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STABILITY OF THE ELEVATED RIVER BANK AT RÁCALMÁS

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Abstract

In the neighborhood of the Danube embankment of Rácalmás near the surface soil motion came to pass. Eight houses were damaged and it was to be feared even that the motions would continue. On the basis of the soil explorations and field examinations it was possible to make probable the evolution of sliding planes one near to the terrain and the other passing deeper – above the Pannonian clay. The stability tests also confirmed this assumption. The motion has been induced by the combined effect of several causes. For the sake of avoiding greater damages the protection against the motion and increase in the safety coefficient were indispensable.

Keywords: soil motion, stability, sliding plane, stabilization, safety factor.

1. Introduction

We have the field to be tested along the line Százhalombatta – Paks the part of the steep river wall (consisting generally of loess and clay soil) running about 100 km long on the right bank of the Danube, along the section Ófalu of Rácalmás. In the Middle Ages here were already to be found a colony and even a convent, in the place the daughter Margit of the king Béla IV, later canonized, has been educated for a time. (The first written record remained from 1193 on). Under the one-time colony of fishermen and water-mill keepers Rácalmás run numerous long rambling cellars. In the Turkish occupation of Hungary, these have been hollowed out by the inhabitants.

Along the elevated banks of the Danube, near the surface, since millennia, soil motions have taken place. The remains of historic colonies also lead us to conclude that those embankment motions have run their courses long past. So for example only one half of the Roman camp at Dunaújváros (Castrum Intersica) dated back to the third century is to be found west of the present embankment edge; the second half has been carried away by the earlier motions. Following the studying of the historical maps and according to ground plan layout and sizes of the other members of the Roman chain of fortifications beside the Danube, we can arrive to the conclusion that since the historic times, the edge of the loess elevated river bank has been receding 3–5 m every century to the west. Naturally, in the case of the river wall at Rácalmás, containing also beds of clay, this recession is of less extent than that at the loess wall of Dunaújváros, of much higher water-sensitivity.

River wall motions took place at Rácalmás in the past century in the years 1924–1926, 1964–1966 and 1976–1977. The motions near the surface were generally emerged in the years rich in precipitation, many times with a character of slow creeping; they showed themselves in forms of field settlement dislocations, building cracks and terrain fissures. The more important and quicker motions were usually aroused by the sudden recession of the Danube. After having laid the water on to the community and the rapid decrease in quantity of the underground water obtained from dug wells, and under the influence of the desiccated sewage (failing a sewage system), the level of the underground water has been on the increase (in like manner as in numerous other home colonies).

At the end of the year 2002 the river bank of the Danube was again set in motion along the section Ófalu of Rácalmás. In the spring 2003 the motion became more intensive.

2. Geological Conditions

The plateau beyond the elevated river bank is intersected by cleavages and fault lines arising from the tectonic structure of the land; displacements were also taking place along the joint surfaces – having been coming into being, mostly on the basis of crustal movements having preceded the last ice-age – so these were open and water-conductive.

The Triassic limestone and dolomite taking place in a depth of about 2000 m play the main role in the subsurface geological structure of the area. Onto this is located the Miocene series of strata with a thickness of even higher than 600 m, then comes a thick Pannonian recess deposit up to the vicinity of the terrain, the material of which is significantly sand and clay. Above the Pannonian formations (82–88 mBf level) Pleistocene and Holocene deposits are to be found, the total thickness of which is 6–30 m in the area beyond the bank footing, their material consists of sand, silty sand, lime dolls and loess dolls containing sludge, sandy sludge (loess), and clay.

The field beyond the elevated river bank is flat, slightly indented. The erosion caused by the Danube and the gradual displacement to the west resulted in particular combined strata of broken fragments between the river bank and loess plateau. The bed of the Danube has been evolved in the Pannonian clay bank, the surface of which shelves mildly toward the river somewhat surfy. The *underground water* takes place also in the Pleistocene and Pannonian strata and flows in the direction of the Danube at 0.06–0.16 hydraulic gradient. According to experiences, that takes place in general under pressure. In the critical area along the bank clay is to be found in bigger thickness under the terrain level (the sand with gravel filling and the gravel with sand filling are missing), so the permeability of the slope footing is low, the water quantity being able to leave is small, this is why the piezometric pressure increases reacting upon the stability of the bank and the ‘slope of broken fragments’. The periodic current fluctuations of the Danube increase the disadvantageous effect; so does first of all the sudden recession.

The edge of the slope of about 6° on the average, being now in motion, facing to the Danube, continues in a nearly flat area, with a valley running north-west – south-east beyond which before the regulation, the slope footing joining the low-water mark river bed had a 11–20° slope as a result of earlier collapses, and a variable height, and blended into the marginal sediment zone of the Danube at Rácalmás (Little Branch of the Danube), the width of which was variable and had a mild gradient, near the 92 mBf (meter above the Baltic Sea) level.

3. Description of the Damage

In autumn 2002 the Branch of the Danube at Rácalmás in the area reaching from the Szávó-köz up to the Bruck-köz was dredged hard in order for gravel exploitation. The river bed has been deepened down to about 2.5–3.5 m. After having dredged the bed the movements appeared, then in February 2003, following the lasting wintery thawing of the snow they were increased in a marginal zone with a length of about 200 m and a width of about 100 m. On the basis of the surface signs the motion can be considered a motion of mass sliding character, ‘expanding’, receding motion towards the hill. In the area from the hill side, in some places, inside of the moving mass, strongly marked fracture openings are to be well observed, caused by the tensile stresses, the course of which is nearly parallel with the Danube and at the edges arching towards the river; moreover, they are to be seen in the field and on the walls of the houses (*Fig. 1*) and in the fence footings (*Fig. 2*) as well. The fracture width in footing to be observed in the photo was in May 5.4 cm, at the end of August, however, 6.1 cm. The ‘cover’ of footing came also out of place. In the moving area were eight houses damaged. The fact of the sliding also became unambiguous by the tilting of the trees (*Fig. 3*) and fences.

The uppermost one of cracks was observable in a distance of about 100 m from the bank-line of the Danube along the street parallel with the river. 6 dwelling houses were damaged in the moving area. There was a house in the case of which the pavement next to the building came out of place in an extent of more than 10 cm from the building (*Fig. 4*). On both of banks of the low water mark river bed of the Little Branch of the Danube (in the area corresponding to the length of the dredged river bed and the surface motion in the elevated river bank) ‘fresh’ sliding movements were happening (*Fig. 5*). Fortunately, the motion slowed down in the course of the droughty spring in lack of precipitation, and the dry hot summer and stopped providing time in such a way for protecting.

Fig. 1. Fracture on the wall of a house

Fig. 2. Strongly marked fracture in the fence footing

4. Subsoil Conditions

Earlier in the moving part of the bank and now following the motion numerous drill-holes were deepened. Unfortunately, most of them did not exceed 12 m and so did not reach the stratum to be considered critical from the point of view of sliding, they reached transversely only the sandy sludge under the terrain level, the sludge under the former and the following lean and medium clay strata. Above the clay and below the underground water the sludge consistency was soft. 3 drillings deepened with 5.5–8.8 m depth in the 20 m wide inundation area before the river bank area have gone thoroughly along clay. *Fig. 6* shows the soil stratification. Here, down to 7.5 m range the Pleistocene and Holocene rich clay strata ($I_p = 32 - 85\%$), containing in some places chalky 'stone dolls', and calcareous crushed gravel. The underground water skirting these stone settlements is seeping with relatively low intensity. The lower part of this Pleistocene deposit is light gray coloured, having a loose ($e > 1$), mushy consistency. Its water content is 40–55%. The creeping motion of this doughlike clay is only too conceivable for lack of passive soil resistance 'terminated' owing to the dredging of the river bed. We reached the grayish-blue coloured Pannonian, very rich clay, here and there with a purplish shade of colour, having the following consistency characteristics:

$$\begin{aligned} w_L &= 121 - 134\%, \\ I_p &= 84 - 95\%, \\ I_c &= 0.89 - 0.90, \\ w &\approx 45\%. \end{aligned}$$

We detected the seeping of low intensity on the surface of the Pannonian clay in the presented drilling; then, after having finished the drilling 60 hours later the level at rest of the underground water took place at 3.9 m depth. Later came also the turn of deepening a drilling with 23 m depth in the moving area at the bank (see *Fig.7*). It can be seen that the drill proceeded transversely the loess down to 4.3 m, under which the medium and rich clay strata followed. The clay was in a relatively hard and good condition, however, the sandy sludge above it and below the underground water had a soft and disadvantageous consistency. Here, we reached in 19.2 m depth the light gray coloured plastic rich clay, then in 19.7 m depth the dark gray very rich ($w_L = 123.5\%$, $I_p = 88.2\%$) Pannonian clay, the motion of which can be just excluded.

By means of the specimens obtained from drillings we determined the parameters of shearing strength of the soils playing roll with a view to stability, assisted by direct shearing tests. Low shearing strength was shown by the underwater loess (sandy sludge, silty sand) and the light gray coloured, plastic, rich clay ($\phi = 5.5°$, $c = 16$ kPa) above the Pannonian clay.

5. Investigation of Stability

On the basis of the field experiences and earlier investigations and studies a picture can be got of the mechanism of the motions. As mentioned above, a slow deformation and creeping process were usually observed. The soil mass did not run a circular course. It indicates that the 'focus' of the movement is to be sought in a stratum sloping slightly outwards, in which the shearing strength decreases in consequence of some kinds of effect, conversely, shearing stresses act through

Fig. 3. Tilting of the tree

Fig. 4. Pavement next to the building came out of place

Fig. 5. Sliding movements

the terrain configuration – well outlined drift terraces – so the possibility of local cracks is given. Another question to be cleared is what the reason for the initial crack itself is. It *can have* two *reasons* for that: either the shearing strength, so the resistance, thus the passive force decreases or the stress increases on the 'sliding plane'. The cause for the *decrease in shearing strength* is the increase in the neutral stresses – so in the pore-water pressures (u); then according to the correlation $\tau_s = (\sigma - u) \cdot \mathrm{tg}\,\phi + c$, the shearing strength will be less on account of the decrease in the effective stresses. The precipitation and the water streams seeping from the public utilities (canals, pressure pipe, underground drain pipe) and sewage desiccating plants increase the pressure level of the underground water, it is, however, effected also by the water level of the Danube.

The *increase in shearing stresses* can be certainly brought about by the increase in some kinds of mass forces, since the weight of soil masses touched by the movements is so big, that the importance is insignificant, for example of the increase in weight caused by the possible building operations, compared to the former one. Such kind of mass force is the *stream gravity* that is the force transferred through friction to the soil particles by the underground water seeping towards the Danube. Specific value of the stream gravity per volume unit is proportionate to the specific hydraulic gradient and the gravimetric density of the water ($i_p = i \cdot \gamma_v$), in this way, the increase in the gradient brings an important increase in the resultant of mass forces. The gradient can be increased by the quantity of high precipitation beyond the riverside inclination or the increase in quantity of water seeping from public utilities and desiccating plants; however, it can happen under the influence of the sudden recession of the river.

The factor of safety against the soil motions (ν) is to be interpreted as the quotient of the summed up forces acting against the displacement of the soil mass 'along the strata' and the summed up forces being about to evoke the motion of the mass. That is:

$$\upsilon = \frac{T + E_p}{E_a + S + G \cdot \sin \varepsilon},$$

where T: the resultant of the shearing resisting forces arising in the critical lower plan (deriving from friction and cohesion); E_p: the soil resistance of the mass leaving its place mobilized on the occasion of the start of motion, on the lower 'front surface' from the direction of the Danube, E_a: the active soil pressure giving rise to motion. S: projection of the seepage pressure exercising influence on the mass, directed towards the displacement. G: the weight of the moving soil mass, ε: included angle between the eroding plane and the horizontal. Consequently, ahead of each motion the following were brought about (and can be brought about also from now on): the decrease in the force T by the increase in the pore-water pressure; the decrease in E_p (or its ceasing) by the ablation effect of the Danube (or its bed deepening); the increase in S: by the increase in the gradient of the underground water.

Taking into consideration that mentioned in connection with the subsoil conditions it is *to be rendered probable the development of two sliding planes*. The *one* takes place above the Pleistocene clay nearest to the terrain, at the bottom of the soggy silty sand, sandy sludge, which can protrude up to the foot or to the upper part of the existent retaining embankment. But the *other* 'sliding plane' (the deeper one) can be tracked in the soft, light gray coloured, rich clay of high water content, above the Pannonian clay; and this protrudes up to the dredged river bed. It is probable that in the later case one could not speak about a definite sliding plane, seeing that it is a case of the slow creeping motion of the plastic clay stratum. We effected our stability control tests for both of these cases by means of the above-mentioned mass-method.

The development of the sliding plane near the surface is to be made probable according to the simplified sketch in the *Fig. 8*. The coming into existence of the sliding planes marked 1 and 2 is also conceivable.

For the sliding plane marked 1:

$$G = G^{sz} + G^{v} + G^{n} = 3444 \text{ kN/m},$$

where G^{sz} – the weight of the mass above the underground water,
G^{v} – the weight under the motionless underground water level,
G^{n} – the building load (with 150 kN/m wall load).
G^{k} = 330 kN/m (retaining gravel embankment)

$$T = G \cdot \cos\varepsilon \cdot \text{tg}\,\phi + K + G^{k} \cdot \cos\varepsilon \cdot \text{tg}\,\phi^{k} = 479.1 + 320.0 + 118.9 = 918.0 \text{ kN/m},$$

where $\varepsilon = 8.5°$,
$\phi = 8°$,
$\phi^{k} = 33°$,
$K = c \cdot l = 10 \cdot 32 = 320$ kN/m.

$$E_a = 202.7 \text{ kN/m} \qquad (\phi = 15°, \quad c = 5 \text{ kPa}).$$
$$G \cdot \sin\varepsilon = 509.1 \text{ kN/m}$$
$$G^{k} \cdot \sin\varepsilon = 48.8 \text{ kN/m}.$$

In the case of medium water level of the Danube the stream gravity:

$$S = i \cdot \gamma_v \cdot V' = 173.3 \text{ kN/m} \qquad i = 0.152$$
$$\upsilon = \frac{T}{E_a + S + G \cdot \sin\varepsilon + G^{k} \sin\varepsilon} = \frac{918}{933.9} = 0.982 < 1.0,$$

that means the motion.

In a similar way, we obtained a safety factor $\nu = 0.93$ for the sliding plane 2; that is, the possibility of motion is even higher on this sliding plane.

The case of the deeper sliding plane protruding up to the river bed is to be seen in the *Fig. 9*. Here:

$$E_p = 0 \quad \text{(because of the river bed dredging)}$$
$$G = 7892 \text{ kN/m}$$
$$T = G \cdot \cos\varepsilon \cdot \text{tg}\,\phi + c \cdot l = 757.6 + 902.4 = 1660 \text{ kN/m}.$$

$$\varepsilon = 4°,$$
$$\phi = 5.5°,$$
$$c = 16 \text{kPa},$$

$$E_a = 701.1\text{kN/m}$$
$$G \cdot sin\varepsilon = 550.5 \text{ kN/m}$$

$i = 0.213$ (assuming the connection through the crushed gravel settlements between the underground water to be found in the sludge and the soft clay above the Pannonian clay)

$$S = 276 \text{ kN/m}.$$

That is:

$$\upsilon = \frac{1660}{1527.6} = 1.08,$$

that is little over the 1.0 value and that means that the tested soil mass can also take place on the bounds of the standstill and motion along this deeper sliding plane.

Since the possibility of development of both of sliding plane types could also be rendered probable according to the 'traditional' calculations, one near the surface and another deeper one, we examined the stability question by means of the Plaxis program; that means we modelled the section tested on the preceding, considered critical on the basis of motions, by means of computer-aided finite element test. In the course of the calculations we took into account the soil physical characteristics given in *Figs. 8* and *9*. *Fig. 10* shows the slope model.

The cracking mechanism 'according to computer' as the result of the test is to be seen in *Fig. 11*. Consequently, the possibility of the motion is somewhat higher along the deeper sliding plane protruding up to the river bed (running counter to our mass-method calculation). The minimum safety factor obtained $\nu = 0.946$, that means the motion.

6. Causes of Movement

We can sum up the reasons for the slope motion as follows:

- last autumn the drastic dredging of the Branch of the Danube at Rácalmás, ceasing the passive soil resistance under bottom of the earlier river bed;
- the 'soaking' and pore-water pressure increasing effect of the water originating from the lasting wintery thawing of the snow;
- unfavourable dip conditions and shearing strength characteristics of the slope subsoil;
- the soaking and shearing strength decreasing effect of the belt drain, as underground water level deepening drain, conducted under the canal in the street Kiss E., obstructing in the community the rising of the underground water level caused by the 'public utility gap';
- the continuous flooding of the 'flood plain' before the sand-and-gravel retaining embankment covered with stony talus, by the water from the belt drain and culvert at Rác-köz, further by the underground water collecting in the bearing embankment;

- rising effect on the underground water level of the desiccated sewage in the moving area under the street Kiss E., effluent water from swimming-pool, intensive watering, and the cultivation and landscaping of the earlier grassy area;

- effect of the underground water arriving from the area beyond the street Kiss E., with a level significantly risen in the last ten years.

In the interest of avoiding the further damages of higher extent, moreover a possible catastrophe, it was indispensable to insure against the motion and to increase the safety factor.

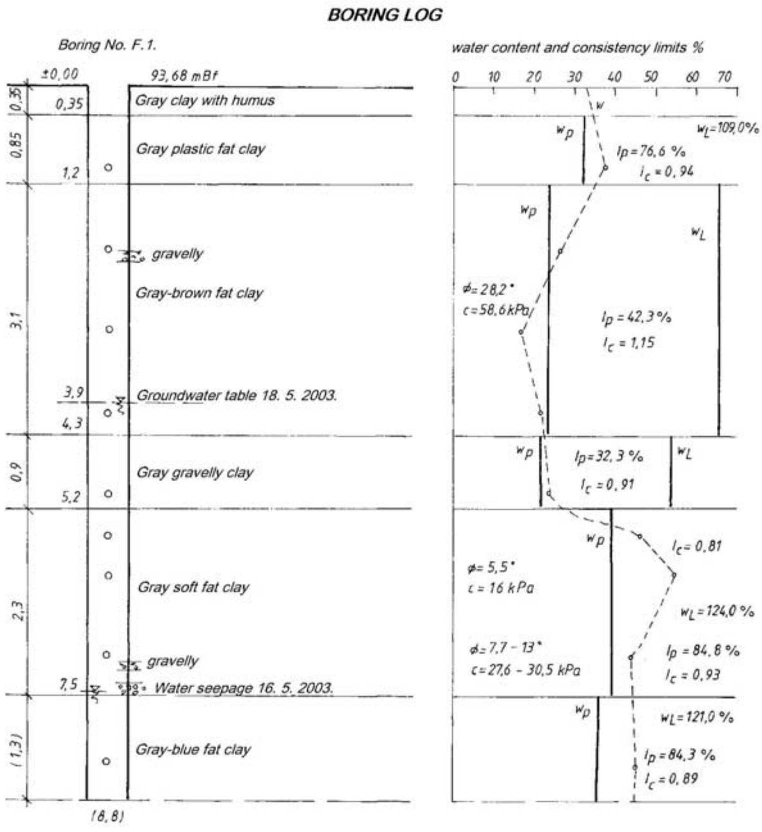

Fig. 6. Soil stratification

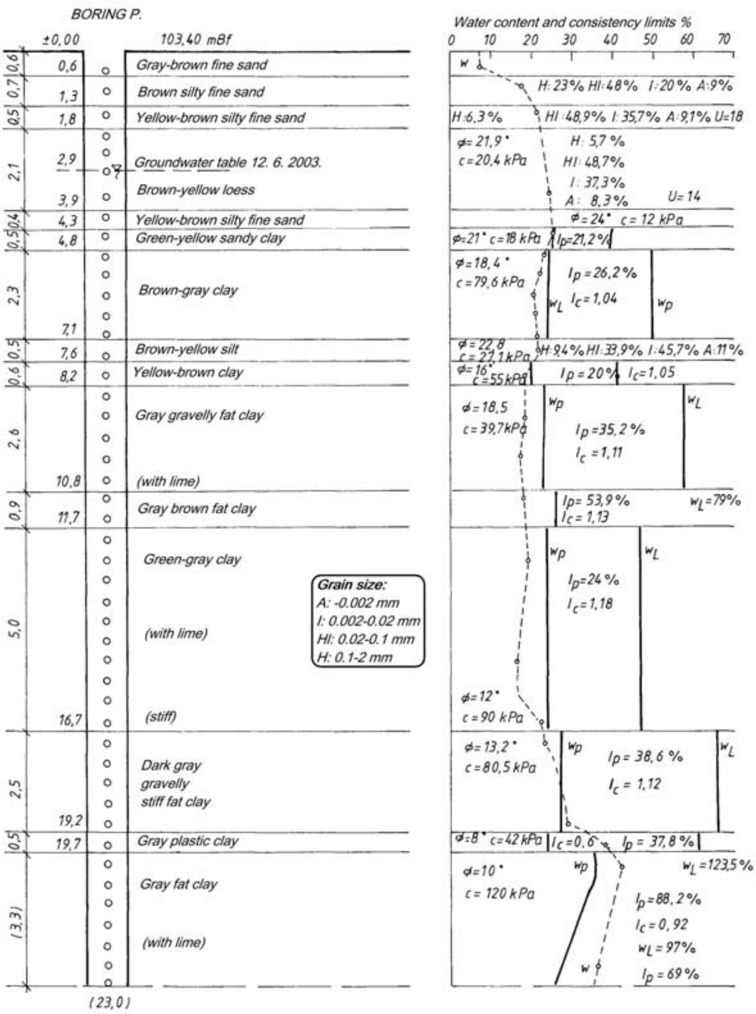

Fig. 7. Deep drilling

7. Possibilities of Stabilization

The recovery after the soil motions near the surface, obstruction of the further sliding movements, deciding the most suitable protecting and stabilizing method are subjects of technical and economic questions at the same time. It is to be taken into consideration the type of motion, the geological, morphological, hydrogeological and climatic conditions. The carefully considered protection reinforced also by stability tests means more than the usual application of a protecting method.

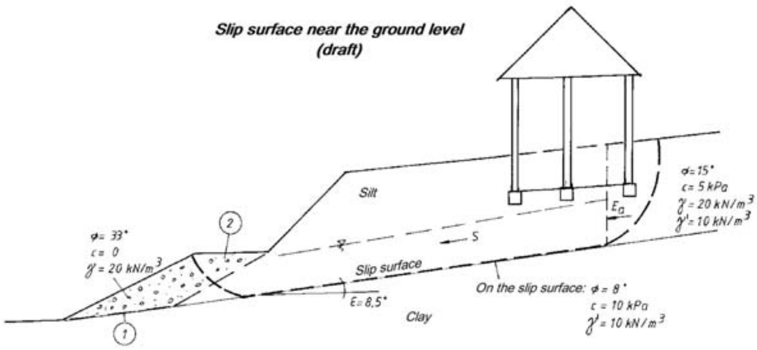

Fig. 8. Slip surface

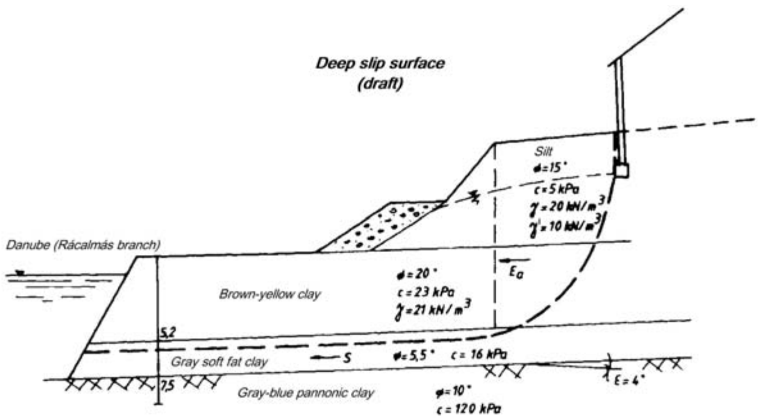

Fig. 9. Deeper sliding plane

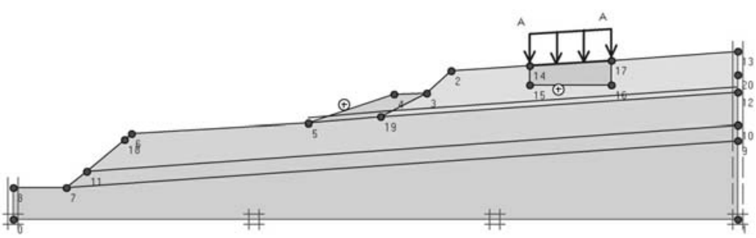

Fig. 10. Slope model

While discussing the reasons for the river wall motion, I have mentioned two main factors as regards the sliding movements, the increase in the shearing stresses and the decrease in the 'available' shearing strength. The recovery, the prevention of the newer motions are to be effected also by two ways: we decrease

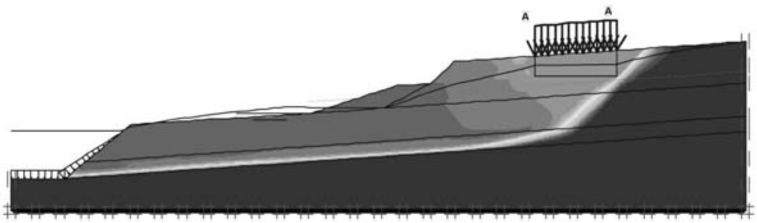

Fig. 11. Cracking mechanism according to computer

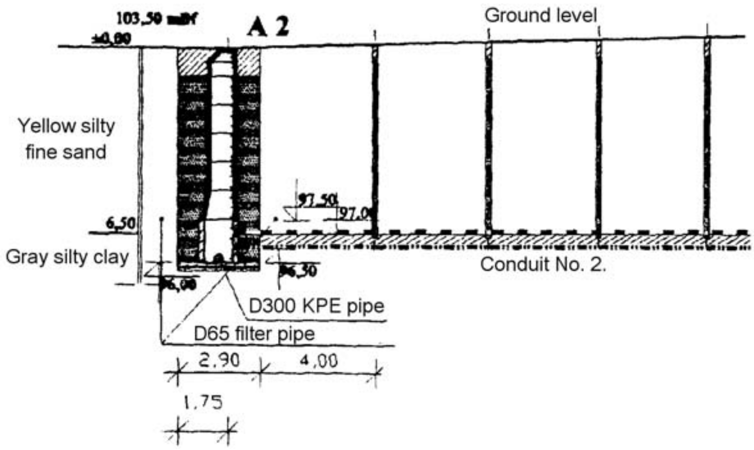

Fig. 12. Stabilization method

the shearing stresses (τ) provoking the sliding or, increase the shearing strength (τ_s) acting against the motion. In the case of stabilizing it is advisable to utilize both effects. All these aim at increasing the

$$\upsilon = \frac{\tau_s}{\tau}$$

ratio, the safety factor.

In the course of choosing the protecting and recovering method it is to be thoroughly considered the extent of the required safety. Increasing the safety factor involves expenses; this is why the economic investigation is indispensable; and the question of risk comes up. Our home design practice regards the solution as lasting, when the safety factor equals at least 1.5. Choosing a value lower than this involves the fact of the assumption of risk. In the international practice, a safety factor lower than 1.5 is used in the case when the designer takes the design data for reliable ones, or the control of the motion of the slope and bank is accomplished, or there is no availability of the financial requirements for the lasting protection assurance.

One of the important tasks is *decreasing the pressure level of the underground* *water*, desiccating the soggy deposits. This can be effected in two different kinds: by means of

- drying – seeping 'stone ribbing'
- water-drain system with bleeder well.

In the case of the solution of *stone ribbing* (retaining ribbing) the retaining ribs filled up with hydraulic quarry stone, coarse gravel, and chippings gravel collect and drain off the underground water and interjacent waters, desiccate the soaked through subsoil having been beginning to move, beyond that, serve also for retaining the soil masses. Each single rib retains of course in that case only if it reaches down beyond the upper potential sliding plane into the solid clay having been remained motionless. So the sliding can not drag off the rib and the friction and adhesion forces appearing on the surface of the rib side exert resistance against the sliding off of the soil mass.

The essence of the *bleeder well method* is that the system of bleeder wells – pit type wells with several radial filtering tubes at bottom – laid out along the street parallel with the Danube, beyond the moving area with about 100 m width minimizes the water reproduction under the surface of the critical soil mass; collects the major part of the water arriving from the hillside behind, above the very area having been beginning to move.

In the street mentioned above, according to the length of the soil mass being in motion, in the line of the pavements on both side, gravel columns with 6.5–9.5 m length and 20 cm diameter, reaching transversely the strata of water conducting loess and sandy sludge, should get fitted into the clay below them, in about 4 m distance each from the other.

In the top section with a length of 1 m of the gravel columns a clay plug will be made for saving the seepage system from getting surface water (precipitate) into it.

The water from the gravel columns is conducted off by the bottom (almost horizontal) wrapped leg pipes developed of pressed PVC filtering tubes with 65 mm or 90 mm diameters, built in by directed boring (see *Fig. 12*).

Both of mentioned stabilization methods obstruct directly only the development of the sliding plane taking place nearer to the terrain and increase only indirectly to a less degree the safety factor against shearing of the mushy clay stratum running deeper and protruding up to the river bed – by decreasing the pore-water pressure, the water reproduction, and the stream gravity. The safety against the motion along the 'sliding plane' protruding up to the river bed could be 'drastically' increased by the building of *seeping – retaining ribs* (located perpendicularly to the bank) on the area between the low water mark river bed and earlier built sand-and-gravel retaining embankment at the river wall footing or, by means of a pile row located in this place, fixed in the Pannonian clay.