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I. Szabó
University of Miskolc, Miskolc, Hungary

A. Szabó
University of Miskolc, Miskolc, Hungary

T. Madarász
University of Miskolc, Miskolc, Hungary

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GEOTECHNICAL INVESTIGATION OF THE HOLLÓHÁZA LANDSLIDE CASE

I. Szabó
University of Miskolc
Department of
Hydrogeology
and Engineering Geology
Miskolc, Hungary

A. Szabó
University of Miskolc
Department of
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and Engineering Geology
Miskolc, Hungary

T. Madarász
University of Miskolc
Department of
Hydrogeology
and Engineering Geology
Miskolc, Hungary

ABSTRACT

Hollóháza is a little mountain village in North-East Hungary. Following a long wet period in 1999 the largest mass-wasting event of the 20th century occurred. The total volume of mobilized earth material was over 1.5 million m^3. One major concern of problem management was that the value of the damaged infrastructure was less than the total costs of restoration and stabilization, while the natural potential of the settlement is outstanding. After investigating the causes of the landslide the cheapest effective solution had to be found. Hollóháza is surrounded with the residuals of a 4-6 km diameter volcanic caldera. The settlement was established in the natural depression of the caldera where the bottom andesite is covered with varying depth of rhiolite-tuff and clayey marine deposits with the tilt of 10-25 degree toward the valley. The rhiolite-tuff that is originally fallen into seawater has a high bentonite content, montmorillonite content is close to 60%. The covering clay layers has almost 40% illite-montmorillonite content. Water from precipitation moves toward the village from every direction both on and bellow surface of the steep slopes. Slope stability analysis was conducted using the GEOSLOPE software. The goal of our investigation was to identify those areas where only by lowering the groundwater levels the stability can be achieved with a reasonable factor of safety. Our analysis proved that out of the three exposed location 2 can be stabilized by managing the groundwater level, while in the third case other engineering solutions are also needed. Due to limited financial resources the stabilization of the former two one is accomplished by lowering the groundwater levels using drains and horizontal wells. The measurements prove that the movement have ceased due to these installations. Besides the slope stability assessment the landslide risk mapping of the area was also accomplished. The risk mapping incorporates the landslide hazard mapping of the site and the damage potential of the settlement. In risk terms high values are the results of significant probability of mass movement and the cost of the potential damages caused. The risk reduction of the stabilizing intervention is the result of the decrease of the former factor while the value of the infrastructure may be considered constant.

1. INTRODUCTION OF THE LANDSLIDE CASE

In Hollóháza, located in North-East Hungary right after the snow melt of March 1999 significant mass movement processes, soil creeps of extensive scale took place. The movements affected some 28-30 houses within a couple of days.

Similar movements have been observed in the area before. Since 1913 there are records of greater scale creeps in the settlement. One can observe along both sides of the Török creek that runs through the town terrace-like structures or landscape steps. These are the places where former backward expanding movements can be studied. Water leakages of varying scale can be observed on the foreheads of these residues of former movements.

In the spring of 1999 the movements occurred at three locations (Figure 1.):

a.) Northern location;
b.) Vicinity of the catholic church;
c.) Southern location in the vicinity of the kindergarten

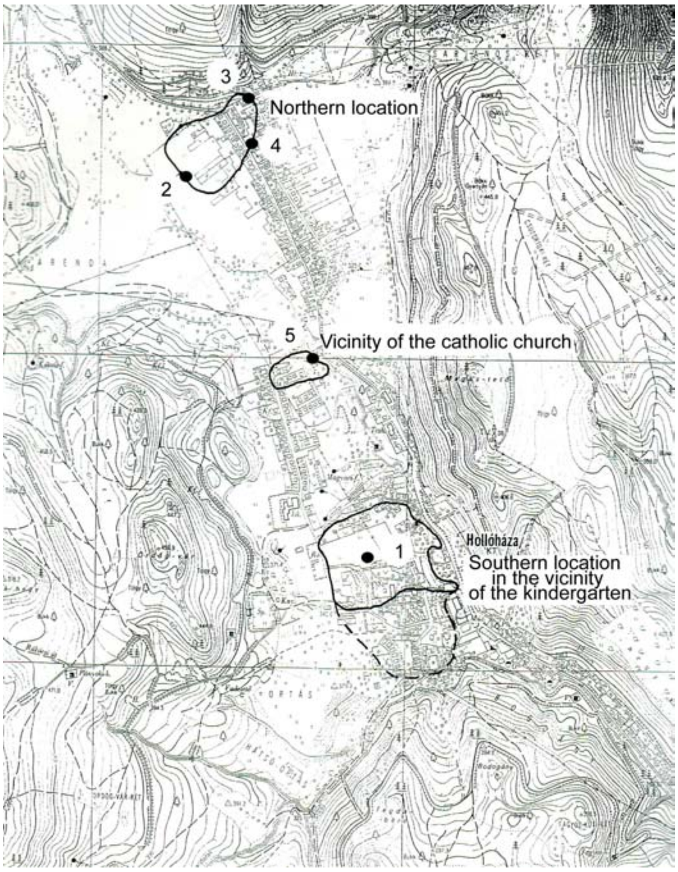


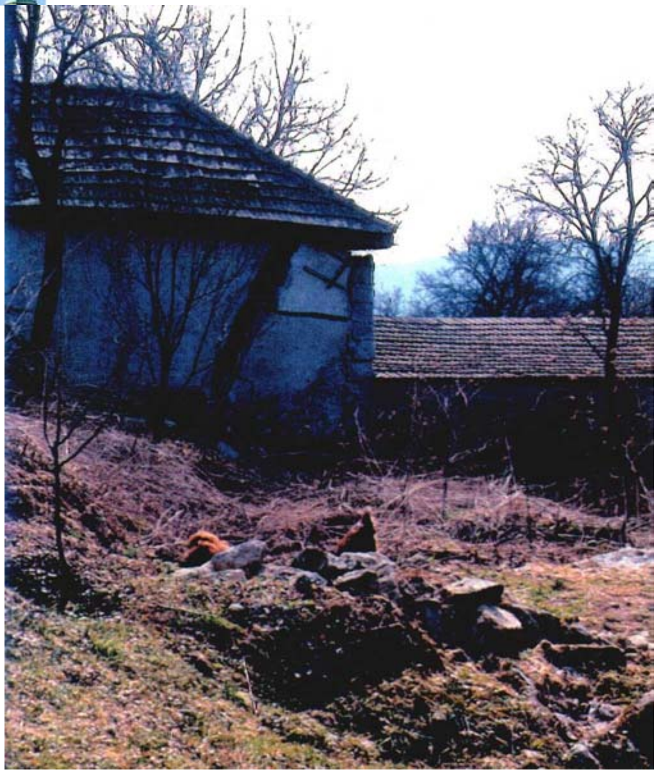
Figure 1. Areas effected by mass movements
(The numbers on the map indicate the spot where photographs were shot)

Slides 1-6. show the movements on the marked locations.

Slide. 1. Transverse ridgers caused by earlier slides

Slide 2. Toe of the slide surface

Slide 3. Transverse crack by the top of sliding surface



Slide 4. Cracked and damaged building on the sliding area

Slide 5. Monmorillonite clay on the sliding surface

Slide 6. A tree splitted of by a transverse crack

There are some historical records about the mass movements in the town. In the 60-es as the town expanded former wooded areas were cleared out thus increasing the infiltration, which initiated some movements. During the investigations colloidal clay sectioned by thin sand and soil debris forms were found with leaking groundwater paths. It was concluded that this thick clay layer slides on an andesite surface, soaked by groundwater and fissure leaks. As preventive measures retaining walls and drainage trenches were installed but they were located strictly close to the creek, leaving the places with higher elevation unprotected.
In 1965 following the relocation of the creek channel a 20*30 meters area was mobilized near the famous china factory.
During the last decades construction was continued even on those areas where previous geotechnical investigations ordered total ban of construction permits.

By now most of the houses of the settlement located in a beautiful area but built on spots with highly ranked mass movement hazards. It is also apparent that the value of the effected real estates are lower than the costs of remediation and stabilization, however decision makers can not neglect the emotional factor of the inhabitants. Thus a relatively safe and cheap solution had to be found.

2. GEOLOGICAL SETTING

The site is located in the Zempléni mountain, which in the Middle and Upper Miocene was a constantly subsiding volcanic area. The volcanism was characterized by lime-alcalic character, in the Baden and Sarmata cycle featured by riolite tuff, andesite-dacite and basalt-andesite lava and debris. Hollóháza is located on the Northern part of this area and is surrounded by the rims of a 4-6 km diameter volcanic caldera that is recognizable from satellite imagery.

This rim being the water divide some 250-300m above the settlement. The average annual precipitation is 600-650mm on an approximately $20km^2$ resulting approximately 12 million m^3 to infiltrate to the soil or runoff in the Török creek. Along the steep slope the precipitation moves toward the settlement from every direction either as surface runoff or as fissure waters.

The settlement was established in the natural depression of the caldera where the bottom andesite is covered with varying depth of riolite-tuff and clayey marine deposits.

This depression is cut across by a NW-SE tectonic valley, which accommodates the channel of the Török creek. The riolite-tuff and clayey marine deposits lay with the tilt of 10-25 degree toward the valley. At the hill foot the rhiolite tuff is covered by massive dacite and andesite lava and their clayey weathered residuals. The riolite tuff mixed with seawater deposits has increased bentonite content (60% montmorillonite) and the covering and bottom sea deposits have also high (40%) illit-montmorillonite content. These deposits tend to expand when contacted by water.

Topographic maps and aerial photographs of the site (Figure 2.) show the bending shaped foreheads of mass movements, creeps and series of bigger scale, flops and sinks on the areas covered by clay or riolite tuff material. At other locations, where riolite tuff and clay layers are covered by hard lava flow these formations do not exist.

Figure 2. Traces of mass movements on the Hollóháza aerial photograph

Based on detailed site inspection, investigations and borings the geological map of Hollóháza (Figure 3.) was refined and the clayey and riolite tuff layers can be delineated. Considering also the previous mass movements those residential areas threatened the movements are identified.

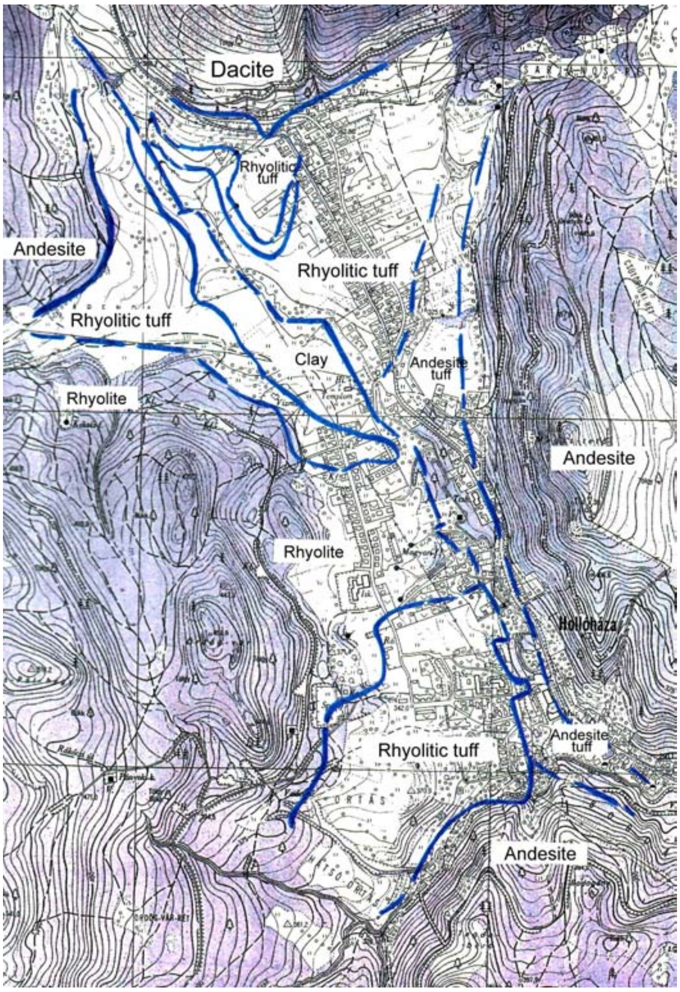


Figure 3. Uncovered geological map of Hollóháza

Integrated evaluation of geological mapping and aerial photographs prove that only those two areas are exempt from mass movement hazards that are settled on solid lava rocks. All other areas covered by Sarmata clay and riolite tuff series are endangered by movements, due to the several series of high angle dip of the layers.

Figures 4-6. show the typical geological cross section of the three locations highlighted on Figure 1.

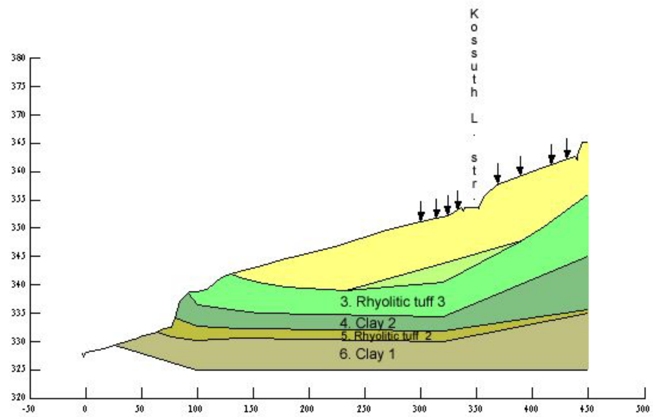


Figure 4. Typical geological cross section of the Northern area

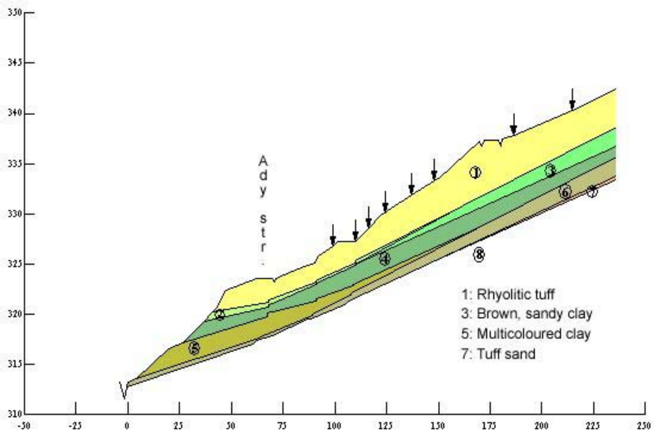


Figure 5. Typical geological cross section of the vicinity of the church

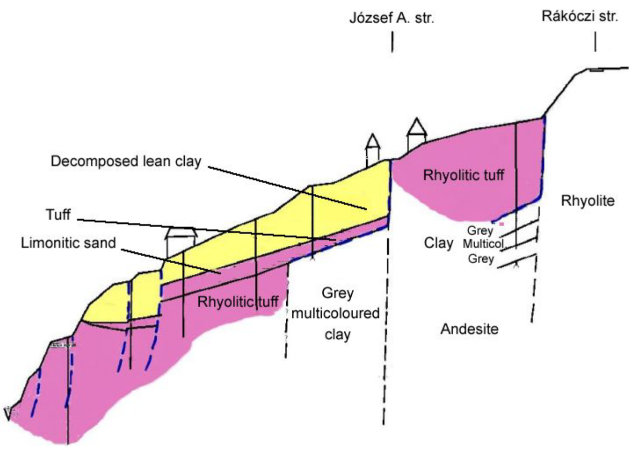


Figure 6. Typical geological cross section of the site near the kindergarten

The figures show that the geological setting of the Northern and church sites are rather simple, the sliding surface is always the boundary between the clay and riolite layers. The difference is that while on the church site only one sliding surface is predicted on the Northern site at least four sliding surfaces are probable. The volume of the mobilized earth material is around 1,5 million m^3, and 0,2 million m^3 at the church site.

The movements near the kindergarten are somewhat different from that of the Northern site. The hillside has a multi-layered terrace structure at this location (Figure 6.). The surface of the 3-5 steps in the topography are leveled or slightly dip backward. These are for sure the residuals of former slides occurred in several steps. Due to the more complicated geological structure geoelectric investigation supported the traditional borehole logging. Figures 7-8. show 2 longitudinal and 2 perpendicular geophysical cross-sections.

On the two longitudinal sections (Figure 7.) one can clearly differentiate the near surface, high resistance layers and the lower resistance deeper formations. The block structure of these later ones are delineated by the resistance minimum (<5 Ohm). On the perpendicular sections (Figure 8.) the block structure although not so significantly but clearly traceable throughout the whole section.

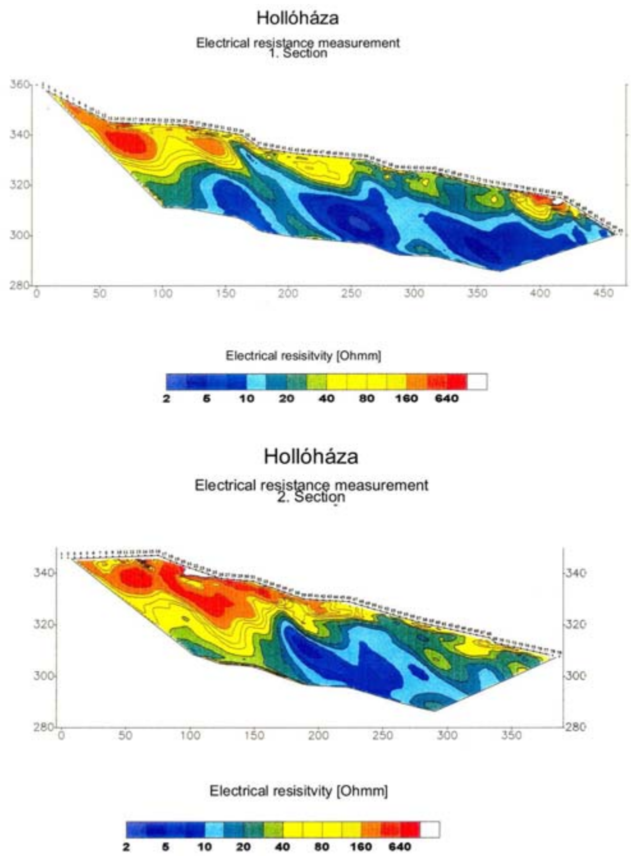


Figure 7. Geoelectric sections along the gradient (ELGOSCAR Kft)

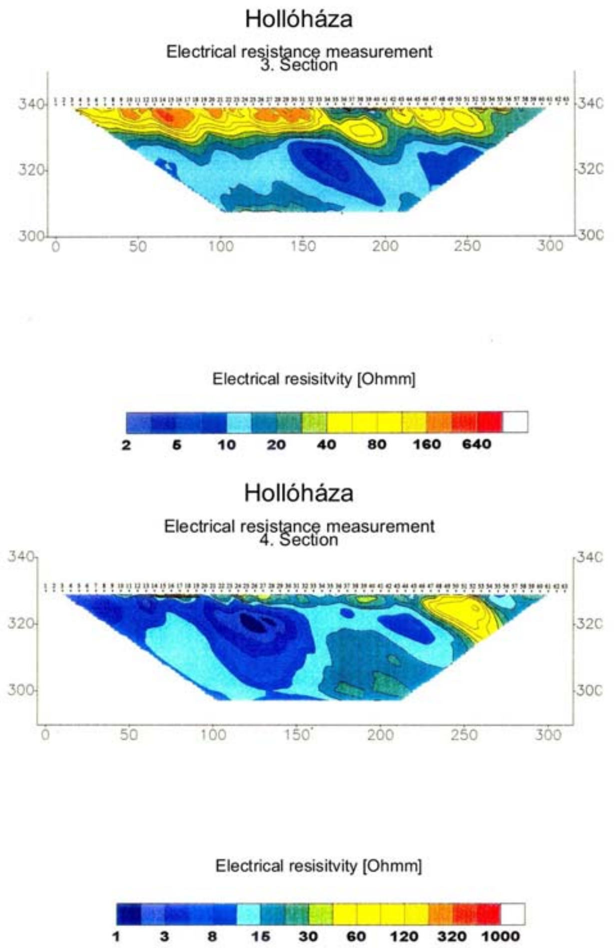


Figure 8. Perpendicular geolelectric cross sections (ELGOSCAR Kft.)

3. RESULTS OF THE SLOPE STABILITY ANALYSIS

The slope stability analysis was supported by the GEOSLOPE SLOPE/W software package and the widely used JANBU method was applied. The applied steering strength parameters (c, Φ) are indicated in Table 1.

Table 1.

Hollóháza Norhtern location

Name of soil	Case 1. c [kN/m^2]	Case 1. Φ [°]	Case 2. c [kN/m^2]	Case 2. Φ [°]	Case 3. c [kN/m^2]	Case 3. Φ [°]
1: debris-till,	80	10	0	10	0	10
2: dacite pebble	0	20	0	20	0	20
3: riolite tuff (type 3)	20	3	20	4	20	4
4: clay (type 2)	20	0	20	0	20	3
5: riolite tuff (type 2)	200	10	200	10	200	10
6: clay (type 1)	50	11	50	11	50	11

During the stability assessment the so called "back analysis" method was applied, which determines c and Φ parameter pairs that are necessary for a given safety level (SF=1) assuming that the slope is in an unstable condition. As default assumption the groundwater level was identical with the surface.

The assessed area is defined on Figure 4. The access load of buildings was substituted by two linear loads along the two external foundations and are indicated with arrows on the figures. During the stability assessments we examined the two most probable sliding surfaces. (see layer labels on Figure 4.).

- upper sliding surface is along the **„riolite tuff (type 3)"–„clay (type 2)"** layer boundary (cases 1. and 2. in **Table 1**),
- the lower sliding surface is along the **„clay (type 2)"–„ riolite tuff (type 2)"** and it reaches the surface (case 3. in **Table 1**.).

Case 2 alters from case 1. (related to the upper sliding surface) by assuming a fault thus assuming zero cohesion featuring the debris till layer. In this case in order to achieve the desired safety level (SF=1) the **riolite tuff (type 3)** layer must have increased angle of friction (4° instead of 3°).

After identifying the shear strength parameters related to unit level of safety, we investigated how the decrease in pore water pressure (lowering groundwater level) would change the value of the safety factor. The results of our calculations are shown in Table 2. and Figure 9.

Table 2.

Groundwater level bellow surface	Factor of safety Case 1.	Factor of safety Case 2.	Factor of safety Case 3.
groundwater on surface	1,023	1,014	0,993
- 2 m	1,050	1,048	1,026
- 6 m	1,102	1,114	1,090
- 12 m	1,157	1,185	1,166
- 16 m	1,165	1,196	1,179

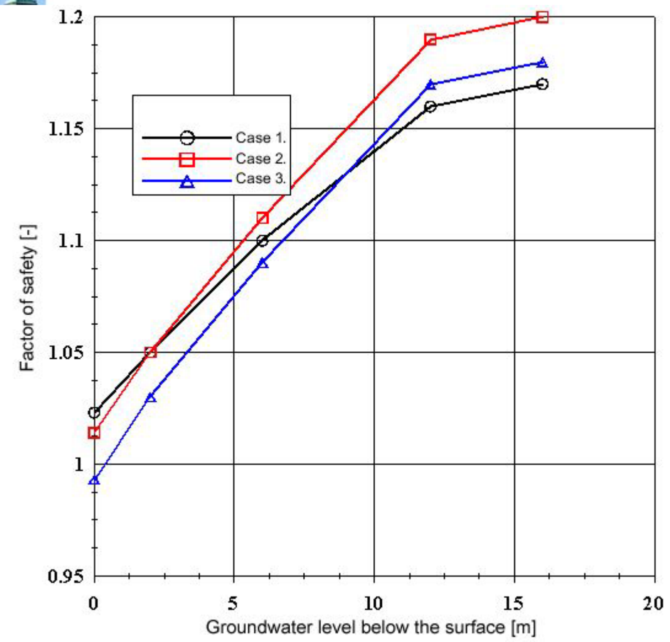


Figure 9. Probable factor of safety related to different levels of groundwater

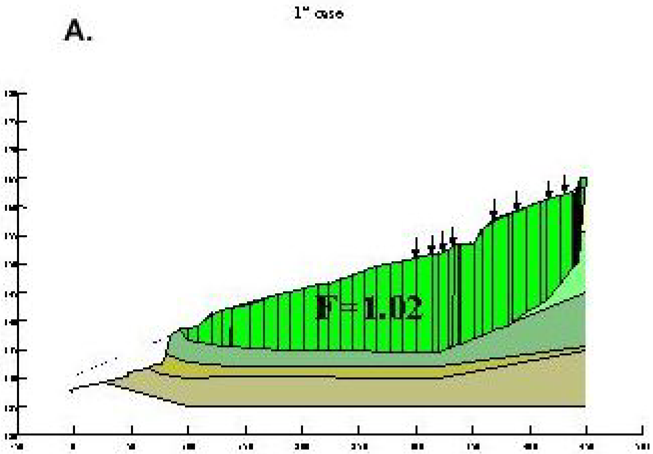


Figure 10a. Slope stability assessment of the Northern site

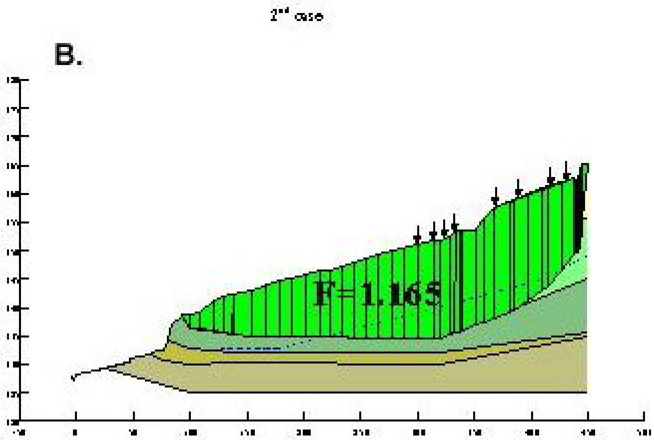


Figure 10b. Slope stability assessment of the Northern site

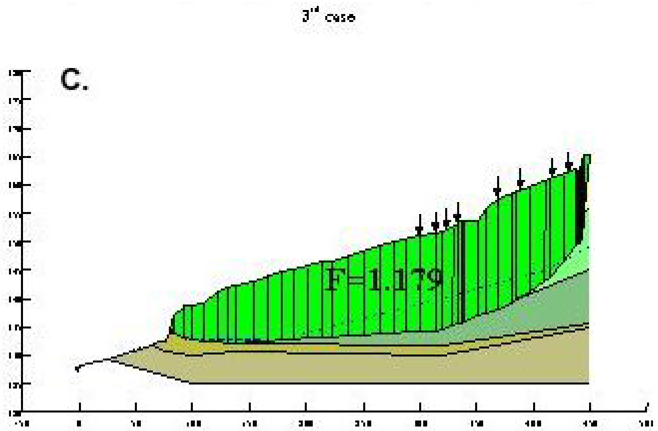


Figure 10c. Slope stability assessment of the Northern site

Out of 15 stability assessments 3 typical cross sections are indicated on Figure 10. On Figure 10a. the sliding surface is that of case 1., with groundwater level on the surface. On Figure 10b. the same case with groundwater level 16m bellow surface. Figure 10c. shows Case 3 with groundwater level 16m bellow surface.

It was concluded during the slope stability analysis that 12-16m lowering of groundwater is necessary in order to achieve the minimum level of safety of stability, which is the partial protection of the site allowing smaller scale instabilities.

4. PROTECTIVE ACTIONS IN ORDER TO SECURE STABILITY

Stability - considering cost–benefit aspect as well - can be achieved by lowering the groundwater level according to our calculations. This way SF=1.2 level can be achieved. Installations needed for lowering groundwater level are the following:

- On residential areas dewatering arms starting from vertical shafts. In the initial phase the existing digged domestic wells can increase efficiency, however their average depth of 6,0-10,0 m; is not sufficient.
- Installation of retaining walls at the tongue of mobilized earth materials. Traditional drainage ditch may cause further instability due to the unfavorable soil characteristics. It is recommended to install geo-drains or flat-drains because only minor leakage is anticipated.
- It would be necessary to install a boundary drain system outside the mobilized area. It is aimed to eliminate potential inflow to the area.

The temporary testing of the proposed methods have already started while the assessment of the site was conducted. The interventions caused couple of meters decrease in groundwater level in existing wells and the installation of 6 geodrains at the front of the mobilized locations. This resulted that the intensity of the daily movements decreased from the scale of cm-s to a few millimeters. The discharge of the 30-40m long drains was not more than 10-30l/min/drain (see Slides 7-8.).

Slide 7. Construction of geodrains

Slide 8. Outcoming water from geodrains

5. RISK-BASED EVALUATION

A major constrain during designing protective action of the Hollóháza case was the lack of financial resources. The small mountain village although accommodates a famous china factory, could not mobilize significant resources to solve their problem. In fact the cost benefit assessment of most protective actions proved that almost any intervention would cost more than the value of the damaged or potentially threatened real estates. Which purely means that the relocation of the affected houses would be less expensive than the final solution of the geotechnical problem. Of course such cost benefit analyses and risk evaluations are not capable of handling social and emotional factors of the inhabitants of the settlement.

It is also relevant that due to the relatively slow motion of the mass wasting processes human life was not directly at risk. Thus when consequence analysis was considered only financial damage had to be assessed.

Risk assessment of landslides had to handle two separate issues.

1. Hazard mapping or assessment that relates to the probability of relocation of certain volume of earth material
2. Consequence analysis that assesses the damage potential related to an event with a certain magnitude.

In case of the Hollóháza mass movements real estates, houses, roads and other infrastructure installations were effected. The damage in every case was caused because the element damaged was *on* the mobilized earth body. Which is typical for rather slow movements. No damage was observed due to an object being *in the path of mobilized* (relocated) soil. Consequently the critical issue of earth material transportation distance is not an issue of concern.

The two major and exclusive elements of the risk assessments are the value of the exposed element and the potential (hazard) for the mass movement at the given spot. Risk for each individual exposed element can be expressed as the function of these two factors.

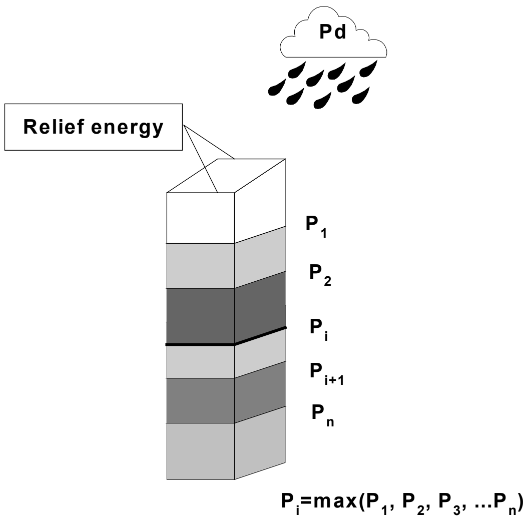


Figure 11. Elements of mass movement hazard.

As earlier discussed the main cause of the geotechnical problems at the Hollóháza case are related to the unfavorable geological setting of clayey sediments and weathered riolite tuff material in a near saturated or saturated condition. Should the pore pressure decrease at these locations the risk of landslides decreases significantly. The high pore pressure is related primarily to precipitation quantity and intensity and secondly to the lack of appropriate surface channeling facilities. The steepness of the slope is also an important factor (See Figure 11.).

Consequently the landslide hazard consist of

1. permanent factors:
   a. the geological setting of a given site is considered as a permanent factor with regards to mass movements
   b. relief energy that is an easy-to-use way of quantifying slope gradient

2. initializing factors: which is the probability of certain amount of precipitation falling on site and infiltrating into the soil

While the former two are spatial variants the later one is time dependent (assuming that one precipitation event is the same on the whole area of study). The former two are handled with the slope stability assessment delineating the most hazardous sites (see Figure 3.) and identifying the most unfavorable geotechnical setting (see Figure 10.) the third one is subject to hydrological statistics affected by several anthropogenic factors.

The risk based evaluation of the Hollóháza case this way does not provide significantly more information than the slope stability assessment unless the real estate values are considered in the assessment. In a case study with more diverse settlement structure, with broader scale of real estate values the risk distribution of the site could significantly alter from that of the landslide hazard map. This aspect of the assessment can be really important for insurance companies insuring real estate at the site having refined analysis about the risk of the insured object