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THE INFLUENCE OF HUMAN ACTIVITY ON THE DEVELOPMENT OF LANDSLIDES IN SLOVAKIA

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About 90 % of new landslides take place by activation of potential landslides due to man's negative intervention in Slovakia. Antropogeneous interventions act on the stability of old, dormant landslides differently. The landslides are either artificialy loaded or undercut. Man's activity induces changes in the regime of groundwaters or causes dynamic effects on the landslides. The paper analyses the cases of activization of old landslides due to the construction of civil or industrial structures, bridges, roads, tunnels, pipe-lines and water artificial reservoirs. Numerous landslides were induced by deforestation of land, incorrect agricultural meliorations works, worsening of flow – off surface and underground waters and failures of the underground pipe-lines. The high number of artificially activated dormant landslides in the areas with an intense economic activity in Slovakia is alarming. With the constantly increasing urbanization of Slovakia, it can be expected that this trend will be maintained in the future, if we do not learn from the present mistakes. Man's activity in the densely populated areas is becoming the most important geological factor. Its influence is activating landslides of bigger dimensions, which usually cause the biggest damage. However, the risk of renewing movements of old landslides may be reduced to the minimum, when we know the degree of danger, which threatens all the planned and existing structures in the sliding areas.

Key words: Slovak Republic, landslides, activation of movements, negative antropogenous activity

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THE REGIONAL EXTENT OF LANDSLIDES AND THE CAUSES OF ACTIVATION OF THEIR MOVEMENTS

The territory of Slovakia is characterized by very frequent occurrences of various types of old gravitational failures of slopes, especially landslides. Presently registered in our country are about 15 000 more important old landslides, covering an area of 1630 km^2. Their occurrence, however, is permanently studied.

In the Slovak Carpathians (the landslides are concentrated into the regions formed by neovolcanites, weakly consolidated and consolidated flyschoid sediments of Cretaceous – Paleogene age, in the consolidated sediments of Mesozoic age and in the areas of crystaline rock of Paleozoic age (Fig. 1).

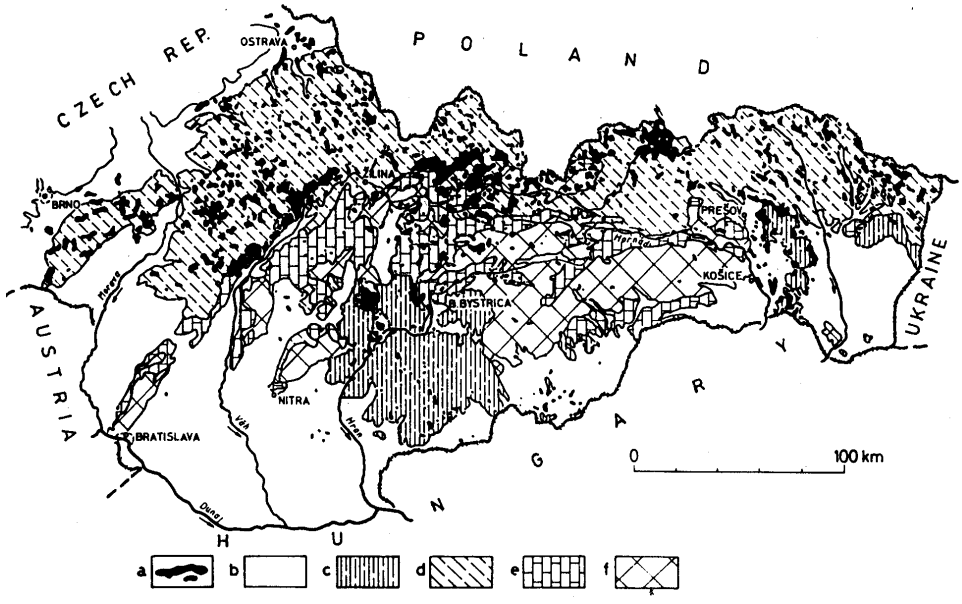

Fig. 1. Areas of slope landslides in the Slovak Carpathians

a – slope deformations, b – unconsolidated and weakly consolidated sediments of Quarternary and Tertiary, c – neovolcanites, d – weakly consolidated and consolidated flyschoid sediments of Cretaceous - Paleogene age, e – consolidated sediments and vocanites of Mesozoic-Lower-Paleogene age, f – rocks of Proterozoic (Archean?) and Paleozoic age

The occurrence of landslides in the territory of Slovakia is distributed quite-unevenly. In the areas of the Carpathian flysch the landslides have disturbed about 20 % of the area of slopes, in certain basins, for example in the Liptov basin, 30 % of slopes. In the Handlová basin the landslides cover 67 % of the area.

Sliding affects mainly slopes with favourable geological structure, as characterized by Nemčok (1982) and with suitable geomorphological, climatic and hydrogeological conditions. Slopes have been affected by landslides of various

age, different developmental stages and degrees of activization. Most frequent are landslides, which we assess as dormant and stabilized. Dormant landslides can be activivated by the impact of various factors (weathering, rainfall, erosion, construction activity, etc.). Stabilized landslides can be activivated solely by such factors, which did not occur so far – for example by construction or other human activity.

Slope sliding represents one of the most important present geodynamic processes in Slovakia. Damage caused by sliding exceeds all the others, caused by geological hazards in our country.

Sliding of slopes causes a substantial devaluation of the utility value of the affected area. Landslides bring about various forms of direct and indirect damage. They represent a potential danger not only to existing structures, but also to further construction in the affected area. They have a negative influence on the further economic development of the area. The regional investigation of the sliding areas in Slovakia (Nemčok 1982, Malgot 1980) proved that new landslides occur mainly in places, which have already been affected by sliding.

Reactivization of landslides by factors in the vast affected areas is a relatively rare phenomenon. In occurs most frequently in the spring season immediately after the snow melts. The landslides are not of considerable dimensions. They form part of sliding territories in unpopulated areas. As a rule they do not evoke an increased public attention.

Substantially different, however, is the situation in those sliding areas, where human activity is concentrated. It is so in the vicinity of towns and villages, in the main valleys and basins of the mountainous part of Slovakia, where industry, construction of residential quarters, communications, water reservoirs, etc., are concentrated. An important new stability factor, which did not act here before is beginning to appear. It is man's activity. The intensity of this activity sometimes exceeds the influence of the present negatively acting natural factors. Landslides activated by negative intervention of man's activity are of considerable dimensions, bring vast damage and evoke considerable attention from the general public.

Based on the investigation of landslides in Slovakia it can be stated that 90 % of all landslides, which occurred in populated areas in the last 30 years and which caused the greatest damage, were brought about fully, or partly by man's intervention in the sensible stability regime of old landslides (Malgot 1980).

The fact that inconsiderate human activity and the effects of construction work on old landslides are the most frequent cause of reactivization of movements in areas of intense economic use are also confirmed by several foreign studies. Thus Nilsen and Turner (1975) state that 80 % of the landslides, which have taken place since 1971 in California, were brought about by artificial interventions. Similarly Briggs et al. (1975) prove that in Pensylvania artificially caused landslides amount to 90 % of newly occurred landslides. In the former Soviet Union the influence of anthropogeneous activity was dealt with by various authors (Šeko 1984, Kotlov 1988). Interesting examples of human impact on landsliding are given by Sassa (1999) in this overview "Land-slides of the world".

The construction intervention in the slope environment causes in it several simultaneously and consequently acting forces and processes, which may end in various changes on the slopes. These may also reflect back on the state and behaviour of technical works. The changes may be not only of a varied type, but also of varied intensity and duration (temporary and permanent, slow and quick, reversible and irreversible, etc.) The changes may be mediated directly or indirectly.

In analyzing the anthropogeneous influences on the slope geosystem, we started from the most important interventions, which bring the most substantial changes to slope stability. They are above all negative influences in the form of artificial loading of slopes, slope undercutting, negative anthropogeneous influence of regime changes of groundwaters and the influences of artificial vibrations.

NEGATIVE INFLUENCES OF ARTIFICIAL SLOPE LOADING

Artificial loading of a slope has two main negative consequences (Fig. 2). Either active forces increase, or after slope loading undesirable changes are caused in the regime of groundwaters.

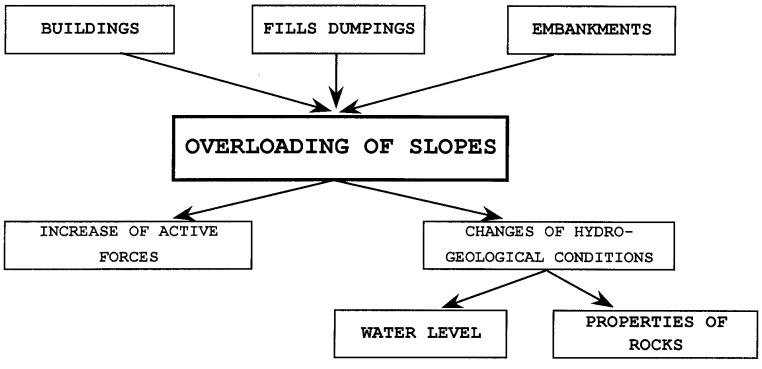

Fig. 2. Negative influences of artificial slope loading

In Slovakia loading of slopes takes place most frequently during the construction of new roads, which are led over potential landslides on embankments. From the numerous cases, we can use the example of a landslide on the body of the 8 m high road embankment near Nitra (Fig. 3). The correction was very complicated. The sliding sector was solved by a bridge construction. A landslide on a road and railway in Central Slovakia activated after building an embankment had to be corrected by a pile supporting wall (Figs. 4 and 5).

Certain old landslides were activated due to loading by various dwelling structures or by other less exacting agricultural structures. Numerous landslides took place as a result of terrain adjustments in the vicinity of industrial buildings or due to waste disposal (Fig. 6).

Fig. 3. Failure of the body of a highway embankment near Nitra town (Photo J. Malgot)

Fig. 4. Landslide on the body of a highway near Holčíkovce village (Strážov Mts., Photo F. Baliak)

Fig. 5. Activation of landslide after construction of railway embankment near Kremnica town (Photo J. Malgot)

Fig. 6. View of slide on the body of dump in Bratislava (Photo J. Malgot)

ARTIFICIAL UNDERCUTTING OF UNSTABLE SLOPES

Undercutting of slopes prone to sliding changes the forces ratio acting on the slope to the advantage of active forces. Negative influences, after slope undercutting, are also manifested by worsening the rock properties in the cut and by the acceleration of erosion processes (Fig. 7). The deterioration of the properties of the rock forming the slope appears by loosening the horizontal stresses on the slope, which brings about loosening of the slope and swelling of rocks little resistant against weathering. The rocks freeze and weather more quickly.

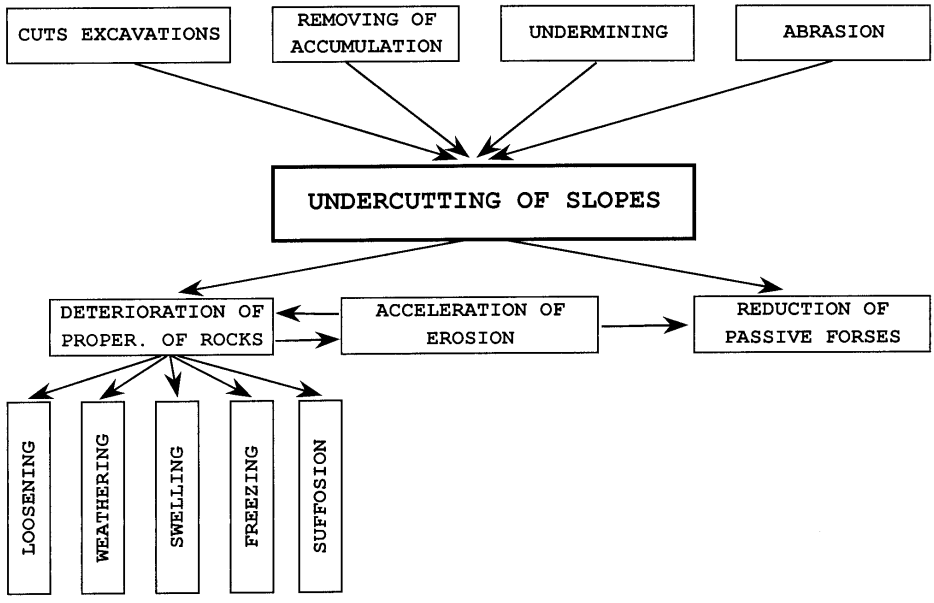

Fig. 7. Negative influences of undercutting of unstable slopes

In special cases when realizing cuts below the groundwater table their stability may also be decreased by the occurrence of suffosion phenomena. Under the conditions of Slovakia slope undercutting usually occurs as a result of mining activity, construction works at the foot or in the central part of slopes, by making cuts for roads and by excavations for pipe-lines.

a) Underground mining activity is the cause of considerable activation of slope movements on the surface in the area of the Handlová brown coal deposit (Central Slovakia). The extraction of brown coal is going on here without backfilling the extracted spaces below the slopes, which are affected by vast potencial landslides. After extraction of two to nine metres thick coalseam subsidenceof the overlying strata takes places in the course of one to two months. When the slope foot or its lower part is thus undermined, the subsidence immediately acts on the slope as its undercutting down to the depth of extraction. The landslides react to the subsidence of their forefield by movement activation. In time the landslides usually become quiet, but the secon-

dary effects of the subsidence are permanent, so that instability brought about by undermining can be renewed in time. In the Handlová coal deposit landslides of gigantic dimensions took place on the Vtáčnik mountain range west slopes due to coal extraction. They brought about not only surface devastation, but also destroyed numerous surface mining equipment (Malgot et al. 1986).

In June, 1978 coal extraction in the Handlová deposit caused activation of a stabilized landslide, on which lies the Podhradie village. The movement affected 110 houses (Fig. 8). The total volume of the activated landslide amounted to about 24.5 mil.m^3, its thickness is about 40 m (Malgot and Mahr 1980).

b) Cases of undercutting potential landslides when building civil and industrial structures are relatively frequent (Fig. 9).

c) Undercutting of landslides occurs most frequently during road construction, which usually cut across going convex accumulation of landslides. Each year several landslides take place due to undercutting. It is very difficult to stabilize them (Figs. 10 to 12).

NEGATIVE CHANGES IN THE GROUNDWATER REGIME

Changes in the groundwater regime bring two main kinds of consequence – slope stress state change and negative changes in the properties of the rock forming the slope (Fig. 13).

Fig. 8. A house destroyed in the Podhradie village in Central Slovakia (Photo J. Malgot)

Fig. 9. View of a landslide evoked by undercutting of a slope in a new part of Košice town (Photo A. Nemčok)

Fig. 10. View of a landslide caused by undercutting of a dormant landslide near Prešov town (Highway D1 – Photo J. Malgot)

Fig. 11. View of a landslide in a cutting of the highway D1 near Poprad town (Photo J. Malgot)

Fig. 12. Stabilization works on the landslide caused by undercutting on the highway near Dolný Kubín town (North Slovakia – Photo J. Malgot)

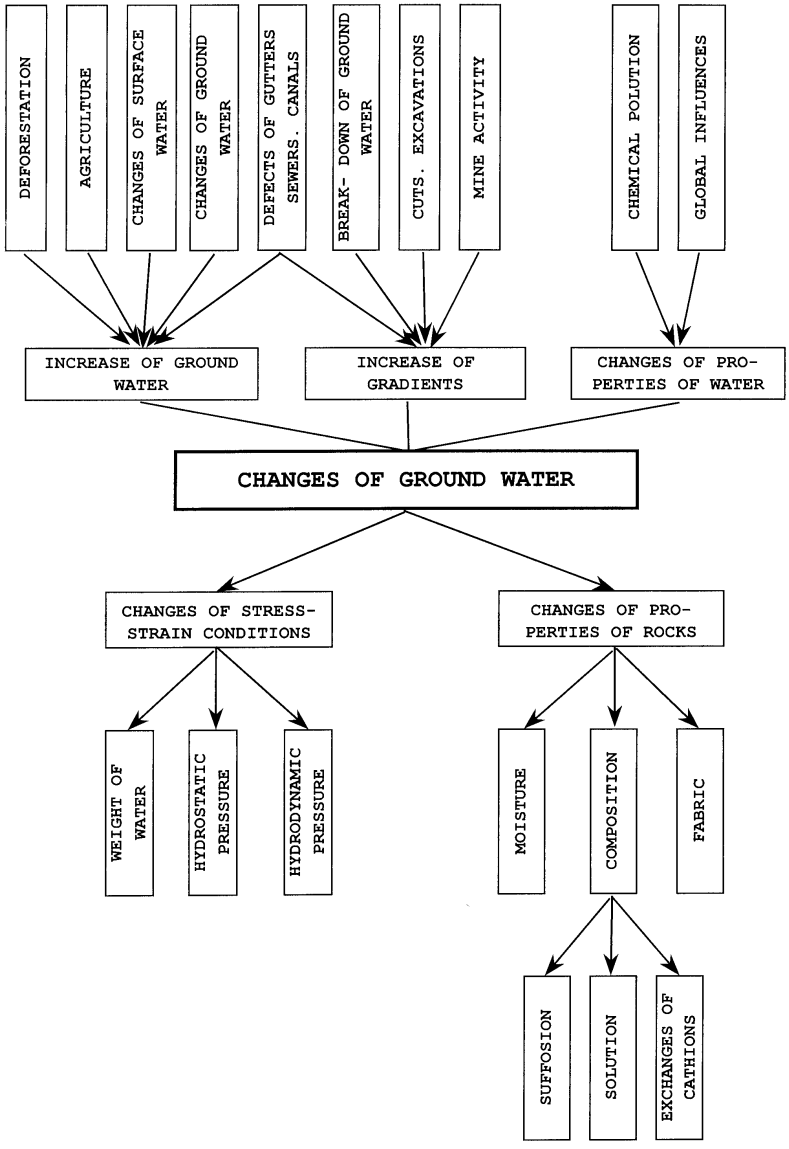

Fig. 13. Influence of artificial changes of ground waters

Changes of slope stress may be caused by increasing hydrodynamic pressure on the soil particles due to the increase of free water load in the landslide active part and by the increase of the hydrostatic pressure, which is most frequently manifest by negative effects of uplift pressures (relief of the slope's passive part, decrease of friction on the shear surface), eventually by upward pressure in slow, rheologically acting seepage through weakly permeable rocks.

Changes of rock properties are manifested mainly in those parts of slopes, which are strained by tensile stresses in the separation area of landslides and in gravitational loosening of slopes. Soils, under these conditions, are able to absorb water, which causes change in their moisture, consistency and in the final effect also decreased resistence to shear.

Changes in the ground water regime may also cause further changes in the composition and structure of rocks due to the influence of mechanical suffosion, chemical leaching and exchange of cations in sensible clays.

Changes in hydrogeological conditions caused by anthropogeneous factor usually do not act quickly. Negative effects are manifested by gradual change in the stress state of the slope. Evidently there are also exceptions a (sudden fal of the water table in an artificial water reservoir, etc.). From the great number of negative interventions in the hydrogeological landslides conditions of Slovakia we are giving at least the most frequent ones (Figs. 14 to 16).

a) Deforestation and humus stripping of areas.

   Various authors have differing opinions on the effect of forests. This is caused by considerable differences in the function of various kinds of wood species, as well as by differences in the local geological, hydrogeological, geomorphological and climatic conditions. In some cases deforestation of an area may have even a stabilizing effect by removing the trees loading the slope, eliminating the wind influences on the slope and allowing the slope to dry sooner after intense rain. In most cases, however, deforested areas represent a negative intervention in the slope stability regime.

Fig. 14. View of landslide on the shore of the Domaša water reservoir (East Slovakia, Photo F. Baliak)

Fig. 15. Landslide on the bank of the reservoir near Košice town (Photo P. Abrahám)

Fig. 16. Destroyed house by landslide near Košice town (Photo F. Baliak)

Fig. 17. General view of the activated landslides in Ľubietová, Central Slovakia (Photo I. Modlitba)

Fig. 18. View of destroyed houses by the landslide in Ľubietová village (Photo J. Malgot)

b) Incorrect melioration adjustments and neglect of old drainages.

Incorrect large-surface meliorations, in which removal of shrubs, trees, anti-erosion terraces and grass vegetation took place, increases substantially the surface erosion and supports rain water infiltration. Erosion trenches are formed on the slope causing its articulation. The upward pressure of groundwater increases. Soils gradually become muddy and lose their strenght against shear. Excavations made for sporadic drainage also have a negative effect, if they are not maintained for a long time.

Unsuitable recultivation of slopes was one of the causes reactivating the landslide at Ľubietová in Slovakia in 1977. The landslide 1 200 m long (4.5 mil. m^3) destroyed four recently built family houses (Figs. 17 and 18).

Social changes occurring in Slovakia in the last decades had some degree of negative influence on the stability of numerous villages and localities built on old landslides (solely in the flysch they number more than 400 in Slovakia). Neglect of old surface and underground drainage brought about a critical situation in numerous localities. Landslides of considerable dimensions were activated, destroying a part of Handlová (150 houses) and other villages.

c) Worsening of surface and subsurface water discharge is caused by incorrect constructions, for example, of embankment bodies of line structures, incorrect laying out of surface drainage, excavation works on the slope, which exert influence upon the increased infiltration of rain waters.

Worsening of underground discharge from the slope is brought about by an upward pressure effect of the surface or underground structures, which have an incorrectly suggested drainage system. Worsening of groundwater discharge is also influenced by incorrectly suggested embankments without filtration layer, or impermeable foundations of buildings sheet pile walls, underground walls, supporting walls, etc.

Worsening of the groundwater regime can also be observed on the banks of artificial water reservoirs, in which a substantial rise of the groundwater table takes place.

d) Increase of seepage velocities.

Increased groundwater seepage velocities take place in the event of a sudden fall of the water table in water reservoirs. The filtration velocity of groundwaters can also be increased, when a saturated slope is undercut. If such a slope is formed by filtrationally unstable soils, suffosion phenomena and hydrodynamic pressure may cause the occurrence of landslides (Záruba and Mencl 1987). The undermined foot of the sliding slope may play a similar role, as described in the case of the Podhradie landslide (Malgot and Mahr 1980).

Failures of water-piping and canalization cause the activization of slope movements in urbanized areas. Water leaking from failed waterpiping brings about a quick water saturation of the slope, which applies all the negative influences to the slope (Fig. 19).

e) Changes in the physical-chemical properties of groundwaters are brought about either by leakages of corrosive waters from underground water-pipes

or by acidic rain. Corrosive waters initiate changes in soil composition on the slope by leaching processes and exchange of cations, or they may substantially accelerate the processes of weathering.

Fig. 19. Failrured water pipe-line by landslide in Hriňová village (Middle Slovakia – Photo M. Kopecký)

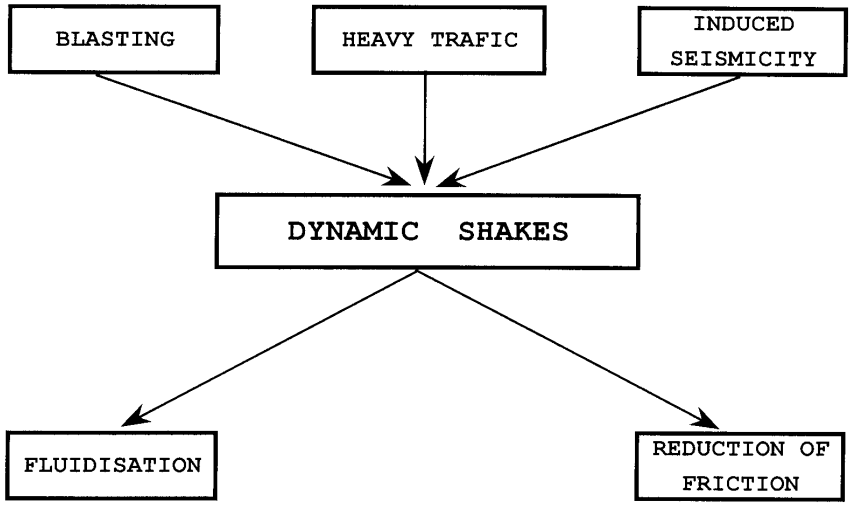

Fig. 20. Influence of dynamic vibrations

DYNAMIC VIBRATIONS

Dynamic vibrations of anthropogeneous origin (heavy transport, detonation works) may initiate in water saturated soils a critical water pressure in the pores and soils on the slope may liquefy. Dynamic vibrations as horizontally acting forces on the particles of rock forming the slope bring in further negatively acting factors to the stability scheme. The particles are strained tangentially by the acting forces and friction is decreased on the shear surface (Fig. 20).

CONCLUSION

The high number of artificially activated dormant landslides in the areas with intense economic activity in Slovakia, suggest that this trend will be maintained in the future, if we do not learn from past mistakes.

Man's activity in the densely populated areas is becoming the most important geological factor. Its influence activates landslides of bigger dimensions, which are usually causing the biggest damages. However, these findings, show that the risk of renewing movements of old landslides may be decreased to the minimum, if we know the degree of danger, which threatens all the planned and existing structures in the sliding areas.

Prevention is important for ensuring the stability of affected slopes. The preventive works are simple, cheap and exceptionally effective. The analyses of expenses for preventive stabilization works in the road network of Slovakia show that they are 5 to 10 times cheaper then those for later repair work after landslides, have occurred, without even mentioning the direct and indirect damage, which each landslide may cause.

REFERENCES

BRIGGS, R. P., POMEROY, I. S., DAVIES, W. L. (1975). Landsliding in Allefheny Country. *Bulletin of US Geological Survey*, 728.

KOTLOV, F. V. (1978). *Izmenenija geologičeskoj sredy vlijaniem dejateľnosti čeloveka* Moskva (Nedra).

MALGOT, J. (1980). Vplyv antropogénnych faktorov na stabilitu zosuvných území na Slovensku. *Geologický průzkum*, 22, 139-143.

MALGOT, J., MAHR, T. (1980). Zosuvy v okolí Podhradia pri Prievidzi. *Geologický průzkum*, 22, 358-362.

MALGOT, J., BALIAK, F., MAHR, T. (1986). Prediction of the influence of underground coal mining on slope stability in the Vtáčnik Mts. *Bulletin of the International Association of Engineering Survey*, 30, 57-65.

NEMČOK, A. (1982). *Zosuvy v slovenských Karpatoch*. Bratislava. (Veda).

NILSEN, T. H., TURNER, B. L. (1975). Influence of rainfall and ancient landslide deposite on recent landslides (1950-51) in urban areas of Contra Cose County. *Bulletin of US Geological Survey*, 1399.

SASSA, K. ed. (1999). *Landslides of the world*. Kyoto (Kyoto University Press).

ŠEKO, A. I. et al. (1984). *Landslides and mud flows*. Moskva (GKNT).

ZÁRUBA, Q., MENCL, V. (1987). *Landslides and their control*. Amsterdam (Elsevier).

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VPLYV ĽUDSKEJ ČINNOSTI NA AKTIVIZÁCIU ZOSUVOV NA SLOVENSKU

Zosuvy sú dôležitým geofaktorom ohrozenia životného prostredia na Slovensku. Regionálnym výskumom je v súčasnosti registrovaných viac než 15 000 starých potenciálnych zosuvov, ktoré pokrývajú plochu o rozlohe okolo 1620 km^2. Zosuvy sú sústredené predovšetkým vo flyšových vrchovinách, vnútrohorských panvách a na okrajoch mladých vulkanických pohorí. Zosuvy znehodnocujú lesy, ornú pôdu, lúky a pasienky. Ohrozujú železnice a cesty na 1300 úsekoch. Obmedzujú rozširovanie miest a obcí. Stabilita svahov je často limitujúcim faktorom optimálneho využitia krajiny. Asi 90 % nových zosuvov vzniká reaktivizáciou potenciálnych zosuvov v dôsledku negatívnych zásahov človeka.

Antropogénne zásahy pôsobia na stabilitu starých, upokojených zosuvov rozlične. Zosuvy sú buď umelo priťažené, alebo podrezané. Činnosť ľudí vyvoláva zmeny v režime podzemných vôd, alebo tieto dynamicky účinkujú na stavby. Článok analyzuje príčiny aktivizácie starých zosuvov vplyvom výstavby pozemných a priemyselných stavieb, mostov, ciest, tunelov, inžinierskych sietí a vodných nádrží. Početné zosuvy boli vyvolané odlesnením krajiny, nevhodnými melioračnými úpravami, zhoršením odtoku povrchových a podzemných vôd a poruchami inžinierskych sietí.

Vysoký počet umelo aktivizovaných zosuvov v oblastiach s intenzívnym ekonomickým využitím na Slovensku je alarmujúci. Je možné očakávať, že tento trend bude zachovaný aj v budúcnosti, ak sa nepoučíme z doterajších chýb.

Činnosť človeka sa stáva v husto obývaných územiach najdôležitejším geologickým činiteľom. Jej vplyvom sa aktivizujú zosuvy väčších rozmerov, ktoré obyčajne vyvolávajú najväčšie škody. Z uvedeného však vyplýva fakt, že riziko oživenia pohybov starých zosuvov môže byť minimalizované, ak poznáme stupeň nebezpečenstva, ktoré vzniká pri plánovaní nových stavieb v zosuvných územiach.