

## LANDSLIDE – ANALYSIS AND STABILIZATION

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### Abstract

Several metres thick top cover of a hillside slid down in a town near to Budapest. Buildings, communication and utility lines suffered damage. The author has found the cause of the movement in the seeping ground-water on the top of the underlying highly plastic clay. The design of stabilization rested on underground investigations and finite element analysis. The actual event calls the attention what type of careful arrangements are needed at similar construction projects.

*Keywords:* hillside slip, slope stabilization, finite element analysis.

### 1. Introduction

Extensive surface movement occurred on the spring of year 2002 in the internal district of a peripheral town near to Budapest. Five buildings were directly and further five buildings indirectly involved in the disaster, beside the damage caused to the communication and utility lines. The movement encompassed a 100 m long and 60 m wide hillside above a 15 m deeper lying shore. The initially slow creep turned suddenly into a several metre deep and forward directed sliding, what, in an attenuating manner continued for weeks. On the first week, the rate surpassed 20 cm in both directions (see *Fig. 1* and *Fig. 2*).

Movement in the area has already begun in the early '70-s, when the building of the district started. The experienced tiny slips at the beginning should have warned that the hillside above the shore was not sufficiently stable. Our investigation proved an unambiguous correlation between the occurrence of slides and the quantity of accumulated ground water that was seeping toward the shore. It is worth to mention that in the same days, in some few kilometre distances from our site, a similar (fortunately smaller) sliding occurred under similar morphologic conditions.

### 2. Soil Exploration

Parallel with the geodetic survey of the site, completed were the large diameter borings and the seismic sounding tests. The encountered characteristic layering in



*Fig. 1.* The crown of the landslide



*Fig. 2.* The toe of the landslide

the region was as follows.

The ground surface is covered to various depths with clay mixed tuff with stony fragments. This is underlain by variously coloured layers of sand and fine sand with silt, together with sheets of tuff what is weathered to various degrees

(generally a loosely composed mass of sand and soft stones). Next the determinant grey fat clay comes as the first water carrying layer below the ground surface. All borings detected the downward seeping groundwater on the top of this formation. Our investigations proved later that the sliding surface coincides with the top of this layer. The layer is several metres deep and extends to the end of the borings, or where not, there the fine sand with silt repeats itself in dense condition.

### 3. Boundary Conditions for the Development of the Sliding

Longitudinal soil profiles were plotted on the basis of the borings placed in rows in the direction of the movement. Such a geotechnical model for the calculation can be seen in *Fig. 3*. Properly visible is the sliding surface on the top of the clay.

The condition for the movement was produced by the shearing resistance depriving seeping groundwater on this outward slanting surface. The outward leaning layers of the soil mass over the moulded and wet clayey surface slid first slowly, then (supported by the leakage from the that time already broken water mains) abruptly in the downward direction of the slopes at the shore.

The movements occurred always in the spring, when the evaporation is hindered, the melted snow and half-years precipitation is stored in the underground and, the springtime rainy storms add to provoke such unfavourable events.

So was the situation in our case as well. Only in one out of 34 years before the sliding was the yearly precipitation above the 800 mm/year limit in the region, while it attained 803 mm in the year of the slide. The monthly precipitation attained 66.5 mm in the month immediately before the sliding, what was also an outstanding observation in the given season and place. All together, relatively enormous water quantity became stored in the underground. One may conclude therefore, that the large scale sliding occurred after an extraordinary wet year and unfavourable month.

Contributing to the water saturation of the underground was the lack of proper sewerage, while the water supply was provided in the region. Water consumption increased tremendously through the inhabitation. The provided cesspools just above the slid area caused leakage and nourished the saturation of the ground. Beside the health and environmental backside, the lack of proper sewerage was surely a basic contributing factor in the devastating damage on the given slopes.

Further impact on the stability of the area was caused by the inhabitants who started to exercise gardening and made landscaping facilities like retaining footwalls, cut slopes and refilling embankments on the plots near to the shore side, to gain flat and horizontal surfaces. These caused additional loads by using miscellaneous water storing earth materials on the already unstable ground that hindered evaporation.

Another detrimental interference was due to the unregulated hillside slope section. The irregularly cut slopes, deposited fills and uprooted natural vegetation obstructed the originally existing natural drainage.

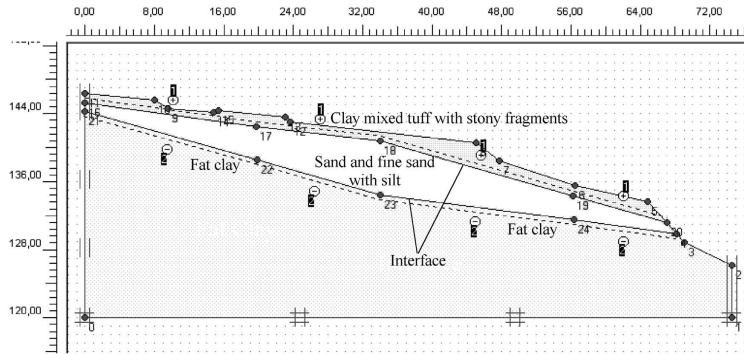


Fig. 3. The geotechnical model for the calculation

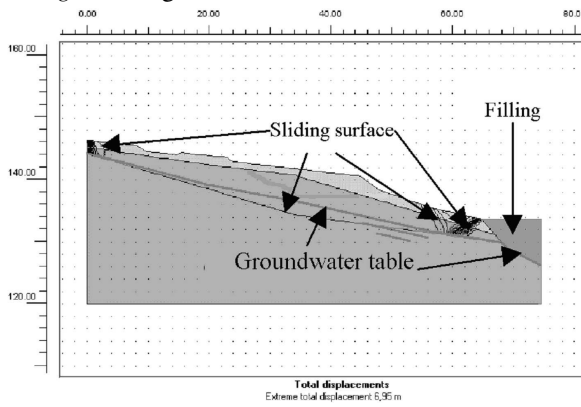


Fig. 4. Failure mechanism

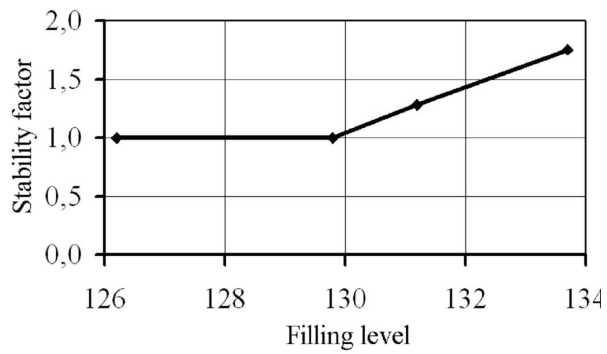


Fig. 5. The stability factor

#### 4. Stability Analysis

Computerized finite element programmes were used for calculating the stability of the hillside slope. The surveyed geometry of the site, measured rigidity of the underground and the shear parameters of soils played the main roles in the calculation. Determined were the values of those parameters at which the sliding occurred.

This may have happened when, due to the wetting action of the groundwater, the shear parameters on the surface of the otherwise sound clay mass diminished to one quarter of their original value. The realistic value of friction angle is  $3^\circ$  and  $c = 15$  kPa resulted from these calculations, even when the additional influence of the broken water mains was difficult to include in the programme.

#### 5. Stabilization of the Hillside Slope

Two realistic approaches were investigated for the stabilization of the slope with the ruined 25 000 m<sup>3</sup> earth mass. Drawing the blue prints and the realisation followed accordingly, so, the successful stabilization of the slope has been completed in due course.

Core of the first solution was to eliminate (or at least to diminish) the destructive impact of seeping groundwater movements, whereby the shear parameters may not attain (or go below) the critical value on the sliding surface. The concept was that the soaking of the critical surface will cease through the help of proper drainage, therefore the originally acceptable shear parameters of the clay will prevail and, in the meantime, also the pushing forces from the water flow will lose their influence. Horizontally bored 'Ramney-wells' were proposed which (through the 'tentacles') could collect the seeping water in the shafts. Sketch of the actually completed and efficiently operating drainage system is presented in *Fig. 4*.

The second concept of retaining the moving earth mass with a retaining wall and refilling the gorge to some level was discarded by the parties, though it was demonstrated by the presented computerized finite element programme that the balancing load may withstand the pressures (*Fig. 5* explains).

The pertaining works were completed since and the control survey has not shown any movement on the area.

#### 6. Conclusion

Under the Hungarian conditions the main reason of landslides is the not well provided land use. The impairments draw the attention to those conditions which must be considered in case of earlier unbuilt ground.

## References

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