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SMALL LANDSLIDES ON THE FLYSCH OF ISTRIA

SUMMARY: This piece of work presents the "small" landslide occurrences in the part of the Istrian peninsula, named "Grey Istria", where the Paleogene flysch sediments shaped the terrain. This is the area of the very significant exogenetic processes, like erosion and accumulation of material. The fore mentioned landslides are of the relatively small dimensions and with landslide body volume lesser than 20.000 m^3. The sliding of material regularly occurs inside the weathering zone or in slope formations, while the slide surface is formed in the contact with the flysch bedrock. This paper deals with the landslide in the vicinity of the Krušvari settlement, which caused the damage of the local road in the section of Cerovlje-Buzet. It could be said that particular landslide is the typical one for the "Grey Istria" area, while its causes and sliding phenomena are similar to the numerous landslides in this region.

Key words: Istria, flysch, landslide, slope stability

INTRODUCTION

The central area of the Istrian peninsula roughly stretches from the Trieste Bay in the west to the Učka Mountain in the east and is called "Grey Istria". The Paleogene flysch sediments shape this area. Flysch rocks have very diverse physical and mechanical properties, due to its lithological composition. This particular fact also determines very expressive exogenetic processes in this terrain. The flysch areas are eroded and partly covered with weathering deposits, as well as with slope deposits of greater thickness. The eroded surfaces are of the strongly grey colour, and the area is named after it. The unstable slopes in the Istrian flysch area present a very common phenomenon, mostly on the spots of the visible human intervention. These landslides are of the relatively small dimensions and the slide body volume is lesser than 20.000 m^3. The landslide happens, as a rule, in the weathering zone or in slope formations, while the slide surface is formed in contact with flysch bedrock. The landslide usually causes damages on constructions, particularly on roads. The authors of this piece of paper have carried out the field investigations so far, and created the remedial projects for the greater number of small landslides in the flysch area of Istria, near the towns of Buzet, Pazin, Lupoglav and Boljun. This particular piece of paper shows the example of such an investigated landslide-the one in the vicinity of Krušvari settlement, which caused damage on the local road Cerovlje-Buzet. Some other two similar occurrences in the close vicinity were also investigated (fig. 1). The authors also consider this particular landslide typical of the area of "Grey Istria", while causes and sliding phenomena are similar to the ones happening in the numerous smaller landslides in the same area.

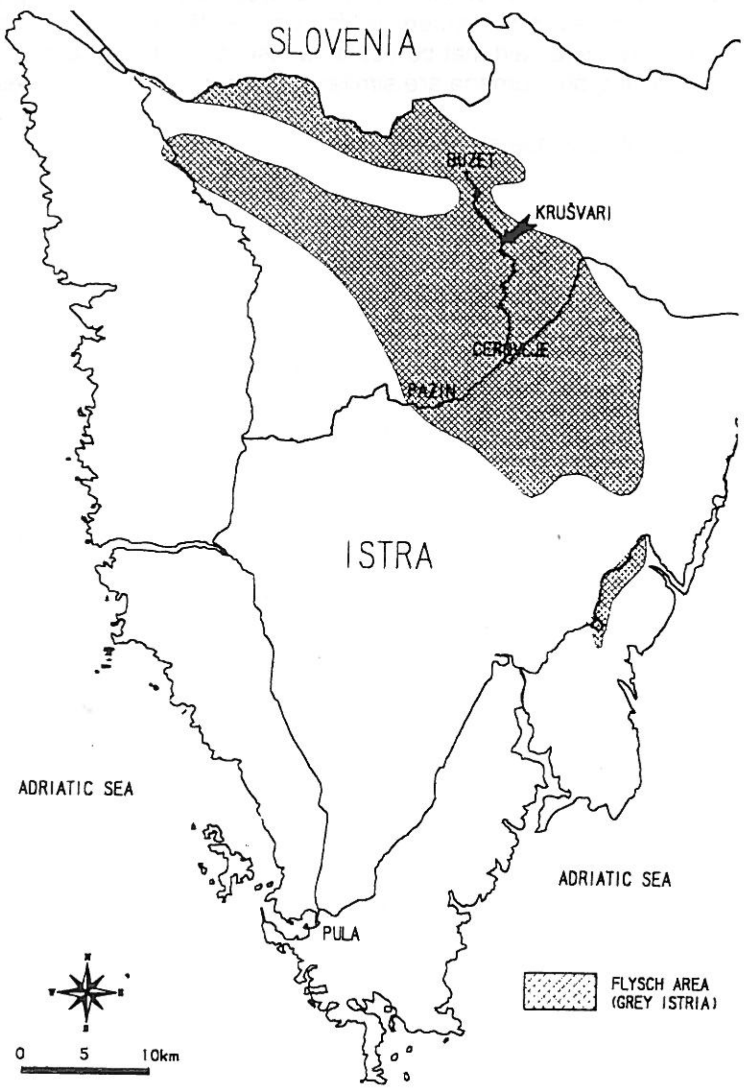

Figure 1. Generalised geological map

GEOLOGICAL DESCRIPTION AND MORPHOLOGICAL EVOLUTION

The clastic sediments from the Paleogene period with flysch characteristics shape the wider Krušvari area. This area belongs to the Pazin Paleogene basin. The layers show a slight tectonic disrupt and therefore are sub-horizontal beds. Flysch rock mass has lithological heterogeneity. It mostly consists of claystones, siltstones with intercalated calcareous sandstones and breccio-conglomerates. The lower part of the flysch deposits is composed of marls (Šikić et al., 1969; Šikić & Polšak, 1972). The above-mentioned local road Cerovlje-Buzet goes through the hilly areas of the northeastern part of the Paleogene flysch basin.

The previous investigations show a great activity of weathering processes in the fine grained flysch deposits, such as claystones and siltstones. As opposed to this particular phenomenon sand-stones and breccio-conglomerates are considerably more resistant to the influences of the exogenetic forces (Mihljević & Prelogović, 1992). Mechanical weathering helps and accelerates chemical weathering, which is very characteristic for flysch rock mass. Clay weathering zone is being gradually formed. In case of the intensive erosion processes, weathering zone is not formed, because the clay material is being driven.

In the process morphogenesis of this particular area of Istria, during the Pleistocene and Holocene period, the differential erosion of flysch areas occurred. Hilly sites were formed in parts of the terrain where more resistant sandstones and breccio-conglomerates were present. The greater load of mass was simultaneously deposited in the earlier eroded depressions. The eroded material still left on slopes is liable to sliding (fig. 2).

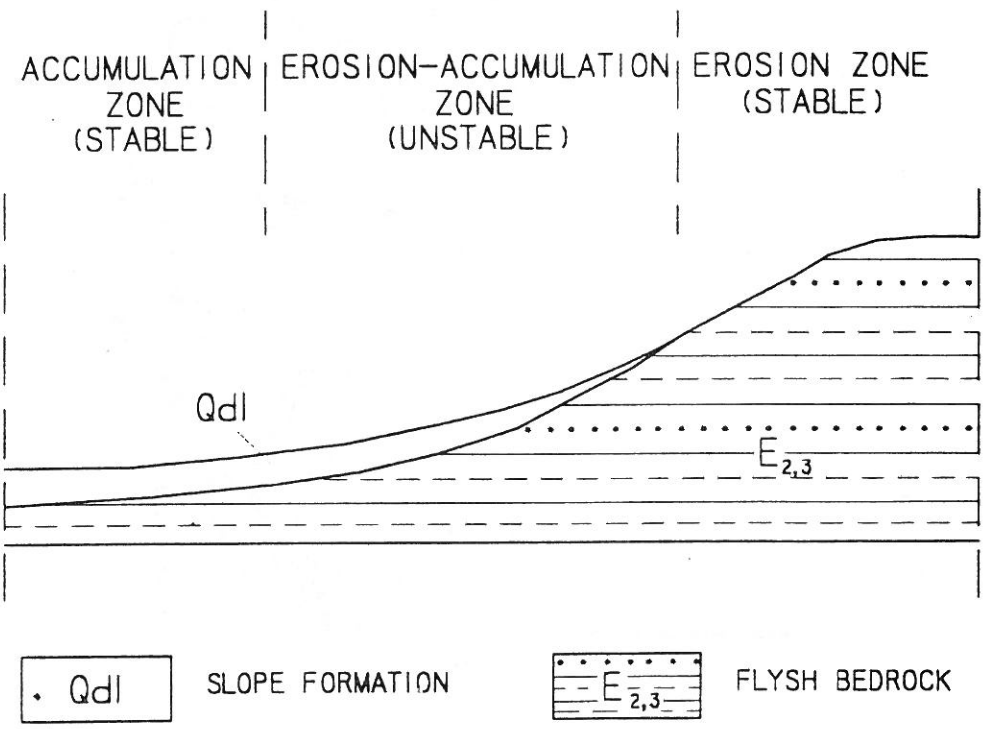

Figure 2. Generalised geological cross-section

On the flysch formed slopes in the Croatian coastal area it was concluded that sliding most often occurs along the failure surfaces. They are marked with the geological boundaries or with slope formations and weathering zone contacts. The sliding is possible even inside the weathering zone (Jašarević & Jurak, 1987). Landslides are regularly shallow and the slide surface depths do not exceed 3 m. Usually the part of the mass is started inside the inactive landslide.

The flysch slopes instability in the area of "Grey Istria" is a common phenomenon too. It occurs mainly in the areas of the visible human intervention. These types of landslides are of the relatively small dimensions , and landslide body volume is usually lesser than 20.000 m^3. As a rule, slope deposits as well as the part of weathering zone is being moved. Slide surface presents the consequence of the stronger material moistening.

DESCRIPTION OF THE KRUŠVARI LANDSLIDE

The Krušvari landslide presents the typical example of the "small" landslide on flysch. Due to its dimensions it is one of the greater phenomena of that kind. The investigated area is situated on the local road between the Cerovlje settlement (near Pazin) and the town of Buzet near the northern entrance of the Krušvari settlement. The terrain is of the sloppy shape with terraces going downwards towards southwest. Cutting and filling during the road construction formed the higher part of the slope. The slope surface relief hypsometrically lower to the road, has been considerably changed during the terrace formation. The average slope inclination is 14^0, while it ranges from 10^0 in the lower parts of the slope, to 30^0 below the roadbed. The surface with visible instability phenomena is not larger than 2 hectares (fig. 3)

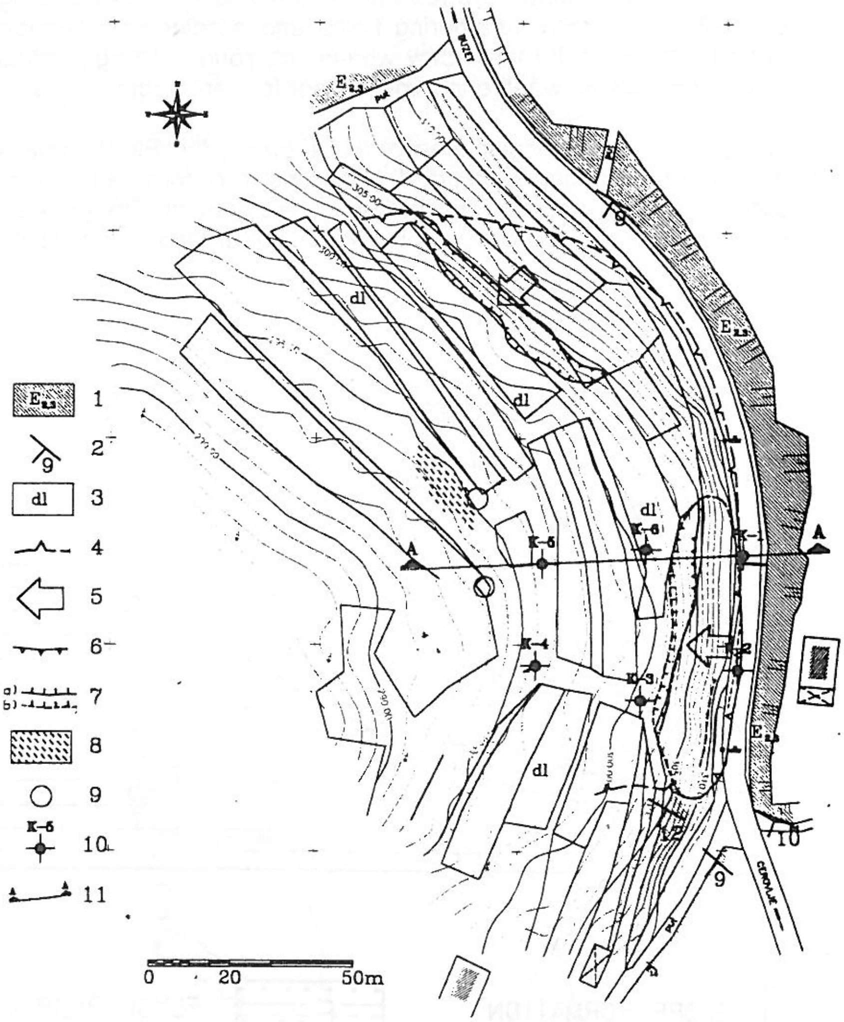

Figure 3. Engineering geological map of the landslide
1 - flysch (bedrock)
2 - strikes and dip of the layer
3 - slope formation (clay and fragments)
4 - margin of the landslide (approximately placed or supposed)
5 - recent movements in the landslide
6 - head of the landslide
7 - toe of the landslide a) visible b) approximately placed
8 - swampy land-
9 - puddle
10 - borehole
11 - trace of cross-section

On the basis of the engineering geological mapping and borehole drilling it was determined that the terrain was composed of the slope deposits-cover and flysch bedrock. In the upper flysch zone the weathering zone was established. Slope deposits cover the greater part of the investigated area. Flysch bedrock is visible at side cuts along the road (fig. 3).

Slope deposits are composed of the yellow-brown to grey-yellow high plastic clay. Depending on its moistening composition, clay is from firm to stiff consistency. There are 10% to 20% of sandstone fragment in clay. The lithogenetic unit thickness varies from 0.3 to 0.7 m in boreholes located on the road, while the thickness between 4.0 to 7.7 m's was measured in other boreholes along the slope. Road embankment, sand and stone mixture ranging from 0.9 to 1.4 m of thickness is situated in the narrow belt. Paleogene clastic sediments-flysch makes the bedrock base. It is lithologically heterogeneous complex. It is composed of siltstones, marls, and calcareous sandstones. Flysch rock mass is well bedded. The beds are slightly bent towards southwest. Flysch rock mass is strongly weathered, and therefore on the basis of the boring core inspection, it was possible to separate greater number of weathering zones, ranging from completely (WC) to highly (WH), moderately (WM) and slightly weathered (WS) to the fresh or intact rock mass (FR) (ISRM, 1978). Weathering zone thickness differentiates in each borehole regarding to its different lithological composition. During the period of great rains in spring 1993 the part of material sliding on road embankment occurred, and consequently caused the road damage in length of 30 m. On this part of the section a part of the roadbed was carried away, causing damage on the southern traffic line of the road.

Sliding developed closely along the slope, and practically reached the very edge of the road. The other active landslide was discovered on the northern slope, but farther to the road. The inspection didn't show the roadbed damages in the area, which was not directly affected by sliding.

But the overall potentially unstable zone is much bigger. The zone head is clearly limited with the stable flysch rock mass phenomenon, visible on surface in the hypsometrically higher part of the slope, along the road-cut. On the opposite side, the lateral boundaries and the landslide toe can not be separated without larger and longer measurements, and therefore they are given in approximate values (fig.3).

With borehole drilling inspection through the road embankment it was not possible to establish the potentially slip surface. On the other hand, with drilling core inspection on the slope below the road the extremely wet material zone was depicted, with its consistency near to liquid limit. This type of zone can be considered as a slip surface. Geometrical elements of landslide can be hardly precisely marked, regarding the fact that the slide body, as a whole, is not clearly expressed. The proposed elements of the landslide are (IAEG,1990):

-total landslide length from the head to the toe L = 115 m;
-length of displaced mass L_d = 80 m;
-maximum length of slide surface L_r = 115 m;
-maximum width of displaced mass W_d = 145 m;
-maximum width of slide surface W_r = 85 m;
-thickness of displaced mass D_d = 4.5 m;
-maximum depth of slide surface D_r = 7.0 m.
-level difference from the head to the toe of the landslide ΔH = 23 m.

The whole slope below the road is potentially unstable, inside which the creep process occurs, and therefore creep failure and slope sliding are to be expected inside that particular bed in the further phases of the landslide development. A very close scrutiny reveals the existence of instability phenomena, which occurred on slopes and in several occasions. The old scars of transverse cracks, transgressive ridge-wave shape parts of the slope and the bending trees of different age can serve as a proof. It could be said that it is a complex sliding, a multiple retrogressive landslide (Skempton & Hutchinson, 1969), starting its development from toe to head. Because of the fact that geological fabric (the contact between cover and flysch bedrock) caused the slip surface position, this is, at the same time, the translational type of landslide (Antoine & Giraud, 1995).

The greater part of the potential slide body is completely saturated by groundwater, which is filtered through the cover zone, along the contact with impervious flysch bedrock. This also suggests the extremely wet core material existence. Hypodermic water is found in the lower hypsodermic boreholes. In its lower part the swampy land and puddles with water even during the dry season, can be seen (fig. 3). there are also present the species of plants that appear on the extremely wet soil, such as willows, poplar-trees, swampy grass and others.

As regard to the fact that all the field investigation measurements have been done during the relatively dry season, it is also possible to expect higher water table. The traces of the embankment's toe and K-4 borehole imply such a possibility.

SLOPE STABILITY ANALYSIS

Slope stability analyses were carried out after the field and laboratory investigations, with the help of PC and the SLOPE/W V4, GEO-SLOPE (Geo Slope, 1998) program package, used for the present slope condition in the critical profile. The investigation stated with the hypothesis of the extreme hydrogeological conditions-the groundwater level in the upper part of the slope is nearly on surface, while in the lower part it comes out on surface. The calculation stimulates the higher groundwater level (10 m below the field surface in the lower part of the slope). Such conditions cause the lower level of safety factor below 1.0, or very probable sliding phenomenon in the upper part of the slope. For the purpose of the existing geometry on that particular location, three analyses have been carried out (for the upper, middle and the slope toe). The critical slip surface with the lowest safety factor (0.9) was estimated in the upper part of the slope. The critical slip surface corresponds the depicted traces of sliding, or road damages, in regard to their location (fig. 4).

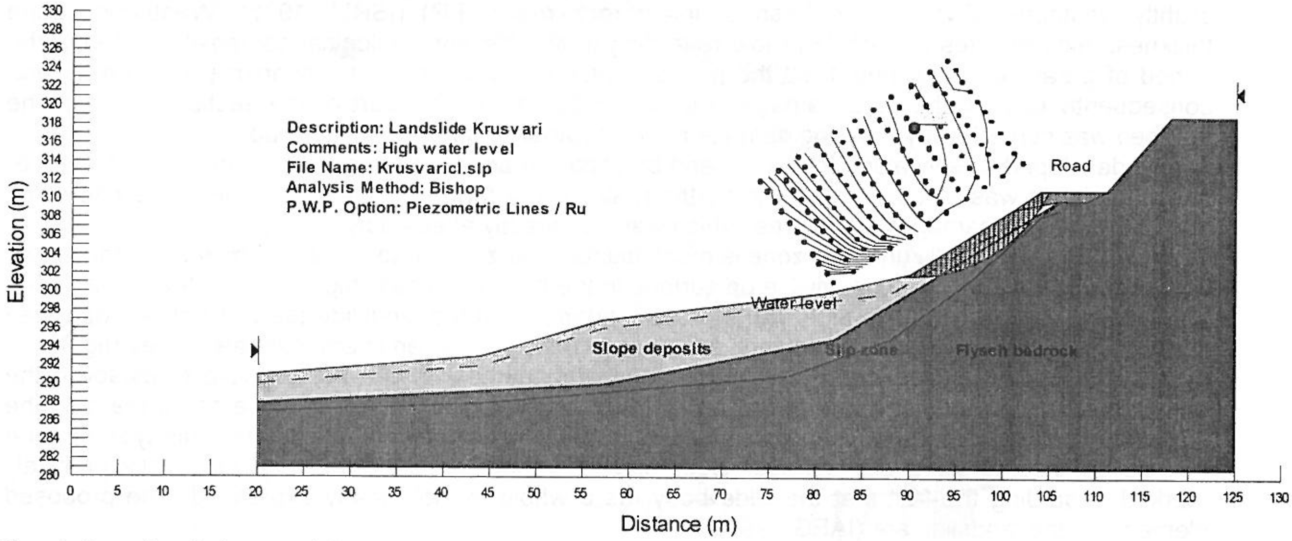

Fig. 4. Results of slope stability analysis

In choosing of remedial works possibilities, two major approaches have been studied:

1. The change of geometrical slope relief in its upper part with more effective water drainage;
2. The constant lowering of groundwater levels with subsoil drainage system construction.

As more rational solution the groundwater level lowering was chosen, without major interventions in slope geometry. The permanent level lowering, except from different orientation of hydrodynamic forces and their decrease, enables the cover water content lowering. That leads to cohesion increase as well as the shear strength of material in the slip surface zone. Slope stability controls with the groundwater lowering suggest the larger increase of safety factor in the area of the entire slope.
The construction of the boring drain pipes on the embankment's toe, as well as the overall drainage system serve as the intervention at that particular location.

DISCUSSION

The sliding phenomenon on flysch terrain in Istria is regularly connected to the inadequate hydrogeological conditions. That means the slight permeability of cover deposits, while the flysch bedrock is effectively impermeable. The waterflow filtration through the jointed beds of the sandstone can serve as exception. In natural slopes during the extremely wet period, surface waterflow usually appears, and relatively lower quantity of water penetrates into soil. During the constructions, such as side cuts, which usually penetrate to flysch bedrock, works on road surface, the natural dewatering changes completely. The great impermeable surfaces are created on the places of precipitant water gathering, and because of the impervious flysch bedrock at the places where it enters the cover. All these facts improve the final embankment layers constructions, using the material more porous than the mostly clayish slope deposits.
By water penetration from the road construction into the relatively slightly permeable deposits, the local zone of the considerably higher groundwater level appears in the embankment's toe precisely. The

water inflow into cover during the extremely wet periods is of much greater in quantity than the outflow. This fact causes sudden groundwater level increase and very common outflow at embankment's toe, or closely to it.
From the static point of view the slope witnesses a whole range of new deformations as result of the road constructions. As a rule, partial cutting and filling in the road cross section have neutral effects on the lower parts of the slope. However, the slope groundwater level uplift causes the considerable change of forces in the slope. Groundwater creates additional load with the entire mass increase in the upper part of the slope, hydrodynamic forces appear because of the flow, shear strength of soil decreases at the places of contact between cover and bed, and finally, water content increase causes the shear strength parameters decrease. In unfavourable conditions it all leads to the sliding phenomenon.

CONCLUSIONS

In the area of "Grey Istria" with the visible Paleogene flysch deposits on its surface, the relatively small sliding phenomenon is noticed in the cover zone-slope deposits and weathering zone. The formed landslides are of the relatively small surface and volume. They are noticed on the slopes where construction works disrupted the natural balance. In the last 15 years more than 10 landslides of that type and with remarkably similar characteristics have been determined. The landslide Krušvari on the local road Cerovlje-Buzet serves as a typical example.
In the investigated area which is situated close to the local road Cerovlje-Buzet, in the vicinity of Krušvari settlement a multiple retrogressive slide with its development from toe to head has been determined. The sliding phenomenon affected the slope deposit material. The landslide is relatively shallow and the slide body thickness is relatively small regarding the fact that geological fabric (cover-bedrock contact) determined the slide surface position.
It assumes the possibility of the creep process current motion on a larger part of the slope, while the sliding phenomenon occurred only on its upper part. Because of the relatively small shifts, the scars of the hypsometrically lower slide bodies (which mark the boundaries) are not visible. Only after the slide body shift occurrence on top (the last one in row), the roadbed damages appeared, as well as opens cracks and over-sliding of sliding mass in toe. The landslide is typical of the area of "Grey Istria" where the instability phenomena, in Paleogene flysch formations, are very common. Potentially unstable slopes on Istrian flysch are very numerous. Therefore it is difficult or even impossible to neglect them during the new roads design and construction. In the contact zone between flysch and carbonate complex, precisely, on the Ćićarija Mountain slopes, the large and complex landslides are discovered, as the one in the area of Dolenja Vas, near Lupoglav (Noveiller, 1987; Biondić et al., 1995). As opposed to them the landslides in the area of "Grey Istria" are, as a rule, of smaller dimensions and different genesis. They are 200 m wide and nearly the same size in length, most often considerably smaller. Sliding body depth is also small and reaches up to 10 meters, being predisposed by the place of contact between the cover and the rock base. However the damages of this kind of sliding are not to be neglected, because the remedial works need a remarkable sum of money. Therefore for the purpose of the new roads construction and reconstruction of the existing ones, the slope stability decreasing shouldn't be allowed, since it usually happens because of the efficient dewatering absence.

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