Stability problems of abandoned clay pits in Budapest

PÉTER GÖRÖG[1] & ÁKOS TÖRÖK[2]

[1] *Const. Mat. Eng. Geology, Budapest Tech. Univ. (e-mail: gorogp@levele.hu)*
[2] *Const. Mat. Eng. Geology, Budapest Tech. Univ. (e-mail: torokakos@mail.bme.hu)*

Abstract: The study area, a previous brick-yard, is located in the valuable lands of the Buda Mountains. The brick production ended in 1972 and the open pit was recultivated by heterogeneous landfill. The mining area was a natural slope that experienced landslides prior to the clay production. The mining activity accelerated the sliding and catastrophic landslides took place several times in the brick-yard. The abandoned clay pit became a valuable construction site from the 1990'ies. A computer slope stability model was used to analyse whether this area is suitable for housing or not.

The raw material belongs to two clay formation the Oligocene Tard clay, and Kiscell clay. The clays are covered by loess and debris slide. The Kiscell clay is divided into two units having different properties. The lower layer is grey and impermeable, while the upper one is yellow, limonitic and has a limited permeability. For the slope stability analyses data from boreholes and geophysical tests were used. The main cause of landslides is related to the rainwater infiltration. The precipitation seeps into the upper debris layer and gets into the surface of the grey clayey unit decreasing the friction. Additional water is driven from springs that were covered by former landslides and the missing drainage pipes of the area. The sliding surface is at the boundary of the grey and yellow clay.

The slope stability and factor of safety was analysed in selected sections along the slope by using Plaxis and Geo4 softwares. The Plaxis software uses finite elements methods while the Geo4 software uses conventional methods, it calculates with circle and polygonal slip surfaces.

Résumé: Le secteur d'étude, un brick-yard précédent, est situé dans les terres valables des montagnes de Buda. La production de brique finie en 1972 et le puits ouvert était recultivated par le remblai hétérogène. Le secteur d'extraction était une pente normale qui a éprouvé des éboulements avant la production d'argile. L'activité d'extraction a accéléré le glissement et les éboulements catastrophiques ont eu lieu plusieurs fois dans le brick-yard. Le puits abandonné d'argile est devenu un chantier de construction valable du 1990'ies. Un modèle de stabilité de pente d'ordinateur a été employé pour analyser, que ce secteur convienne au logement ou pas.

La matière première première appartient à la formation de deux argiles l'argile d'Oligocene Tard, et à l'argile de Kiscell. L'argile de Kiscell est divisé en deux unités ayant différentes propriétés. La couche inférieure est grise et imperméable, alors que le supérieur est jaune, limonitic et a une perméabilité limitée. Pour les données d'analyses de stabilité de pente des forages et des essais géophysiques ont été employés. La cause principale des éboulements est liée à l'infiltration d'eau de pluie. La précipitation s'infiltre dans la couche supérieure de débris et entre dans la surface de l'unité argileuse grise diminuant le frottement. L'eau additionnelle est conduite par les ressorts qui ont été couverts par d'anciens éboulements et les pipes absentes de drainage du secteur. La surface de glissement est à la frontière de l'argile gris et jaune.

La stabilité de pente et le facteur de la sûreté ont été analysés dans les sections choisies le long de la pente en employant Plaxis et softwares Geo4. Le logiciel de Plaxis emploie des méthodes d'éléments finis tandis que le logiciel Geo4 emploie des méthodes conventionnelles, il calcule avec le cercle et les surfaces polygonales de glissade.

Keywords: abandoned mines, clay, finite element, landslides, slope stability

INTRODUCTION

Urban development often conquest areas of previous quarries and pits. These locations are used as landfill sites and subsequently faces to slope stability problems. To assess the present state of abandoned quarries or pits field surveys of discontinuity surfaces, weathering maps, shear strength tests are used (Koca and Kinsal 2004). Slope stability analyses of recent landslides and potential slide areas include on site monitoring by using extensiometers and tensiometers (Okamoto et al. 2004), piezometers (Angeli et al. 1998) as well as collecting data on precipitation and local geology (Calcaterra and Santo 2004). The mineralogical and geotechnical parameters of clayey slopes are obtained by laboratory testing (Calcaterra and Santo 2004) and conventional parameters such as LL, PL, PI are used for slope stability assessments (Isik et al. 2004). In computer modelling of slopes finite element models are commonly used (Isik et al. 2004).

In this paper, we are investigating the slope stability of an ancient brick-yard, modelling the load of the future buildings and analysing the slope stability by using two geotechnical software. The two software have different approaches to calculate the slope stability and safety factors. The results of finite element calculation method (Plaxis software) and calculation of circle and polygonal slip surfaces with conventional methods (Geo4 software) are presented and compared here.

Similarly to others cities the urban development of Budapest focuses on the development of scarce available lands that are located within the area of the city. An Oligocene clay covers large areas in Budapest, Hungary. The subsoil of the most valuable lands of Buda is usually this clay. In the municipal area of Buda there are three ancient clay pits, where several landslides occurred. These areas would be potential building sites of Budapest, but landslides developed in weathered clay hamper the site development. The forced utilization of inherently unstable slopes and clay pits often cause landslides and thus slope stability analyses of such areas are essential for urban planning and site development.

MINNING ACTIVITY AND LANSLIDES

The clay formation of Buda (Kiscell clay) has been used for brick and tile production and clay pits were already established in the middle of the 19th century (Fig. 1). The economical development at the end of the century caused rising production of construction materials, thus it was necessary to enlarge the clay pits.

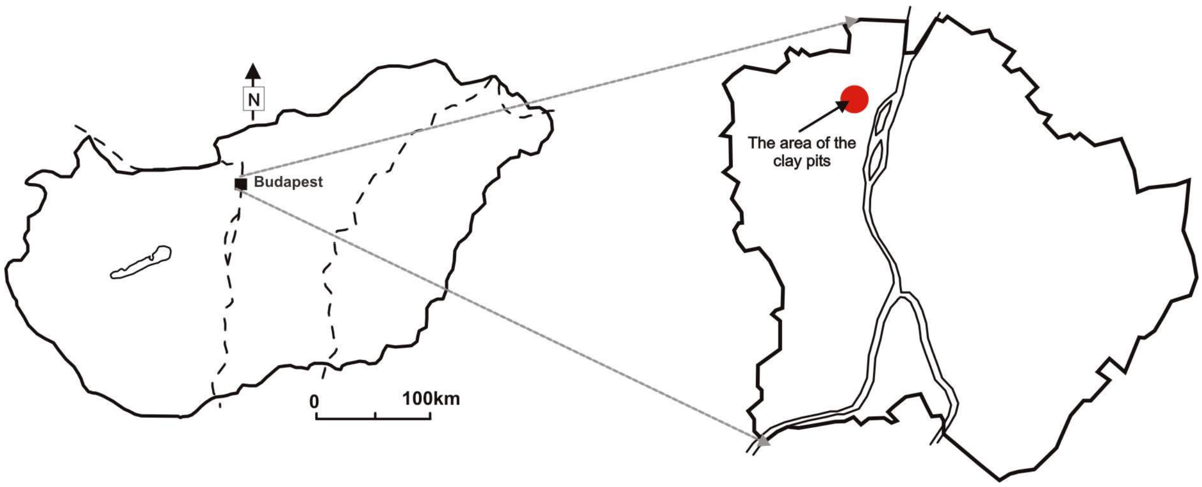

Figure 1. Location of the ancient clay pits

The mining area was a natural slope that experienced landslides prior to the clay production. The clay exploitation accelerated the sliding, because the extension of the pits was not planed and the slopes were cut steeper than it was allowed. The improper mining and the insufficient drainage induced several catastrophic landslides in the brick-yard. The landslides endangered buildings and streets. That is why it was planned to close the mining activity in the 1920'ies but due to the 'after-war reconstructions' the clay exploitation continued till 1972 (Németh, 1980).

The soil-cover of the raw material was deposited on the margins of the pit, especially on the southern part. The dirt consists of the yellow weathered part of the Kiscell clay, clayey slope debris which contains rock fragments and loess.

The abandoned clay pit (Drasche pit) was mainly used as a waste disposal site, and thus nowadays it is filled with a very heterogeneous landfill. The deepest area was filled by household waste of Budapest and even with excavated materials from the tunnelling of the metro (Németh, 1980).

GEOLOGY, HYDROGEOLOGY

The studied clay pit is at the foot of the Hármashatár hill in Budapest (Fig. 2). The bedrock is a massive Triassic limestone or dolomite. The Triassic sequence is covered by Eocene limestone and marl. The raw material is located on the east slope of the hill, consisting of Oligocene clay formations (Tard clay and Kiscell clay). The clays are covered by Pleistocene loess and slope debris. The Kiscell clay is divided into two units having different properties. The lower layer is grey, dark grey and impermeable, while the upper weathered one is yellow limonitic and has a limited permeability (Vendl, 1932; Paál 1997). The grey clay contains pyrite, while in the yellow clay the pyrite is oxidised and limonite is the main iron mineral.

In the Pleistocene the investigated area was covered with loess. Subsequently the loess mixed with the weathered Kiscell clay and the bedrock due to erosion and landsliding, resulting in the formation of a slope debris layer. The thickness of the slope debris layer varies between meters to 10-15 meters.

The main water-catchment area is the hillside above the pit. Meteoric water seeps through the slope debris and the weathered yellow clay, and gets to the surface of the grey Kiscell clay. The groundwater is mainly supplied by meteoric water. The surface of the grey clay is also soaked from the seepage of the cracked drainage pipes. Fortunately, nowadays this is reduced since a new system of drainage pipes are under construction. Additional water to the slide surface is driven from springs that were covered by former landslides (FŐMTERV, 1998).

The modelled slope is located on the SE edge of the clay pit (Fig. 2) where the burden material was deposited in the 1950's.

FIELD SURVEY

In order to analyse ground conditions and detect possible slip surfaces more than 10 bore holes were drilled on the slope. When drillings did not provide enough data geophysical tests were used to delineate the slide surface. The bedding and slope angles were also measured on site. For the slope stability analyses the physical parameters of soils were tested under laboratory conditions. Geotechnical properties of soils were recorded including, LL, PL, PI, shear strength and water content.

All the boreholes of the slopes penetrated into landfill that was composed of loess and clayey slope debris. The landfill contains the weathered yellow Kiscell clay which was the burden material of the clay pit, while the grey Kiscell clay were found below. The borehole C4 cannot reach the grey Kiscell clay because of a fault zone (Fig. 3).

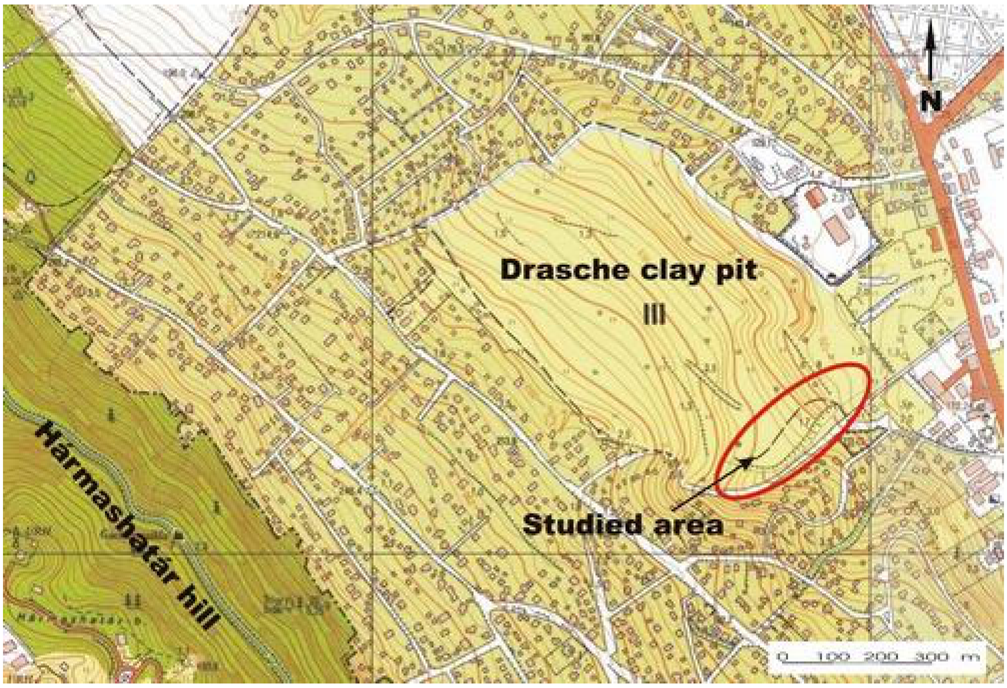

Figure 2. Site plan of the studied area

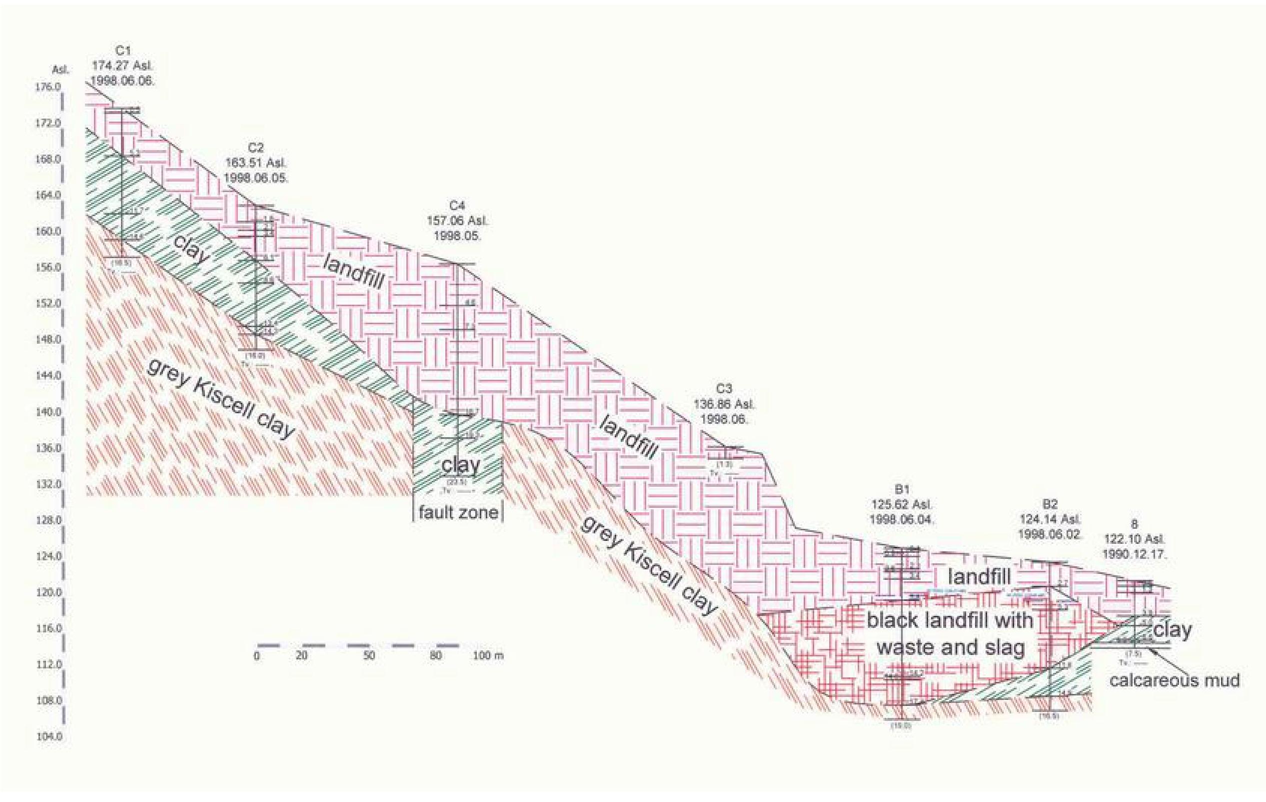

Figure 3. The geological profile of the analysed slope showing the location of drillings (borehole data from FŐMTERV, 1998)

The strength parameters of the fault zone are not very different from the grey clay, so it has no effect on the stability analyses. The upper clayey landfill layer is more than 50 years old so the condition of it is usually good and it has a good load bearing capacity, but at some places the boreholes penetrated into soils with weak strength. The grey

Kiscell clay has especially good load bearing capacity. No groundwater was found during the field explorations between May and June 1998 in this area. (Fig. 3). The borehole C3 did not reach the grey clay because of a concrete mass therefore geophysical measurements were also made to determine the surface of the grey Kiscell clay.

The bedding of subsoils at the flat area in front of the deposit is more disadvantageous. A deep basin left after the mining activity, which was later filled with waste and slag. This landfill has very weak soil-physical parameters, thus the soil samples were insufficient to determine the strength analyses. Furthermore, this small basin is filled with groundwater.

STABILITY ANALYSIS

The stability of the cover deposits and the flat area in front of the slope were also analysed. The slope stability and safety factor were analysed in selected section along the slope by using Plaxis and Geo4 softwares. The Plaxis software works with finite elements method while the Geo4 software uses conventional methods, it calculates with circle and polygonal slip surfaces. The model was set up along the section shown in the Fig. 3. Consequently, in our model there are three soil layer, the impermeable grey Kiscell clay, the slope debris landfill with the weathered clay and the landfill with waste and slag.

The input parameters were obtained from the explorations and the geotechnical laboratory tests. The most disadvantageous parameters were used to have a realistic model. (Table 1).

Table 1. The soil-physical parameters of the model

name of the soil	ρ_n [kN/m^3]	φ [°]	c [kN/m^2]
yellow kiscell clay and landfill with clayey slope debris	19	15	50
landfill with waste and slag	14	5	1
grey Kiscell clay	22	30	250

The soil-physical parameters of the weathered yellow Kiscell clay and the clayey slope debris landfill are almost the same therefore the two layers are not divided in the model (Fig. 4-5.).

Another aim of our analyses was to demonstrate the effect of the site development on the slope stability by using a 300 kN/m^2 distributed load at the top of the slope. This intends to model the effect of the construction of houses on the slope.

RESULTS OF THE ANALYSIS

In the first case we analysed the stability of the slope without the distributed load. For Geo4 analyses we have to chose an initial slip surface and the software optimalize it, namely it searches the location of the slip surface when the safety factor is the smallest. It can both work with circle and polygonal slip surfaces.

At first we determined the weakest point of the slope, where the safety factor has a minimum, with circle slip surface. This area is at the foot of the deposit. This slip surface penetrates into the landfill with waste and slag (Fig. 4). The calculated safety factor is n = 1.7. The analyses with the Plaxis almost give the same slip surface (Fig. 5) and the safety factor is n = 1.6. It is necessary to note that the Plaxis works with combined safety factor it means that n = 1.6 safety factor which is calculated with Plaxis is equal to about n = 1.7 – 1.8 calculated with conventional method.

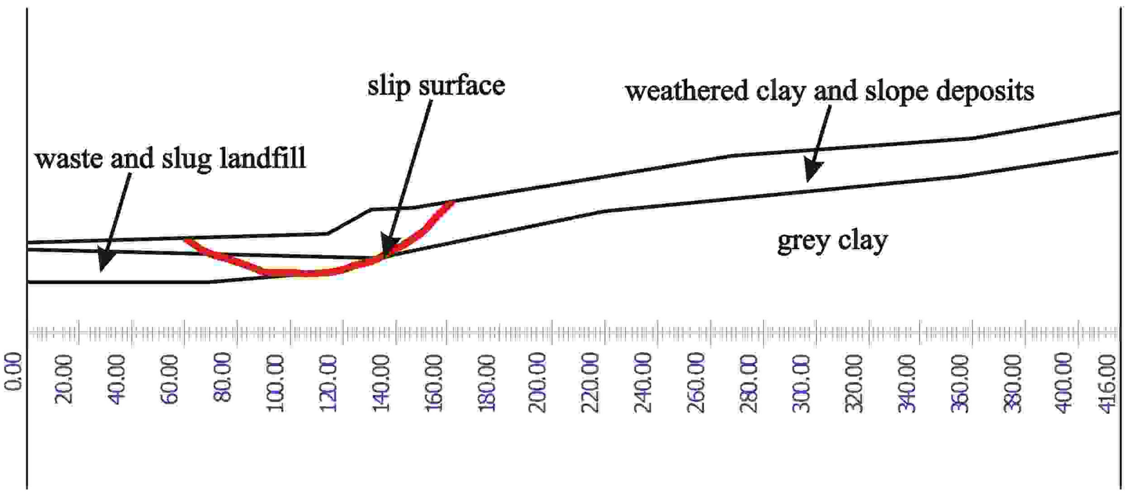

Figure 4. The model and the circular slip surface by using Geo4 (factor of safety n = 1.7)

We have also analysed the global safety of the slope with polygonal slip surface. The main trigger mechanism of landslides is related to rainwater infiltration. The precipitation seeps into the upper clay layer via debris down to the boundary of yellow weathered and grey clay, and the water reduced the physical parameters of this boundary zone. So in this case the slip surface is located at the boundary of the impermeable grey clay and the upper layer (Fig. 6). The safety factor with this slip surface is n = 2.0. The angle of friction of the slope debris landfill is higher than the slope, thus the safety factor is higher when we analysed the whole slope. The safety factor is smaller because of the landfill with waste and slag at the foot of the slope and therefore it cannot support the slope especially when water infiltrates. Former experience showed us that in such clays increasing water-content radically decreases the angle of friction.

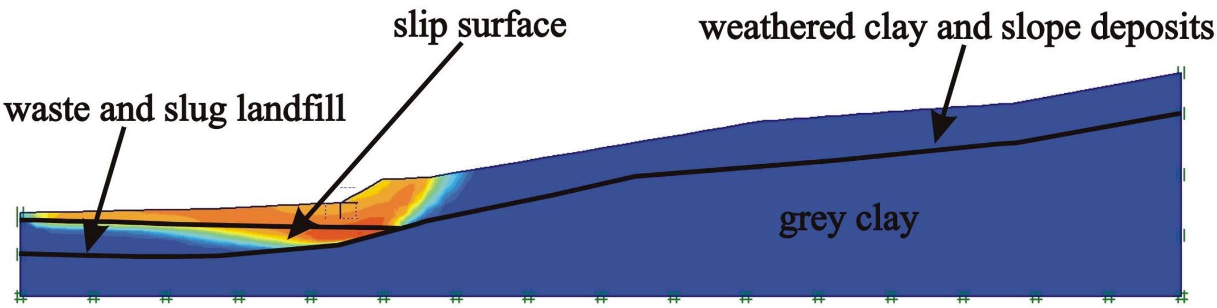

Figure 5. The model and the slip surface by using Plaxis (factor of safety n = 1.6)

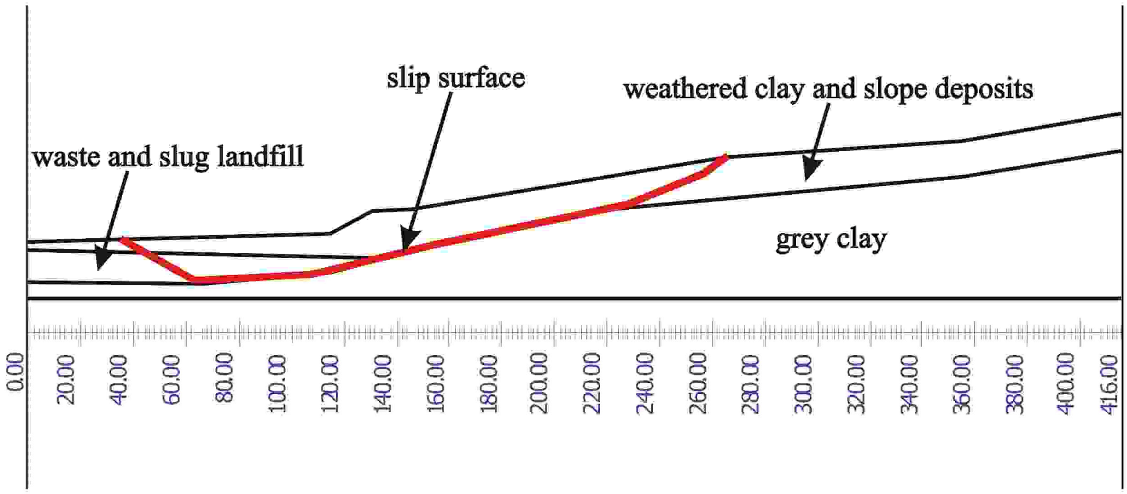

Figure 6. The polygonal slip surface by using Geo4 (factor of safety n = 2.0)

The loads from possible housing has no influence on the safety factor calculated with circular slip surface, but it reduces the global safety of the slope to n = 1,6.

CONCLUSIONS

Landslides are triggered by meteoric water infiltration. The water penetrates through the upper slope debris layer and reaches the surface of the impermeable clay. The stagnant water of springs and the seepage waters due to missing drain pipes increases the water-content of the subsoil. Such processes decrease the strength of the clay and trigger landslides.

During the analyses we have used the minimum values of the physical parameters of the layers. The calculated safety factors were higher than the n = 1.5 value of the long-term safety in all cases. However the risk is higher when construction activity begins at the slope, therefore the safety factor should be increased to n = 2.0, to reduce the risk. When parts of the area are built-in by houses the infiltration is increased and thus the risk of landslides increases. According to these analyses it is necessary to set up limitations of construction activities at the area which was previously considered as a potential building site. The surface movement must be regularly monitored.

MINING ACTIVITY AND LANDSLIDES

The clay formation of Buda (Kiscell clay) has been used for brick and tile production and clay pits were already established in the middle of the 19th century (Fig. 1). The economical development at the end of the century caused rising production of construction materials, thus it was necessary to enlarge the clay pits.

The mining area was a natural slope that experienced landslides prior to the clay production. The clay exploitation accelerated the sliding, because the extension of the pits was not planed and the slopes were cut steeper than it was allowed. The improper mining and the insufficient drainage induced several catastrophic landslides in the brick-yard. The landslides endangered buildings and streets. That is why it was planned to close the mining activity in the 1920'ies but due to the 'after-war reconstructions' the clay exploitation continued till 1972 (Németh, 1980).

The soil-cover of the raw material was deposited on the margins of the pit, especially on the southern part. The dirt consists of the yellow weathered part of the Kiscell clay, clayey slope debris which contains rock fragments and loess.

The abandoned clay pit (Drasche pit) was mainly used as a waste disposal site, and thus nowadays it is filled with a very heterogeneous landfill. The deepest area was filled by household waste of Budapest and even with excavated materials from the tunnelling of the metro (Németh, 1980).

Acknowledgements: We are very grateful to T. Paál who provided field data and had several useful comments and suggestions. The help of B. Kleb is also acknowledged.

Corresponding author: Mr Péter Görög, Const. Mat. Eng. Geology, Budapest Tech. Univ, M egyetem rkp. 3, Budapest, H-1111, Hungary. Tel: +3614632415. Email: gorogp@levele.hu.

REFERENCES

ANGELI M.G., BUMA, J., GASPARETTO P, PASUTO, A. 1998. A combined hillslope hydrology/stability model for low gradient clay slopes in the Italian Dolomites. *Engineering Geology,* **49**, 1-13.

BARON I., AGLIARDI, F., AMBROSI, C., CROSTA, G.B. 2005. Numerical analysis of deep-seated mass movements in the Magura Nappe; Flysch Belt of the Western Carpathians (Czech Republic), *Natural Hazards and Earth System Sciences* **5**, 367-374.

CALCATERRA, D.; SANTO, A. 2004. The January 10, 1997 Pozzano landslide, Sorrento Peninsula, Italy, *Enginnering Geology* **75**, 181 – 200.

FŐMTERV 1998. Geotchnical report on the soil mechanical investigations of the Drasche brick-yard, by Paál T. 32p (in Hungarian).

NÉMETH G. 1980. Analyses of the sliding at the Újlak 3rd pit, near the Jablonka street. *Mélyépítéstudományi szemle* **30(**5), 195 – 206 (in Hungarian).

PAÁL T. 1997. Geotechnical analysis of the area of Újlak clay pit no. II. *Mélyépítéstudományi szemle* **47**(7), 295 – 303 (in Hungarian).

VENDL A. 1932. Kiscell clay, *Földtani Intézet Évkönyve* **29**(2), 97 – 156 (in Hungarian).

SINAN, I.N.; DOYURAN, V.; ULUSAY, R. 2004. Assessment of a coastal landslide subjected to building loads at Sinop, Black Sea region, Turkey, and stabilization measures, *Enginnering Geology* **75**, 69 – 88.

OKAMOTO, T., LARSEN, J.O., MATSUURA, S., ASANO, S., TAKEUCHI, Y., GRANDE, L. 2004. Displacement properties of landslide masses at the initiation of failure in quick clay deposits and the effects of meterological and hydrological factors. *Engineering Geology,* **72**, 233-251.