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SPECIAL PURPOSE ENGINEERING GEOLOGICAL MAPS OF SLOPE FAILURES IN SLOVAKIA**

1. Introduction

The territory of Slovakia is characteristic with extremely frequent occurrences of various types of slope failures. Especially landslides are one of the major geotechnical problems in Slovakia. The landslides significantly affect building and operation of large amounts of transport, watermanagement and underground constructions. Currently there are documented more than 20 000 old slope failures in Slovakia — mostly landslides, which cover an area up to 1900 km^2 [4]. Results of regional research of slope stability of certain areas are perfectly illustrated in the special purpose engineering-geological maps of slope failures, which are usually made in scales from 1:5000 to 1:50 000.

In the article there are some examples of these maps that are available to the general and professional public in Slovakia.

2. Types of slope failure maps

Slope failure maps can be classified by the content, type of compilation and their purpose onto:

— maps of engineering geological conditions of slope stability,
— slope stability zoning maps,
— landslide susceptibility maps,
— landslide risk maps,
— landslide potential maps,
— prognostic maps.

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According to the map scale maps can be divided onto:
— small scale maps (1:100 000 and smaller),
— medium scale maps (1:25 000, 1:50 000),
— large scale maps (1:5000, 1:10 000),
— detailed maps (1:500, 1:2000).

For these types of maps in Slovakia, the most prevalent are large scale (M = 1:10 000) maps of engineering geological conditions and medium scale (M = 1:50 000) landslide susceptibility maps [1].

3. Maps of engineering geological conditions of slope stability

Maps of engineering geological conditions of slope stability are prepared in medium and large scales; scales 1:10 000 are the most common in Slovakia. They are useful for planning of larger urban units, roads and other line projects in unstable areas and for selection of suitable construction sites. They are usually made in three sheets:
— basic map of engineering geological conditions of slope stability (sheet A),
— index map (sheet B),
— zoning map — map of stability risk (sheet C).

Basic maps of slope failures (sheet A) are compiled from a study of archival materials, using interpretation of aerial photographs, field mapping, and using a sparse network of mapping boreholes. Maps can be characterized as partly uncovered map. In the map only those quaternary units are shown which are relevant to the evolution of slope failures. The units include particularly proluvial cones, river terraces and eluvium. There are marked different types of slope deposits that are directly affected by slope movements — sliding deluvium. The stable zones are indicated by color, which symbolize rocks of pre-quaternary substrate, resulting

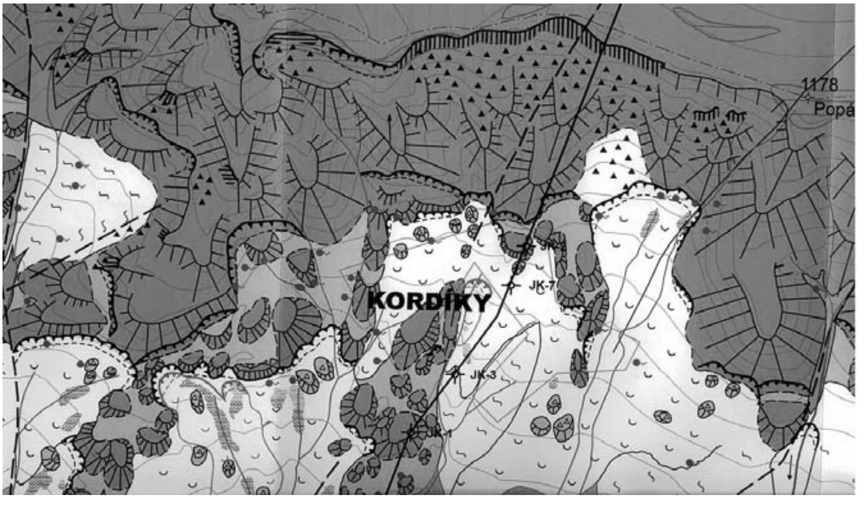

Fig. 1. Part of the map of slope failures in the vicinity of village Kordíky [6]

in better „three-dimensional presentation“ of geological conditions of slope failures. In the maps there are illustrated all activities of groundwater and surface water, which have a significant impact on development of slope failures.

Slope failures are the most important part of the map. The map shows also the details of slope failures, main scarps, side flank, transverse ridge, radial cracks, toe of surface of the rapture surface, types of slope failures respecting the sliding surface shape, activity level, surface shape, etc. (Fig. 1).

In the index map (sheet B) there are plotted all the documentation points, which were used for compilation of the map (outcrop, boreholes, trial pits, springs, etc.). Record sheets of slope failures are the most important part of the documentation. The records have comprehensively encoded essential information about each registered slope failure, and they are computer processed. The database of the records is kept in the central archive in Geofond in Bratislava.

The zoning maps (sheet C) are specifically derived analytical maps. Homogeneous territorial units (zones) are allocated on the basis of assessment of their slope stability and their resistance to reactivate movement. Quantitative value of degree of slope stability (F_s) is not suitable as the criterion. It is not enough reliable for the purpose of zoning mapping, because any violation of the slope has its own characteristic stability regime. The degree of stability varies depending on the reversible and irreversible factors. Any slope, any slope failure must be assessed on the basis of a comprehensive system approach. The categorization of the territory into individual zones with a certain stability (resistance) should therefore take into account the comprehensive assessment of geological-tectonic structure of each slope, the properties of rocks, geomorphological, climatic and hydrogeological conditions with regard to the intensity of interaction of natural factors which affects slope stability. The zoning maps are somewhat stylized, simplified and sometimes influenced by subjective factors. It is necessary to choose more accurate conditions to categorize the territory into individual zones, subzones or districts in order to eliminate any adverse effects that were not revealed during the research works.

On the territory of Slovakia the zoning maps of the slope stability were compiled by Department of Geotechnice of FCE of STU for the area of Handlová kotlina basin, Vtáčnik Mts., surroundings of Prievidza, and for the eastern edge of the Kremnica mountains. The zoning map for the Liptovská kotlina basin [5] covers up to 380 km^2 (Fig. 2).

The mapped area was typologically classified in to the following 3 zones and 15 subzones.

1) Zone of unstable areas — subzones: 1. active landslides, 2. potential landslides in the rocks of Paleogene basin, 3. potential landslides in the Mesozoic rocks, 4. stabilized landslides in the basin fillings, 5. stabilized landslides in the Mesozoic rocks, 6. areas threatened by saltation of debris and rock falls, 7. debris flow.
2) Zone relatively stable — subzones: 8. slopes susceptible to sliding, 9. slopes sensitive on stability, 10. block fields.
3) Zone of stable areas — subzones: 11. alluvial plains, 12. areas of river terraces, 13. areas of proluvial sediments, 14. flat slopes in Paleogene rocks, 15. steeper slopes in the Mesozoic rocks.

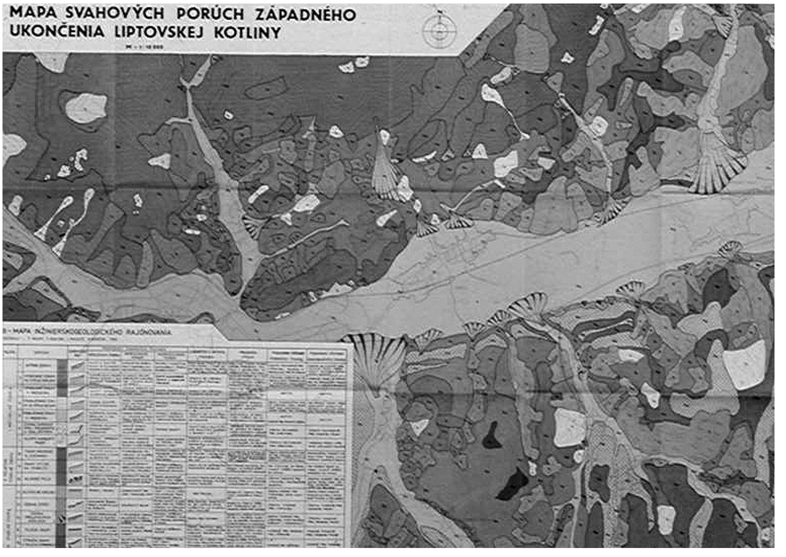

Fig. 2. Map of the engineering geological zoning of the western part of the Liptovská kotlina basin [5]

Map legend together with a summary table is a part of the zoning maps where each zone is briefly characterized. In the table there are also pictures of schematic crosscut of each subzone. In the individual table cells there are briefly assessed the conditions of slope movements (geological, morphological and hydrogeological). The activity and character of movements and prognosis of their development is also evaluated. The conditions for building and road construction are also briefly described.

Zoning maps are also accompanied by a final report where a possible use of the individual low stable subzones is described with respect to the results of the research. An important part of the report is also a proposal of optimal remediation measures for stabilization of the individual subzones, taking into account the purpose and economic possibilities.

4. Landslide susceptibility maps

The map of relative susceptibility of land to mass movement is a part of the set of engineering geological maps of environmental factors in a scale of 1:50 000. The map is required in areas where movements play an important role and constitute a major building-technical problem. In terms of Slovakia, but also in neighboring states, the geology of such areas consists of Cretaceous and Paleogene Formations of Flysch zone and Klippen Belt, the edge of volcanic mountains, basins filled with Neogene sediments, ect. The map of relative susceptibility of land to mass movement is a unique map of the engineering geological zoning. The territory is evaluated there in terms of slope stability. In the map there are allocated zones and subzones with the same or a similar susceptibility to the development of slope deformations. Methodology of map compilation is based on an empirical evaluation of factors creating and developing slope deformations [3].

When evaluation of slope stability, the following conditions should be taken into account, which are crucial for zoning the map area:

— existing slope failures,
— geological conditions (lithology, thickness of Quaternary sediments, occurrences of sliding structures, tectonic settings, degree of rock alteration, course of joints, in adjacent strata their geometric relationship, etc.),
— hydrogeological, hydrological and climatic conditions,
— geomorphological conditions (slope inclination),
— land use, condition and character of vegetation cover.

The first two conditions are considered as the major criteria and the other as the minor criteria.

The mapped area is zonated into three zones:

— zone of unstable areas,
— zone of potentially unstable areas,
— zone of stable areas.

Into the unstable zones those areas are included which contain large amount of slope deformations and have unfavorable geological conditions, or there are present only one major criterion together with several minor ones.

Into the potentially unstable zone those areas are included which contain one major criterion (slope deformations or unfavorable geological conditions) and eventually some minor criterias (morphological, hydrogeological of vegetation conditions). Slope failures in these zones are not very frequent, but also are not very exceptional. They are activated by natural causes (mainly rainfall and water erosion), but more often by intervention of man into natural stability settings of slopes.

A particular type of potentially unstable areas are slopes, where landslides are not present now, but they may arise from man activity (for example. solifluctional deluvium in Flysch Zone, weathered clayey soils and rocks in the Paleogene, etc.).

Into the zone of stable areas there are no conditions or assumptions for activation or and formation of slope failures caused by natural processes. No major criterion occurs in this zone. Occasionally there may occur shallow slope failures in Quaternary deposits (landslides usually), especially due to fatal violation of discipline in technology during earthworks and other major interventions into the configuration of terrain. Slope failures caused by natural causes do not have large sizes and they are very rare (Fig. 3).

Legend, table with general description of selected zones and subzones and report are also a part of the map, which carry very important information for development of the mapped area.

Beside the mentioned maps more maps of slope failures are being compiled. Currently, more and more maps are made in digital form (GIS). They provide detailed information about the mapped area. In 2008, a comprehensive Atlas of landslides in the Slovak Republic was completed in scale of 1:50 000 for the whole territory of Slovakia (Fig. 4).

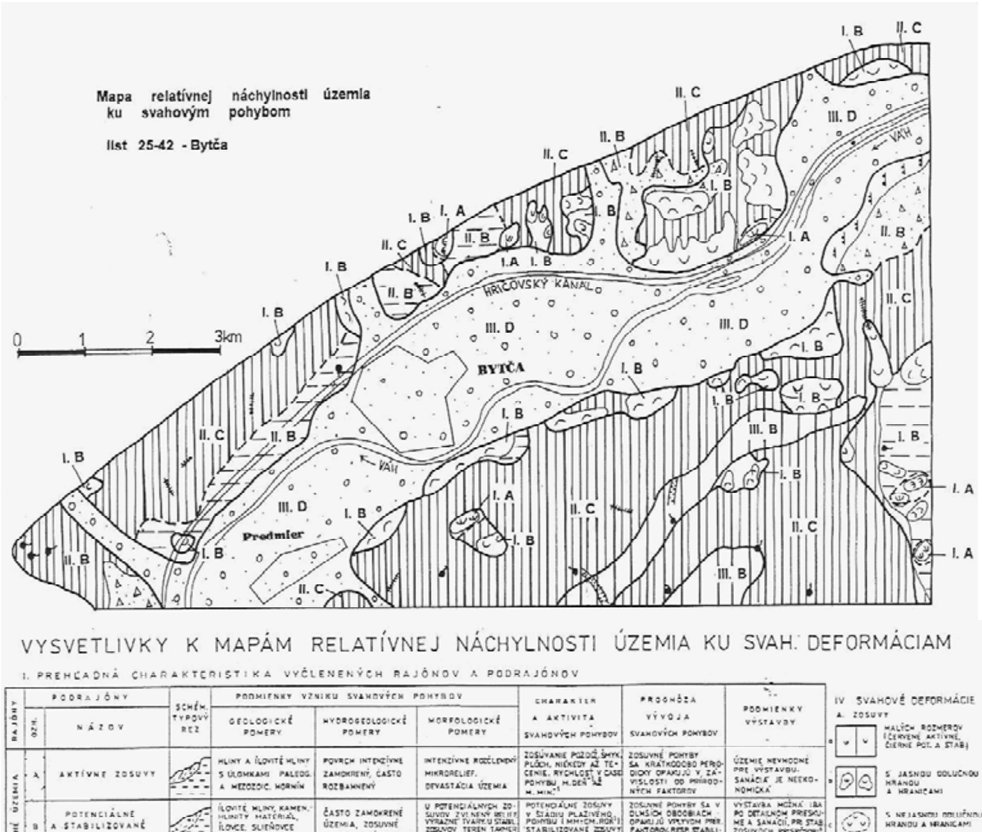

Fig. 3. Map of relative susceptibility to slope movements (simplified after [2])

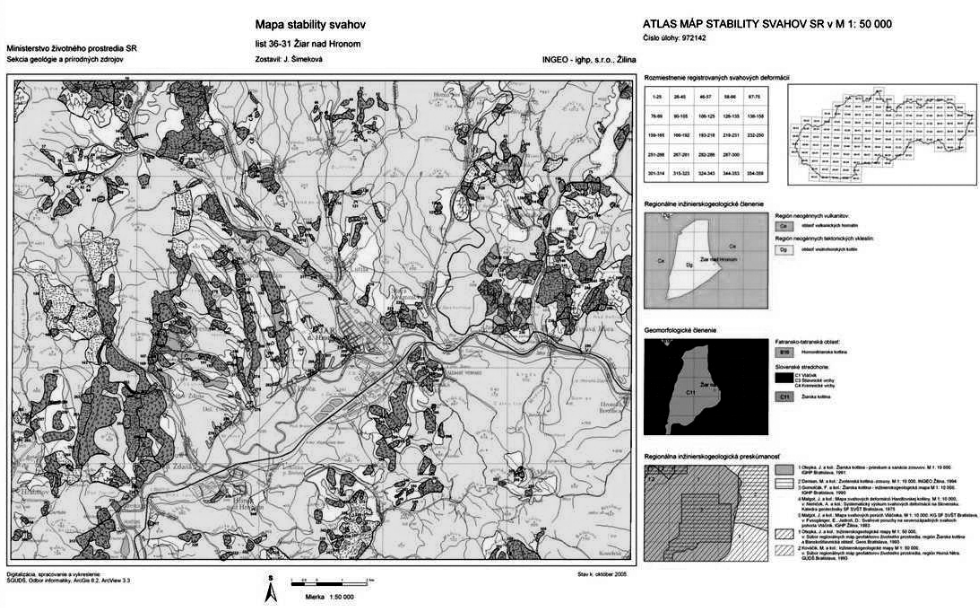

Fig. 4. Map of Slope stability (map sheet Žiar nad Hronom) — Atlas of maps of slope stability of Slovak Republic in scale 1:50 000 [7]

5. Conclusion

Special purpose engineering geological maps of slope failures appear to be the most appropriate information for investors, city planners and developers when making decision about land stability. Such information opens a way to better designing of any engineering constructions on slopes and significantly rationalize the protection of the environment in areas affected by mass movements.

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