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SEEPAGE AROUND STRUCTURES BUILT INTO FLOOD LEVEES

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Abstract

In connection with a research of wider scope, a threedimensional electric analog study of a characteristic culvert built into the flood levee of the Danube at Karászi-fok was carried out at the Department of Hydraulic Engineering, Technical University of Budapest. Both the concrete numerical results and the general conclusions are interesting and informative enough to be published for the profession.

Keywords: seepage, hydraulics.

1. General Background

As a result of the river training works, mainly of the last one and a half century, many meandering sections of the rivers in Hungary – just as elsewhere – have been cut down from the river and have become dead branches having just limited contact through some interconnecting canals, with the river.

The separation became particularly strong when a new flood levee was built between the dead branch and the river, across the mentioned interconnecting canal. Communication between the two water spaces nowadays can occur only through a hydraulic structure built at the crossing point of the interconnecting canal and the levee, mostly a culvert with a sluice, which is to be closed when the flood arrives.

Through this culvert, in no-flood periods, the precipitation run-off from the catchment area of the dead branch can flow to the river, while in dry periods, when the dead branch loses much water because of evaporation, the water needed can be supplied from the river, when it has a higher stage. (Big crossing structures are completed with pumping stations as well, but for our present purpose it does not make any considerable difference.)

When the flood arrives, the culvert, closed in that period, is a crucial point of the flood levee for the higher degree of seepage in its neighbourhood, partly because of eventual imperfect compaction of the soil closely to the structure, partly because of the low level of the bottom of the interconnecting canal at both ends of the culvert, minimizing the length of the seepage streamlines and increasing the piezometric head difference between its two ends.

2. The Karászi-Fok Culvert

The *longitudinal section* of the interconnecting canal across the levee and through the culvert, and the *plan* of these with the neighbouring area, in the case of the rather typical Karászi-fok culvert, can be seen in *Fig. 1*. The neighbouring area developed from the bottom of the throat of the former meander. As a consequence of the serial inundations of the dead branch by the floods of the river, a low permeability top layer of clay and silt has settled down mainly in this throat, on the top of the sandy layer of the bottom of the former meander, and now this top layer constitutes the throat of the dead branch bordered by the natural flood plain. The bottom of the throat is still of somewhat lower level than the natural flood plain. The throat is 200 m wide. In the middle of the throat the interconnecting canal was excavated. This is crossed by the flood levee, through which a culvert ensures the communication of the water between the two parts of the canal, i.e between the river and the dead branch. The culvert has a sluice gate in the middle of its length, which can be manipulated from the top of the flood levee. The base width of the flood levee is 50 m. The river bank edge is at 145 m from the axis of the levee.

The thickness of the top layer can be considered as constant 2 m. Its Darcy coefficient is $k = 10^{-7}$ m/s. The specific weight of the wet (saturated) top layer is $\gamma_w = 20$ kN/m^3.

The sandy layer under it is 32 m thick. Its Darcy coefficient is $k = 10^{-4}$ m/s. The specific weight of the grains of the sandy layer is $\gamma_s = 26.5$ kN/m^3, its porosity $n = 0.4$. The critical exit gradient of the sandy layer $S_{\mathrm{cr}} = (\gamma_s - \gamma)(1 - n)/\gamma = 0.99 \cong 1$, where γ is the specific weight of water.

The Darcy coefficient of the levee is $k = 10^{-7}$ m/s.

The bottom of the interconnecting canal levels with the bottom of the top layer. From the point of view of infiltration the canal can be substituted by a 4 m wide strip at the bottom.

3. The Electric Analog Model

The threedimensional analog model to the scale 1 : 250 mapped the area shown in *Fig. 1* from the top down to the bottom of the sandy layer. Horizontally it expanded to a 100 m wide area on one side of the axis of the interconnecting canal, as the axis of symmetry of the throat, between ±145 m from the axis of the flood levee (from the river bank edge to a section in which the ground water piezometric line could be considered as horizontal). In the top layer the vertical seepage component was only considered, since the horizontal seepage in this layer is insignificant, compared with that in the sandy layer. The seepage through the top layer was either calculated, or – when it was necessary – modelled by a perforated plastic plate.

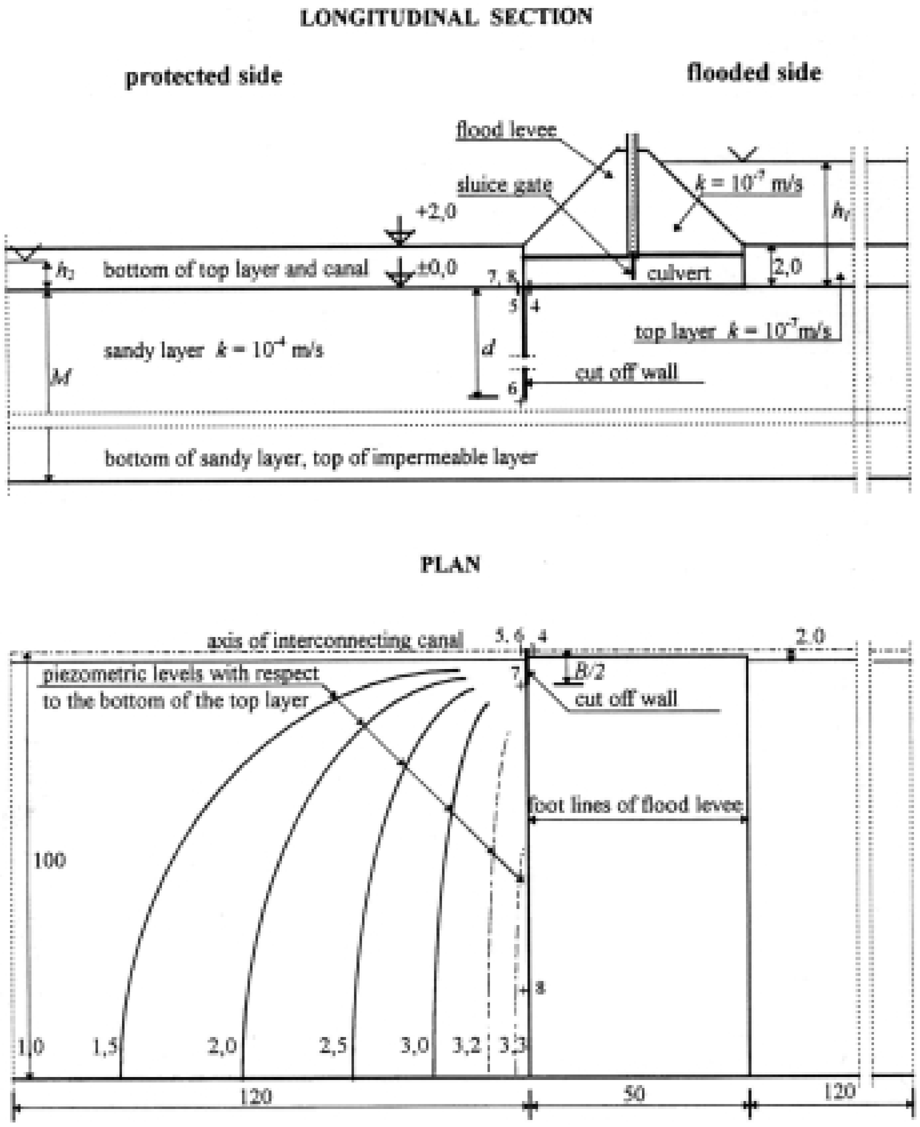

Fig. 1. Piezometric levels on the protected side of the levee with respect to the bottom plane of the top layer $h_1 = 7$ m, $h_2 = 1$ m, $d = 7$ m, $B = 15$ m, $M = 32$ m

4. The Measurements and their Results

During the measurements 25 variants were investigated, partly to draw generalized conclusions, partly to learn about details, important particularly for the reinforcement of the Karászi-fok structure. Here only the most important results will be treated.

The measurements involved those of the piezometric level along the bottom of the top layer and around the cut off walls, and the exit gradients in the interconnecting canal at characteristic points. The datum level of the piezometric system was at the bottom of the top layer. Also the discharge of the seepage under the levee was measured.

1. As first step, the case when *just the levee crosses the dead branch but there are no culvert and interconnecting canal* was studied. This case was determined by the maximum flood level ($h_1 = 7$ m) and for fully saturated but not inundated top layer ($h_2 = 2$ m), which is most unfavourable from the point of view of lift on the bottom of the top layer.

   These conditions resulted in a crucial situation near the protected side foot of the levee, because there the uplift, with $h > 4$ m, on the bottom of the top layer overpassed the own weight of the 2 m thick top layer in a 25 m wide zone along the foot of the levee.
2. The further investigations concerned *the arrangement with the interconnecting canal and the culvert-sluice structure*. In this case the task was to discover to what a degree the cut off walls, joining the flooded end and the protected end of the culvert, influence the lift forces exerted on the top layer on the protected side of the flood levee.

   The sizes of the cut off walls were vertically $d = 5$ m downward from the bottom of the top layer, and horizontally $B = 24$ m. Piezometric levels at points indicated on the Figures:

   Boundary conditions: $h_1 = 7.00, \quad h_2 = 1.00$
   (half full canal),

   Measured values:
   Without cut off wall: $h_7 = 2.45, \quad h_8 = 3.33$
   With cut off wall: at the flooded end: $h_7 = 2.42, \quad h_8 = 3.33,$
   at the protected end: $h_7 = 2.28, \quad h_8 = 3.33,$
   at both ends: $h_7 = 2.26, \quad h_8 = 3.33.$

   These results show that the cut off walls do not influence the seepage along the protected foot of the levee, and the same can be said near to the protected end of the culvert, if the cut off wall is deepened at the flooded end of the culvert. There is a slight effect, if the cut off wall is deepened at the protected end of the culvert.

   From the measurements it could be seen that the exit gradient S on the canal bottom near to the protected end of the culvert is around the critical $S_{cr} \approx 1$.

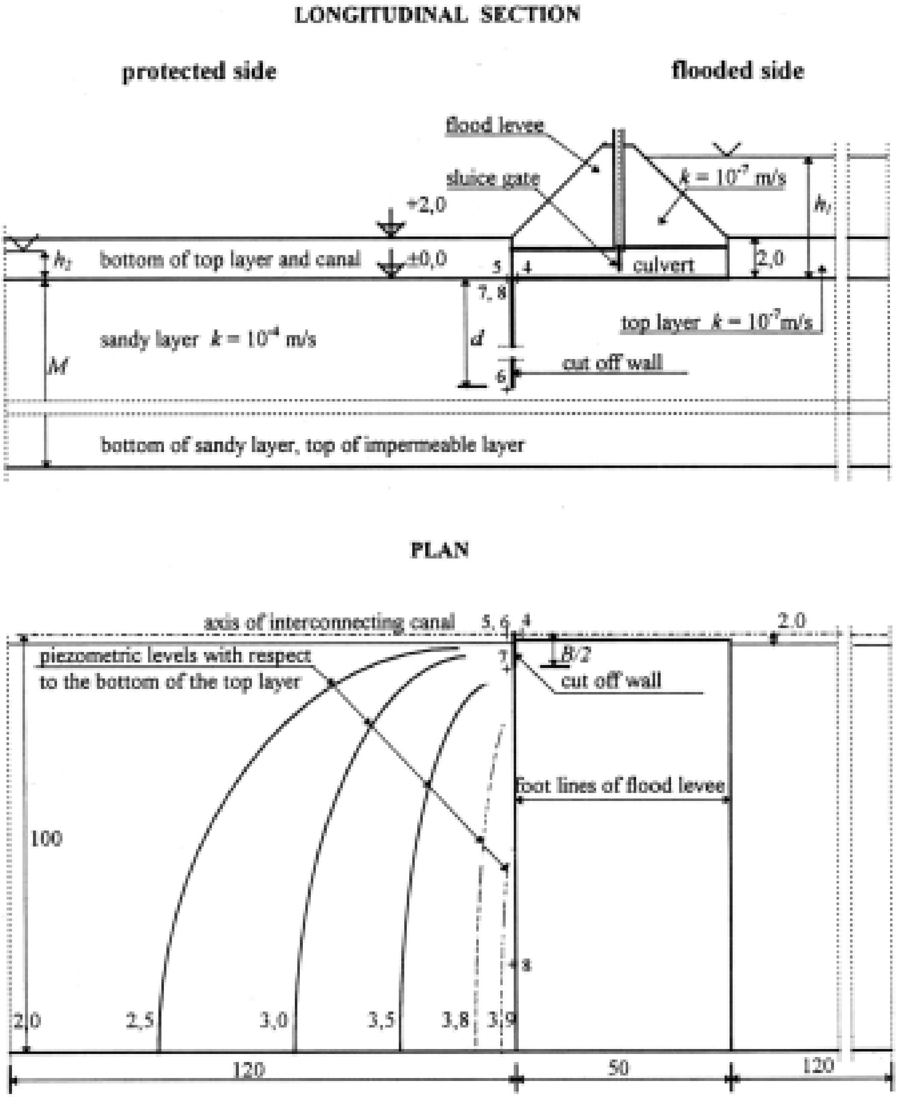

Fig. 2. Piezometric levels on the protected side of the levee with respect to the bottom plane of the top layer $h_1 = 7$ m, $h_2 = 2$ m, $d = 5$ m, $B = 20$ m, $M = 32$ m

3. Evidently, S increases more, if h_2 decreases. The gradient can decrease if a cut off wall is applied at the protected end of the culvert. It is recommended if the required security ratio is $S_{cr}/S \approx 1$. On the basis of the measurements it seemed satisfactory, if $d = 7$ m and $B = 15$ m. For the *extreme case*

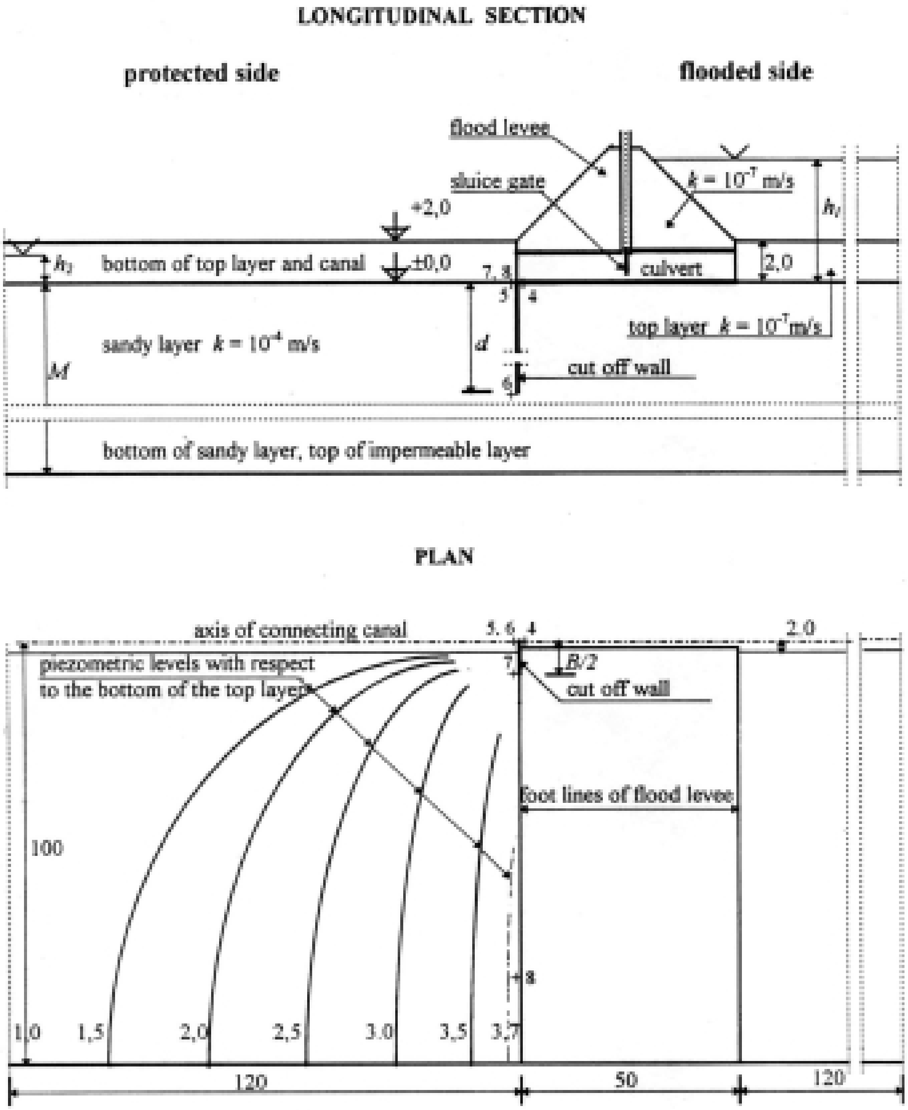

Fig. 3. Piezometric levels on the protected side of the levee with respect to the bottom plane of the top layer $h_1 = 8$ m, $h_2 = 1$ m, $d = 7$ m, $B = 15$ m, $M = 32$ m

($h_1 = 7$ m, $h_2 = 1$ m) *Fig. 1* shows the distribution of the piezometric head on the bottom of the top layer, as datum level, on the protected side of the levee.

The average hydraulic gradient along the protected side of the cut off wall in

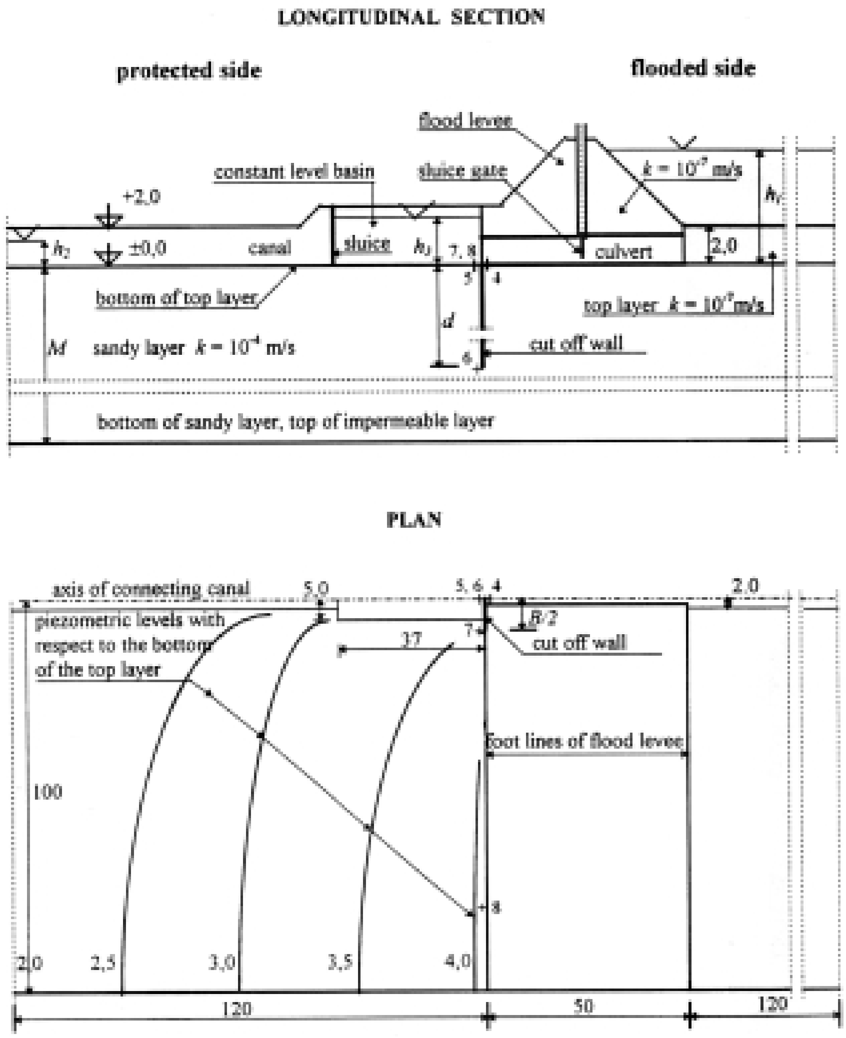

Fig. 4. Piezometric levels on the protected side of the levee with respect to the bottom plane of the top layer $h_1 = 7$ m, $h_2 = 2$ m, $h_3 = 3$ m, $d = 7$ m, $B = 15$ m, $M = 32$ m

the vertical of point 5 can be calculated as $S = (h_6 - h_2)/d$.

In the present case $h_6 = 2.9$ m, therefore the security factor of the canal bottom is $n_b = S_{\text{cr}}/S = 0.99/0.27 = 3.64$, i.e. there is no danger of hydraulic soil failure.

Along the top layer all the piezometric values are lower than the critical

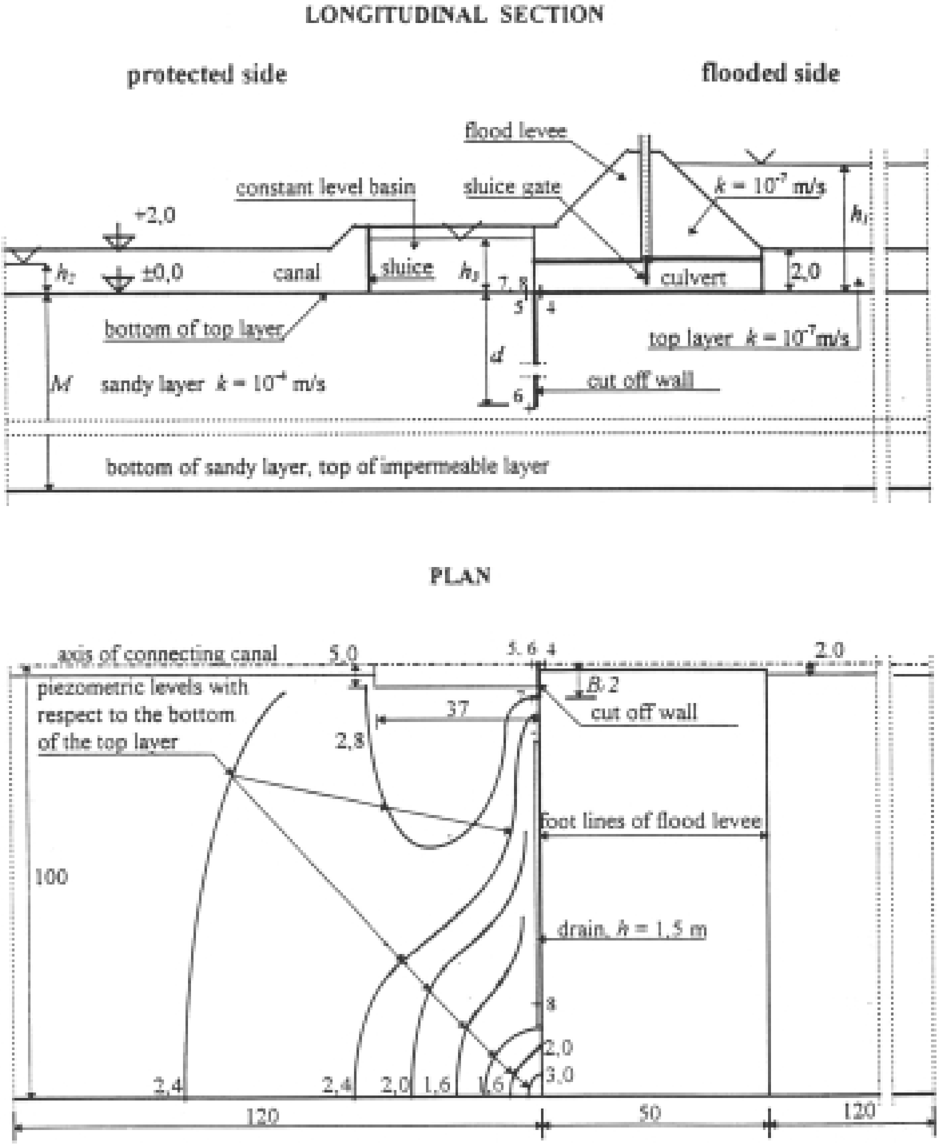

Fig. 5. Piezometric levels on the protected side of the levee with respect to the bottom plane of the top layer $h_1 = 7$ m, $h_2 = 2$ m, $h_3 = 3$ m, $d = 7$ m, $B = 15$ m, $M = 32$ m

$h_{\text{cr}} = 4$ m, so there is no danger for the lift of the top layer.

4. From the point of view of *the possible lift of the top layer* a more dangerous situation is (*Fig. 2*), when $h_1 = 7$ m and $h_2 = 2$ m, and d is only 5 m, though $B = 20$ m. Since h is everywhere smaller than 4 m, there is no lift danger

for the top layer. The security against soil failure on the bottom of the canal at the crucial point nr. 5 is also satisfactory: $S_{cr}/S = 3.62$.

5. *Fig. 3* considers the *extreme flood attaining the crest of the levee* ($h_1 = 8$ m) but the interconnection canal is just half full ($h_2 = 1$ m), and the cut off wall sizes are $d = 7$ m and $B = 15$ m.
   The security against soil failure on the bottom of the canal is $S_{cr}/S = 3.11$, and also the lift onto the top layer is under the crucial.
6. The investigations involved also *different variants for an elevated level basin formed of a part of the interconnecting canal joining the protected end of the culvert*. The purpose of this arrangement is to decrease the hydraulic gradient in the interconnecting canal. Nevertheless, this measure at the same time contributes to the increase of the lift exerted to the bottom of the top layer (*Fig. 4*). The lift is modified also by the effective thickness of the sandy layer: bigger thickness – higher lift, smaller thickness – lower lift.
7. In this respect a countermeasure can be *the application of a drain along the protected foot of the levee*. In the drain, however, protective measures must be applied against soil failure in the drain itself. About the result of such a *combined arrangement (elevated level basin plus additional drain) Fig.5* shows an example. These studies have not yet been finished.

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