# ASSESMENT OF THE LEVEE SLOPE STABILITY AT LABOREC RIVER, SLOVAKIA

**Slavka Harabinova[1], Vlasta Ondrejka Harbulakova[2]*, Martina Zelenakova[2]**

[1] Technical University of Kosice, Faculty of Civil Engineering, Department of Geotechnics and Traffic Engineerng, Vysokoskolska 4, 042 00 Kosice, Slovakia
[2] Technical University of Kosice, Faculty of Civil Engineering, Department of Environmental Engineering, Vysokoskolska 4, 042 00 Kosice, Slovakia

## Abstract

Levee failures due to floods may results in extensive damage to agricultural land, rural and urban infrastructures as well as human. Manuscript deals with failure and the calculation and assessment of stability of right bank protective levee at Laborec River, and suggests possible remedial measures, such as stabilizing mound, raising the levee crest and drainage of levee body. Classification of embankments, legislation dealing with protective embankments and valid standards, designing and description of failures of protective levees are also briefly mentioned in the paper. GEO 5 programme for geotechnics calculations using Petterson's and Bishop´s methods were applied for levee stability assessment. Calculations were done for more alternatives. Better results were found out according to applying Bishop´s method.

## Key words

Bishop´s method; GEO 5; Petterson's method; stabilizing mound

To cite this paper: *Harabinova, S., Ondrejka Harbulakova, V., Zelenakova, M. (2014). Assesment of the slope stability of levee at the Laborec River, Slovakia, In conference proceedings of People, Buildings and Environment 2014, an international scientific conference, Kroměříž, Czech Republic, pp. 568-576, ISSN: 1805-6784.*

*Corresponding author: Tel.: +421-55-602-4269, Fax: +421-55-602-4331
E-mail address: vlasta.harbulakova@gmail.com

# 1 INTRODUCTION

The designing a levee should take into account various technical aspects, as well as interference in the country and the impact on flora and fauna [1]. Solution should be developed in alternatives; the resulting design should be the most suitable option in terms of reliability, of economy, efficiency and environmental acceptability [2]. Shape of the levee cross section, mostly trapezoid shape is given by requirements, such as the location of the levee, the planned height, the purpose, as well as building material and the nature of the subsoil [2, 3]. In the past, cross-sectional shape and arrangement depend on local materials that are available from the slopes of the river bed in the vicinity of the levee [4]. Slope of the levees are designed according to the composition of soil, where the proposal is based on an assessment of the stability and seepage-shaped curve, but also other factors, such as the inclusion of the levee into the surrounding of landscape, maintenance of the levee, the availability of materials for the construction [2], [5]. For lower levees proposes the same slope for both sides is typical. For levees up to 3m height, inclination 1:2 to 1:2.5 is a common tendency. The propositions for higher levees are slopes with different slope on the upstream and downstream slopes. The slope of the levee over the height may not be uniform. At the bottom (at the base) is moderate in the upper parts (the crest) is steeper Levee is an elongated naturally occurring ridge or artificially constructed fill or wall, which regulates water levels. It is usually earthen and often parallel to the course of a river in its floodplain or along low-lying coastlines [6]. The main purpose of artificial levees is to prevent flooding of the landscape nearby territory and to slow natural course changes in a waterway to provide reliable shipping lanes for maritime commerce over time; they also confine the flow of the river, resulting in higher and faster water flow. Levees can be mainly found along the sea, where dunes are not strong enough, along rivers for protection against high-floods, along lakes or along polders. Furthermore, levees have been built for the purpose of empoldering, or as a boundary for an inundation area. Currently, frequent flood events are taking place in our area. Floods are a significant factor in the urbanized landscape. The intensity and frequency of rainfall, as well as snow melting, are capable of causing extreme runoff and subsequent flooding in Slovakia, and have significantly increased in recent years. Floods are destructive and cause damage to human society. They are associated with high water levels and extreme water flow in the river beds [7]. Floods are also associated with rapid erosion processes, which involve the destruction of land resources and consequently may lead to landslides of drenched soil, not only on the slopes of the rivers [8]. In 2010, severe floods hit most of the territory of the Slovak Republic. It was the biggest flooding in last 50 years.

# 2 CHARACTERISTICS OF THE AREA – LABOREC LEVEE

Laborec River is 129 km long, flowing through region almost entire Zemplín territory from north to south. Catchment area of Laborec is 4 522.5 km², while the left catchment has area of 4 076.7 km² and the right catchment area is 445.8 km². This striking difference is conditioned by basin morphology and by tributary river Uh, which significantly increases area of river basin on the left. On the right side Laborec creates a riverbed almost parallel to the flow of river Ondava and it has also influence on the size of catchment area [9]. Stedy are is the right levee of Laborec River, southern from the village Oborín (Fig. 1). It was built in 1964 and belongs to the project of adjustments of water structures of Eastern Slovak lowlands, which lasted from 1961 to 1968.


*Fig. 1: Study area [10]*

For calculation and assessment of slope stability, it is necessary to know the exact geological profile of levee, which was identified using the in-situ works. Geological profile of the levees body and levees bedrock is shown in Fig. 2. Geotechnical parameters of soils located in the body and in the subsoil of the levee were detected by laboratory tests [9].

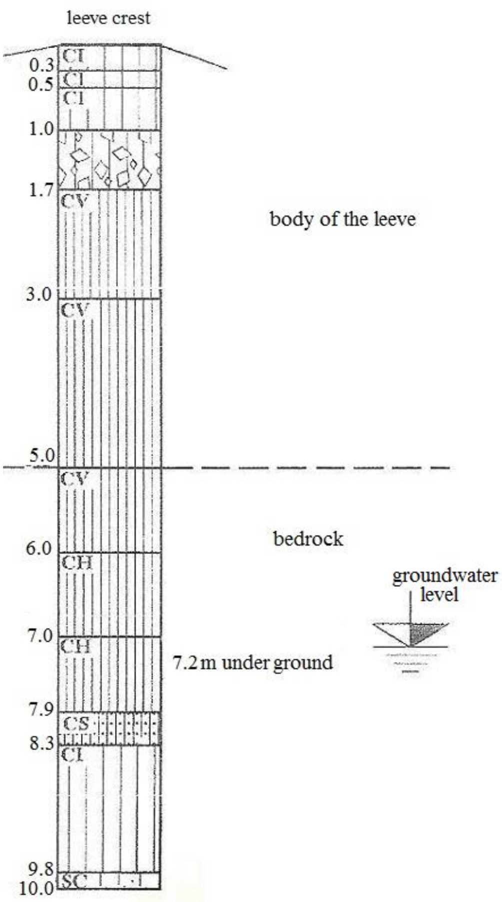


*Fig. 2: Geological profile of the levee body and its bedrock in the place of disturbance [9]*

The levee is a homogeneous and its construction material is from its surroundings. Height of the levee body is up to 5 m. In terms of use it is understood as a major levee. Level of groundwater was found at a depth of 7.2 m below the levee crest. This water is percolating from sands verified at a depth of 10.0 m below the levee crest. Groundwater level is increasing mainly during the flooding. According to information from the catchment area, a landslide of downstream face of a levee was originally seen on 21st May 2010, at 3.4 kilometer, along the right bank of the river Laborec, in length about 20m, with a decrease of soil about 30cm. Occurrence of landslides were observed during the following days. On 25th May 2010, cracks in the landslide were stabilized with Bentovet K (bentonite) [9]. Between 2nd June and 5th June 2010 further decline in soil has occurred. On 2nd June 2010, the enlargement of crack and further declination of the levee crest and downstream slope of about 30cm occurred, without visible landslide. On 3rd June 2010, levee crest and downstream slope decreased for approximately 10cm. Extension of crack continued on 4th June 2010 by a further decline in crest and downstream slope approximately for another 20cm. At this stage, landslide was associated with expanding on both slopes along the levee. At 20:00 the 3rd degree of flood activity at critical water level was subsequently declared. The water level was about 1m from the levee crest at the site of the landslide. At the time of inspection failure (27th July 2010) the edge of detached area intersects the crest of the levee that was breached in a length of about 26m. Decrease of the levee at the site of detached edge was 30 to 40cm [9].

Causes of these failures were most likely [11]:

- The material used for the construction of the levee - cores with very high plasticity (CV) which are less suitable for homogeneous dikes because of their strength when saturated with water is small and very difficult to be compacted,
- prolonged extremely high water levels in Laborec river - flooding that allowed long-term saturation of earth levee body.

The result of these two factors was subsequently loss of strength and the failure of the levee.

Figure 3 depicts the current status of the affected part of the levee; view on the failure of the levee crest is from the village Oborín. On the right side (downstream face of a levee), landslide can be seen. Since 2010, when the fault occurred, levee became completely grassed, and therefore can be identified only by the irregularity of the slope.

*Fig. 3: Disturbance of the leeve on downstream face*

Crest has been levelled for the need of communication fluidity. Given that the flood and landslide occurred 4 years ago, created a new tensile stress state of the levee and the slope can now be considered as "stabilized". In the event of another flood of similar or larger scale, this stability would again be disturbed.

## 3 STABILITY OF LEEVE SLOPES ASSESMENT

As a result of an imbalance there are often excessive distortions and landslides of natural slopes as well as man-made earth slopes and bodies. Violation can be induced by stature active factors (e.g., load of slope by construction, own weight raising caused by increase of soil moisture, seepage of water pressure formation, etc..) or by a decrease in passive factors (e.g., reducing the shear strength of soil due to swelling after unloading the notch, deterioration of consistency of cohesive soil by moisture increase, undermining the slope heel, etc.) [12]. The slope must therefore be designed to ensure its stability.

Currently several methods of calculating slope stability based on the balance of forces, moments or energy balances are used. Most often these are calculations based on the assumption that failure occurs towards shear surface (Petterson, Bishop and the Sarma method). The shape of shear surface depends mainly on the physico-mechanical characteristics of soils or by their arrangement in the profile, respectively.

Calculation and assessment of slope stability of Laborec levee was carried out by using “Slope stability”, which is a sub-program of GEO 5 from company FINE Ltd. [13]. The body of the levee is made up of fine-grained soils, it is assumed that the shear surface is formed a circular shape. That is reason why Petterson and Bishop method was chosen for calculation and assessment of the stability of the levee slopes.

Using the methods of calculation mentioned above was found the minimal degree of stability for the critical shear surface for any proposed variants. The calculation was carried out in accordance with the Slovak standards. The degree of slope stability can be defined as the ratio of the forces contributing to the stability, the stability of the shrinking forces, i.e. the ratio of active and passive forces. Calculation of slope stability has been made in accordance with DIN EN 1997 [14]. The calculated degree of stability was compared with the limit value of stability degree.

The levee slope stability assessment was made on the downstream slope of the levee, i.e. at the area of the levee failures, in five cross sections (in river km 3.4 to 4.0). Calculation of slope stability of downstream face was realized in several variants.

### Variant I and II

The first calculation was made for the original condition of the levee, i.e. before the flood in 2010 (Variant I), further calculation was carried out for flood conditions that arose in 2010 (Variant II). Due to the location of probes (Fig. 4) was for the stability assessment of slope in transverse sections 70 and 72 considered the geological-engineering (GE) profile according to core holes JO-3, and for the sections 74 and 76 it was made according to the GE profile core holes JO-4. The results of the calculation of mentioned variants, for the selected cross sections, are shown in Tab. 1 and 2 [11].

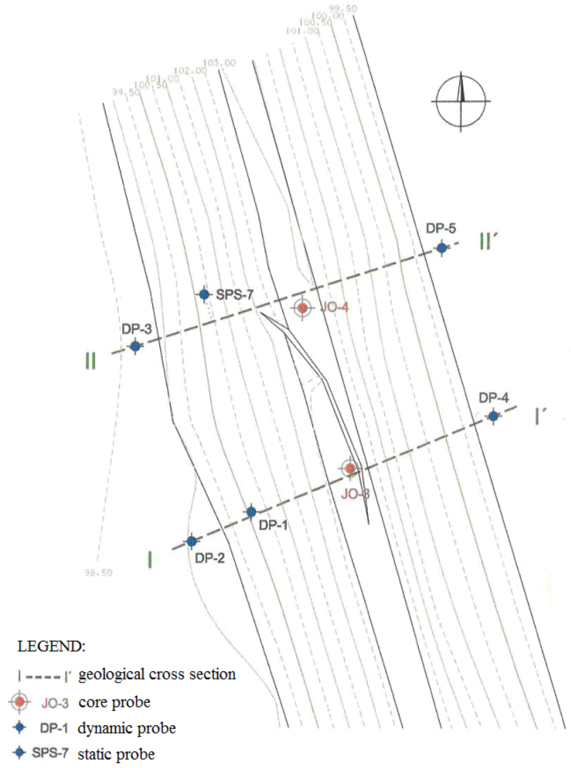


*Fig. 4: Situation of the probes in selected area*

Based on the calculations and the results listed in Table 1 and 2 it can be seen that the stability of slopes did not satisfy the assessment of slope stability before the flood situation (Variant I), except the cross-section No. 72. These results point to the remediation of levee requirement probably not only in the part where the failures are visible after the flood.

*Tab. 1: Degree of slope stability for selected cross sections of Variant I*

| **Number of variant** | **Cross Section** | **Method** | **Stability Degree** | **Degree of required Stability ($F_s$ > 1.5)** |
|---|---|---|---|---|
| Variant I | 70 | Petterson | 1.43 | unstable |
| | | Bishop | 1.54 | stable |
| | 72 | Petterson | 1.54 | stable |
| | | Bishop | 1.66 | stable |
| | 74 | Petterson | 1.24 | unstable |
| | | Bishop | 1.32 | unstable |
| | 76 | Petterson | 1.33 | unstable |
| | | Bishop | 1.43 | unstable |

*Tab. 2: Degree of slope stability for selected cross sections of Variant II*

| Number of variant | Cross Section | Method | Stability Degree | Degree of required Stability ($F_s$ > 1.5) |
|---|---|---|---|---|
| Variant II | 70 | Petterson | 0.96 | unstable |
| | | Bishop | 0.99 | unstable |
| | 72 | Petterson | 1.02 | unstable |
| | | Bishop | 1.06 | unstable |
| | 74 | Petterson | 0.85 | unstable |
| | | Bishop | 0.85 | unstable |
| | 76 | Petterson | 0.90 | unstable |
| | | Bishop | 0.91 | unstable |

Because all grades of calculated stability are greater than 1, we can assume that breach of stability would not happen, but there is necessity for action.

Variant II, which reflects flood situation showed that the levee during flooding with water up to the crest is unstable and prone to failure (assessed in all cross sections $F_s$<1.0). It confirms the flood situation in 2010.

## 4 PROPOSED REMEDIATION MEASURES

Remediation proposal was made because of the availability of the materials used for the rehabilitation and financial undemanding of this solution.

As a first method of remediation measures to ensure slope stability of downstream slope of a levee was proposed additional load of the slope heel. Riprap slope stabilization of local material is simple to implement availability of the material. This is the financial undemanding solution. The most common local materials are clays with very high plasticity, solid consistency (CV, t). This material is not very suitable, little awkward, but given the fact that the entire levee was built so far from local (readily available) materials and has been as one of the alternatives for the design of remediation measures used for this, although not well suitable material – Variant III-A.

A second option Variant III-B was chosen material from the surrounding area of the levee, and the clays with moderate plasticity, also solid consistency (Cl, t), which are more suitable for making riprap slope stabilization, because they can be better compacted. For comparison there was chosen a third option - gravel well granulated, compacted (GW, u), Variant III-C, which is the best for making the riprap slope stabilization.

After the modeling of various shapes and heights of riprap slope stabilization of the downstream face, the most suitable solution, the double riprap of the same material has been proposed. First riprap is 1m below the crest and a slope is about 1: 3.2 and the second riprap is 2m under the levee crest in slope 1: 4. The water level in the design was considered at two levels. Initially has been considered as in Variant I, i.e. water level before the flood situation. Further calculations were made in consideration of the water level as in Variant II, i.e. during flood events. In this way, we wanted to verify the stability of the proposed remediation action in the event of another flood situation.

Based on calculations using the GEO 5 it was found most unfavorable shear stress area in the cross sections and based on that was realized the degree of slope stability. These reults was compared with the desired stability degree. The following figure 5 shows the shear stress area of the cross-section No. 74 of riprap slope stabilization made of gravel (Variant III-C).

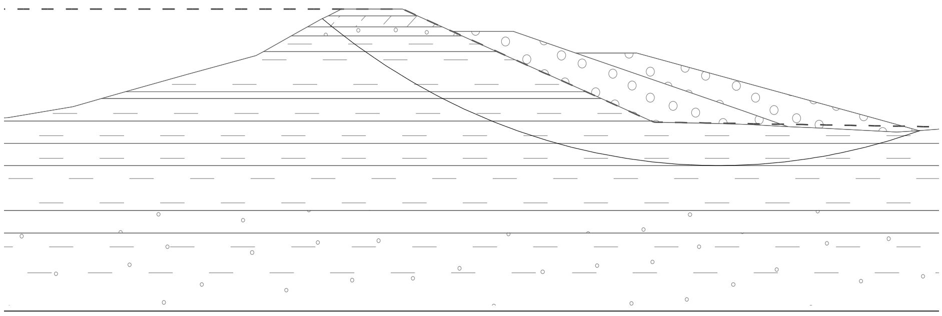

*Fig. 5: Pettersons´s method: Shear stress area after optimization - Variant III-C*

Next, considering the large number of results there are few verbal evaluations presented of established degree of stability and their comparison with the desired degree of stability.

The aim of the riprap slope stabilization of the heel on the downstream face of the levee was to achieve a higher degree of stability than 1.5, thereby improving the stability of the slope itself. Proposal of three variants of riprap slope stabilization (Variant III. - A to C), in which material were varied should point on increased stability when using more suitable soils. Implemented on the basis of calculations and assessments, it is clear that the stabilization riprap (the Variants III-B and C) is certainly one of the possible remediation measures, but probably not sufficient for solving the stability of downstream slope for potential further flood situation. In modeling such a new flood situation similar to situation in 2010, when the water level reached the crest of the levee, this measure did not show as sufficient.

## 5 CONCLUSION

Levees are considered as significant structures and therefore it is needed to pay high attention not only to the choice of materials intended for their construction but also for the design and assessment of these constructions. Because of their importance, security and reliability throughout their lifetime remains the top priority.

This paper is aimed on addressing slope stability and design of remediation of right bank levee of the Laborec river, where during the floods in 2010, the landslide of downstream slope on km 3.4 to 4.0 occurred. To assess the stability of downstream slope before and after the flood, as well as for the design of remediation measures calculations were made for the degree of stability in several versions (original condition, flood status and remedial measures - stabilization using different materials). Remedial (remediation) measures were designed and evaluated in order to make the most of available local materials and to design cost and time-saving solutions to ensure slope stability of Laborec downstream face of the levee.

As it was mentioned before, in variants III-B and III-C was successfully proposed solution to improve the desired degree of stability, but the modelling of possible future flood conditions would be so insufficient in the terms of remedial actions.

Listed and calculated variations of the dam slope stability solutions analyzed several options to address and improve the stability downstream slope of the levee after the flood. In view of the fact that the body of the levee is made of fine grained soil class F8, i.e. unsuitable soil, it will be necessary to deal with remediation measures, which could possibly improve stability across the levee. However, it is already a cost and time-consuming solution, which we want to address in the future.

## ACKNOWLEDGEMENT

The contribution is written thanks to support of project VEGA 1/0609/14.

## REFERENCES

[1] Synkova, J. (2009). Možnosti využití usměrňovacích staveb v rámci revitalizace toku. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis,* **62**(5), pp. 279-284.

[2] The Act no. 50/1976 Z.z. on Spatial Planning and Construction (Building Act), 1976 /in Slovak/.

[3] Slezingr, M. and Fialova, J. (2012). An examination of proposals for bank stabilization: the case of the Brno water reservoir (Czech Republic). *Moravian Geographical Reports.* **20**(2), pp. 47-57. available on: http://www.geonika.cz/EN/research/ENMgr/MGR_2012_02.pdf

[4] Zelenakova, M. et al. (2012). *Design, performance and operation of selected water structure*. Košice: Technical University. ISBN 978-80-553-0939-2.

[5] Svecova, A., Zelenakova, M. (2005). *Water structures*. Kosice: Technical Univeristy, ISBN 80-8073-443-7.

[6] Petroski, H. (2006). Levees and Other Raised Ground. *American Scientist*. **94**(1), pp. 7–11.

[7] Říha, J. and Smelik, L. and Uhmannova, H. (2011). Příspěvek k povodňové problematice vybraných obcí ve správním území státního podniku Povodí Ohře, *Vodní hospodářství,* **61**(11), pp. 406-409. /in Czech/

[8] Smelik, L.; Rousar, L.; Uhmannova, H. (2012). Porovnání způsobů stanovení zrnitostních křivek materiálu dna, příspěvek na konferenci *Vodní toky 2012 - Odborná konference s mezinárodní účastí,* Hradec Králové, Lesnická práce, s.r.o., Kostelec nad Černými lesy. /in Czech/

[9] Ondrejka, J., Sycevova, M.(2010) *Oborín – Right bank landslide of Laborec levee in rkm 3.4*: *Final evaluation*. Kosice, pp. 12.

[10] Available at: https://www.google.com/maps/place/Obor%C3%ADn/@48.5092966,21.8653623,12z/data=!3m1!4b1!4m2!3m1!1s0x4738d766ce4bb395:0x400f7d1c69770a0 (accesed 15 June 2014).

[11] Vargova, M. (2013). *Posúdenie stability svahov na vybranej ochrannej hrádzi*. Košice: TU, SvF, pp. 70. /in Slovak/

[12] Panulinova, E.: *Shear strenght*. Kosice: TU, SvF, [cit. 2013-16-1]. Available on: http://people.tuke.sk/kamila.kotrasova/zPP11/MODULY/M3/zg03.pdf

[13] Slope stability – slope stability ananlysis. [cit. 2013-1-5]. Available on: http://www.finesoftware.eu/geotechnical-software/slope-stability/

[14] STN-EN 1997-1. Eurocode 7: 2005: Geotechnical design, Part 1: General rules.