determine efficiently the type and scope of site investigation works needed (when compared to a "grid-like" site investigation planned without knowledge of the site geology and processes).

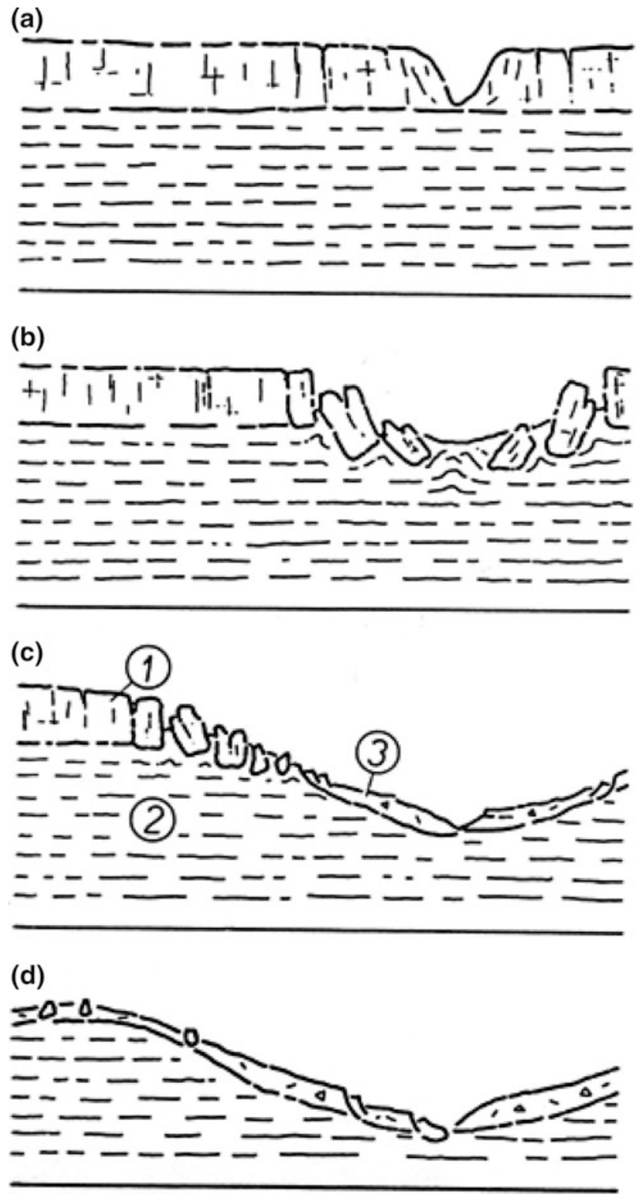

Fig. 2.1 Development stages of a slope comprising a rigid upper layer and a plastic lower layer (according to Rybář and Nemčok 1968)

2.3 Observational Model of the Březno Rotational Landslide

Figure 2.4 presents an example of an observational model of the central part of the Březno u Postoloprt landslide. The model was constructed by the author using a cross section from a site investigation report (in Pašek 1974), aerial view by Google and field mapping carried out by the author.

By sliding along the rotational surface of rupture ("rock slump" according to Varnes 1978, rotational landslide according to Nemčok et al. 1972), the Cretaceous marlstone block was pushed into the river bed, substantially narrowing

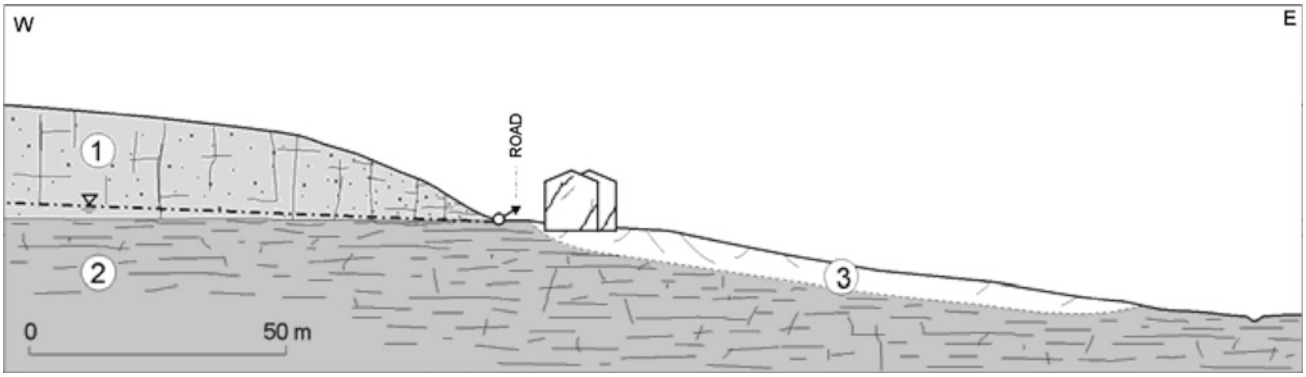

Fig. 2.2 Conceptual model of a slope in Hrubá Skála. *1* Cretaceous sandstones, *2* Cretaceous claystones, *3* landslide

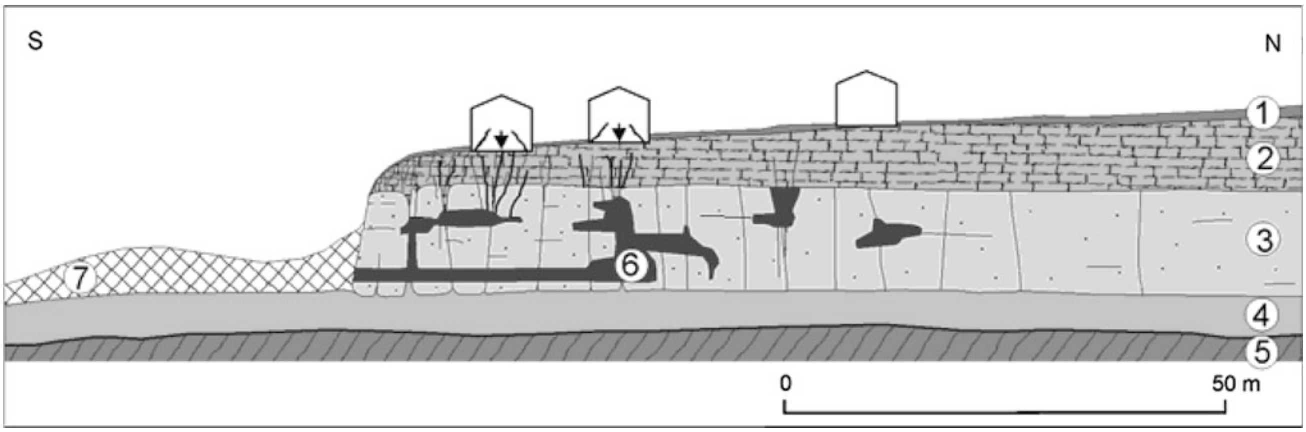

Fig. 2.3 Conceptual model of the edge of the Czech Cretaceous Formation in Prosek (after Pašek 2000 and Lešner 2004 in Novotný 2009). *1* Quaternary loess soils, *2* Turonian marls and marlstones, *3* Cenomanian sandstones, *4* Cenomanian claystones, *5* Ordovician shales, *6* mining cavities, *7* mounds

it in this area. The main cause of the landslide, besides lithology prone to sliding, is primarily the erosive action of the Ohře river which to this day maintains the whole landslide in an unstabilized state. A layer of baked clays located in shallow depth below surface also plays an important role, preventing the area from being denuded into a gentle slope less prone to sliding.

Unlike the simple structure of the rotational landslide, the morphology of the main scarp, resulting from various slope processes, is considerably complex. The main scarp above the rotated block is divided into a series of ridges separated by areas with periodical occurrence of minor landslides and notably earth flows. In long-term conditions, the ridges themselves are also unstable, prone to rock fall and opening of vertical tension cracks which can lead to rock topples of large blocks. The material from minor landslides, earth flows, rock falls and rock topples accumulates in the head area, adding weight here and destabilizing the entire landslide. In the upper part of the accumulations, minor scarps are formed; above them, the terrain locally dips towards the slope, creating undrained basins that further destabilize the slope by the process of water infiltration into the unstable masses.

2.4 Conceptual Model of the Head Area of the Březno Landslide

During the development of the observational model of the Březno landslide, a conceptual evolutionary model of processes in the main scarp area was also established. Without knowledge of the slope's history and evolution, the model would be much simpler in comparison with the following concept (Fig. 2.5).

Figure 2.5(1): State after the development of the rotational landslide. Figure 2.5(2): Irregularly, minor landslides and rock falls occur in the main scarp area, creating partial ridges in the scarp area and accumulations at the base of the scarp. Fig. 2.5(3a): In long-term conditions, local rock falls repeatedly occur in the ridges, heavily fractured by

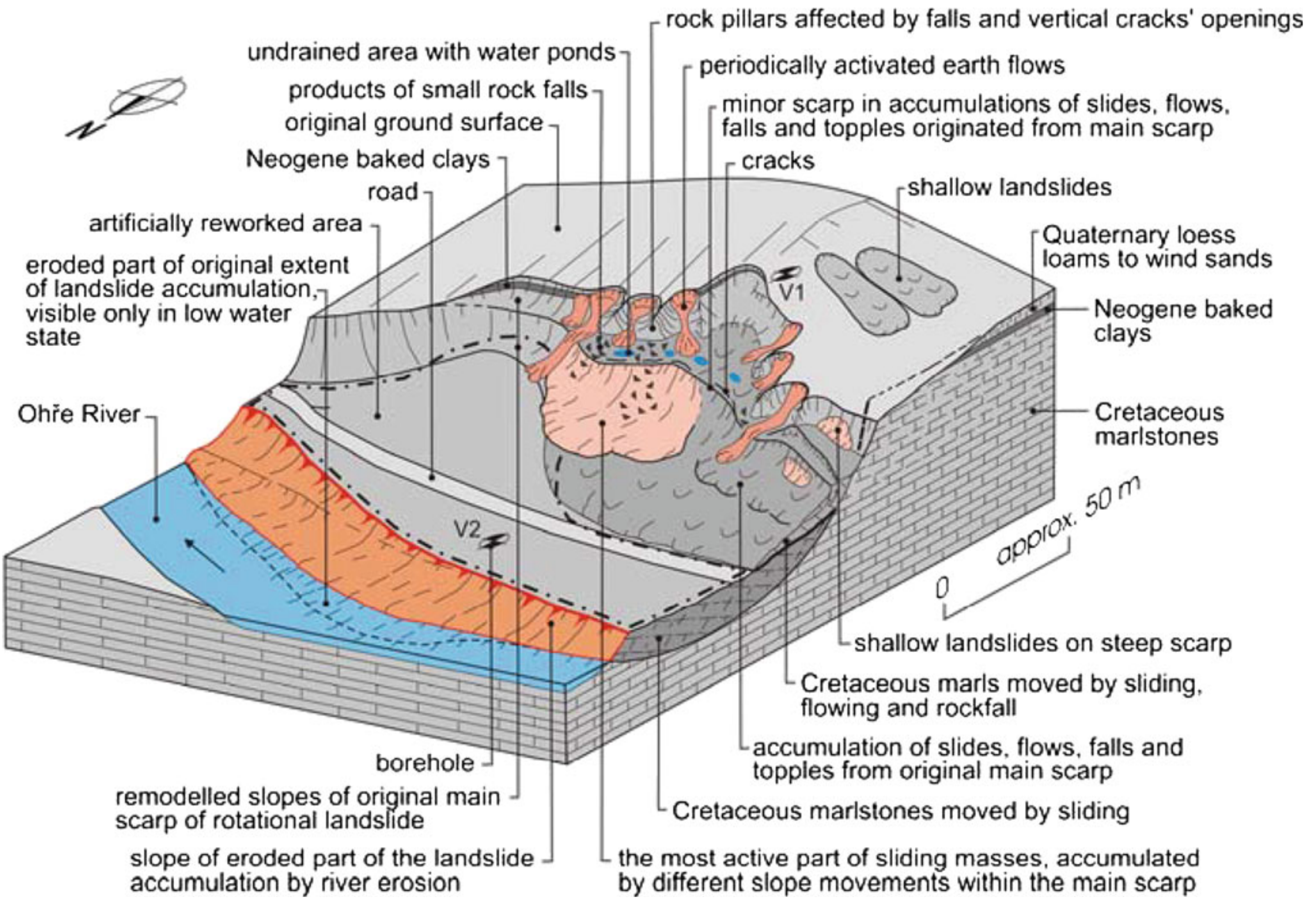

Fig. 2.4 Observational model of the Březno landslide in Cretaceous marlstones

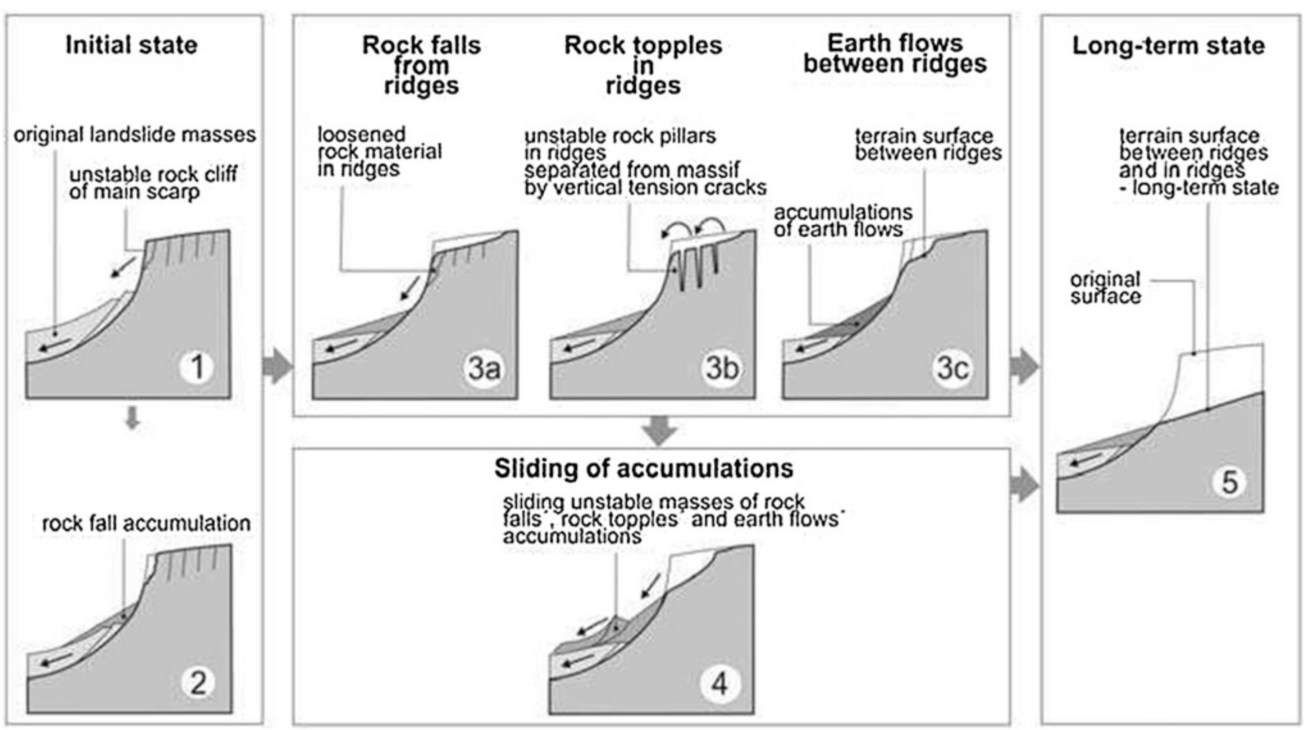

Fig. 2.5 Conceptual model of processes in the head area of the Březno landslide

discontinuities in the marlstone rock mass. Figure 2.5(3b): In long-term conditions, local topples repeatedly occur in the ridges. Figure 2.5(3c): Earth flows repeatedly occur between the ridges. Figure 2.5(4): Rock fall, rock topples and earth flow accumulations are unstable and prone to sliding. Figure 2.5(5): In the long term, the processes depicted in Fig. 2.5(3a–3c)–(4) result in a considerable retreat of the whole main scarp very far beyond its original position (an important factor influencing any potential construction projects in the area) and in the gradual increase of slope stability. In reality, the situation is even more complex than described by the conceptual model presented above.

2.5 Conclusions

A knowledge of the conceptual model of a slope consisting of a rigid upper layer and a plastic lower layer, including its future development, can be used not only to predict engineering geological conditions in all parts of the slope, but also to recognize all issues that have to be resolved by site investigation when compiling the observational model. Sufficient experience is needed to elaborate an appropriate conceptual model, and as shown in the example of the Březno landslide, the experience gained when developing observational models can also be useful.

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