Remediation and reinforcement of embankments for flood protection

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ABSTRACT: Big floods in Croatia in 2014 induced the analysis of flood protection system and remediation measures of embankments after flooding. This extreme hydrological phenomenon was higher than design criteria for flood protection system. The result was many defects on embankments and the largest were two breaches. High water levels caused piping in foundation ground and hydraulic breakdown in the area between trench and embankment base. Optimal was proved an interactive design approach executed parallel with the construction. Bad weather conditions during the remediation and clay with high water content at the site required a modification of design. After analysis was selected solution with reinforced soil using clay as it is on site. Embankment remediation with using reinforced soil was quickly implemented and less sensitive to bad weather conditions. During construction monitoring equipment was installed to keep track of construction and for forecasting and warning about embankment behavior during flood defense. In this paper the behavior of reinforced embankment is analyzed. The aim is a better understanding about the behavior of the reinforced soil and defining design parameters and technical conditions for construction.

Keywords: reinforced soil, embankment, monitoring, flood protection system

1 INTRODUCTION

Outer, natural factors, on which man affects with his actions, are becoming unfavourable factor with negative consequences for people and area in which we live and it is reflected through the risks that are growing more and more. Increase of risks is threat to people, settlements and material properties that has been spreading and consequences are more devastating. The reasons are coming from the human need for more space or because of population growth or from the increase of added value, which requires additional space.

Recent high water level events that have caused damage to the flood defence system and flooded the wider area of Županja city (Fig.1 and Fig.2) have launched a series of actions from the very levee remediation to the analysis of the existing system and suggestions of possible improvement measures. Although this is a unique, linear structure, there were different technical solutions used, conditioned by various factors, such as conditions in the foundation ground, proximity of the houses and the levee construction and upgrading through the period over a hundred years etc.

Figure 1: Levee breach in village Račinovci

All the consequences of high waters were analysed separately for each location of the damaged levee. Construction works on levee remediation had very slow progress due to continued rainy weather. It was necessary to make urgent intervention and modify design solution of levee remediation. By using reinforced soil construction and local clay material from inundation (Fig.3) remediation measures were quickly implemented. This construction is less sensitive to bad weather conditions during building, because geogrid is overtaking bearing function and the levee is immediately fully operational for flood defence. Due to the great length of the structure and the possibility of new damages, it has been proposed a procedure of remediation measure and reinforcement of the foundation ground and levees. This paper will explore the behaviour of reinforced soil embankment and compare the measured value with the numerical models.

Figure 2: Levee landside slope sliding in village Račinovci

Figure 3: Second layer of reinforced soil and temporary levee in the background

2 DEVELOPMENT OF FLOOD PROTECTION SYSTEM IN LOWER SAVA REGION

Flood protection in the Županja area has more centuries' tradition and there are existing data on the levee assessment at the end of the 19th century and the levee maintenance. During the floods in May 2014 there was a breach of the levee in the village Račinovci, after which immediately started the investigation of the levee history and how they were made, especially at locations where levees were damaged. In the National Archives data have been found about design documentation. Levee section from Gunja to Mitrovica was built in the period from year 1928 to 1933. Supervision engineer wrote details about construction of levee and conditions on site.
Levee is constructed as a homogeneous earth structure of clay material with a crest 4 m wide, slope inclination 1:2 and a maximum height of 6 m. Construction material was excavated with a bucket wheel excavator from material ditches along waterside levee toe. Almost all the material was excavated out of the water due to high underground water levels and great depth of excavation and afterwards was spread and manually compacted. The final levee height and profile was shaped during the reconstruction in the 70's of the last century.
On the location of levee breach and damage geotechnical investigation works were conducted. Investigation works confirmed that existing levee was constructed as a homogeneous clay levee on foundation soil which consists of the top clay layer followed by a layer of sand and on the bottom bedding is stiff clay layer. The thickness of top clay and sand layers is varying, but the underlying bedding clay is placed almost horizontally along the observed levee section.

3 LEVEE BREACH IN 2014

Levee breach occurred in May 2014 when the water level of the Sava River was approximately 50 cm below the levee crest. During the period of April and May 2014 was an extremely rainy season (DHMZ, 2014), water was in inundation for a long period and the ground was saturated. High water levels caused the back erosion of sand in the foundation ground below the levee and hydraulic breakdown of soil in the area between landside canal and levee toe.
At the location of landslide on levee slope (Fig.2) fast intervention measures with line of thirty 8 m long wooden piles driven in an hour prevented levee breach. But by that time on the second location, few hundred meters away, levee started collapsing. Before the collapse on the levee two vertical cracks were formed and levee body began to sink. Lowering of levee

opened the way for overtopping. The water overtopped the crest and erosion of levee landside slope started.

Beck et al. (2012) analysed the piping process below the levee on the full scale model. The largest sand transport and sand boiling phenomenon is when it reaches a critical water level in the process of retrograde erosion and then starts pipe expansion. Model research suggests that the whole process may take place in about 50 hours, which is significantly less time than the duration of high water wave in the river. The duration of internal erosion in foundation ground can be assessed on the basis of the soil material characteristics and water pressure (Fell et al., 2003; Wan and Fell, 2004; Chang and Zhang, 2013). Meehan and Benjasupattananan (2012) in their paper dealt with the influence of boundary conditions and surface low permeable clay layer during the analytical seepage modelling. These equations are a practical tool for engineering practice. Seepage analysis and back analysis coupled with results of investigation works was basic for understanding what has happened in Račinovci.

3.1 *Review of conducted geotechnical investigation works*

In-situ investigation works on the levee breach in Račinovci included the geological, geophysical and geotechnical studies (Geokon-Zagreb, 2014a, 2014b). According to the Basic geological map (Buzaljko et al., 1985) the structure location is in an area that is covered by quaternary sediments from Pleistocene and Holocene represented with: alluvial-flood sediments - silts and sandy silts. Fig. 4 depicts an excerpt from the Basic geological map and shows the corresponding legend and location of the construction site.

Geotechnical investigations were carried out according to recommendations set in standard EN 1997-2:1998 taking into account structure, soil category and settlement criteria.

Sixteen geotechnical boreholes from 6.0 to 20.0 m deep were drilled on project locations. In addition to geotechnical drilling, ten static penetration probe (CPTU) were performed up to 19.0 m deep. Undisturbed soil samples were continuously collected from the geotechnical borehole, or instead, standard penetration testing (SPT) was performed. As a part of laboratory testing, classification tests were performed, as well as strength testing, in addition to stiffness and soil permeability testing. Investigation works established soil layering on the location (Geokon-Zagreb, 2014a, 2014b) classified in accordance with their properties and the depth at which they appear. The soil consists of seven different types of soil, but major importance have top clay lacer and underneath sand layer in foundation soil.

Geophysical methods consisted of seismic refraction, MASW and geoelectrical tomography. Geophysical profiles were drawn parallel and perpendicular to the levee at location of damage. Very useful in the interpretation of events during the collapse of the levee showed geoelectrical tomography (Fig.5). On selected profile, which was set parallel to the levee toe, was very clear to see anomalies on the location of levee breach. There was near surface layer of coarse sand with a minimum cover of top clay layer, which served for piping below the levee to canal on landside.

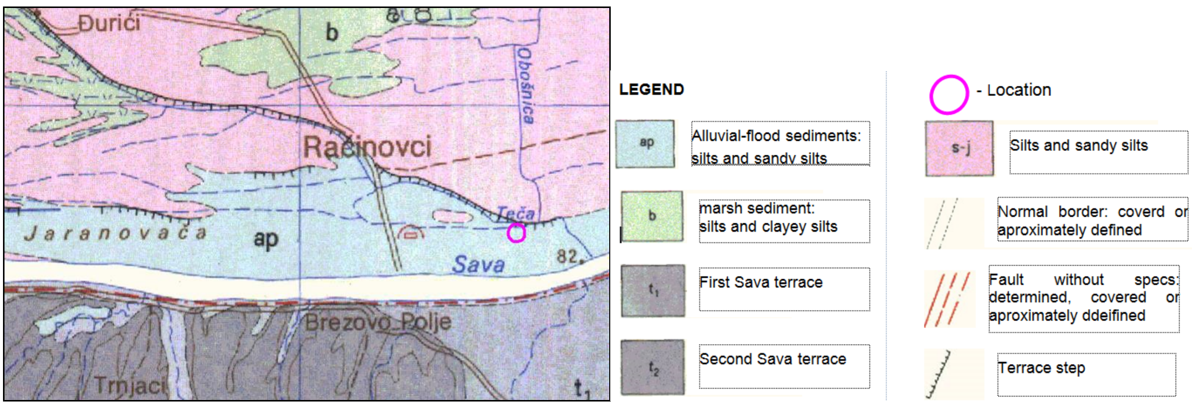

Figure 4: Basic geological map (Buzaljko et al., 1985),

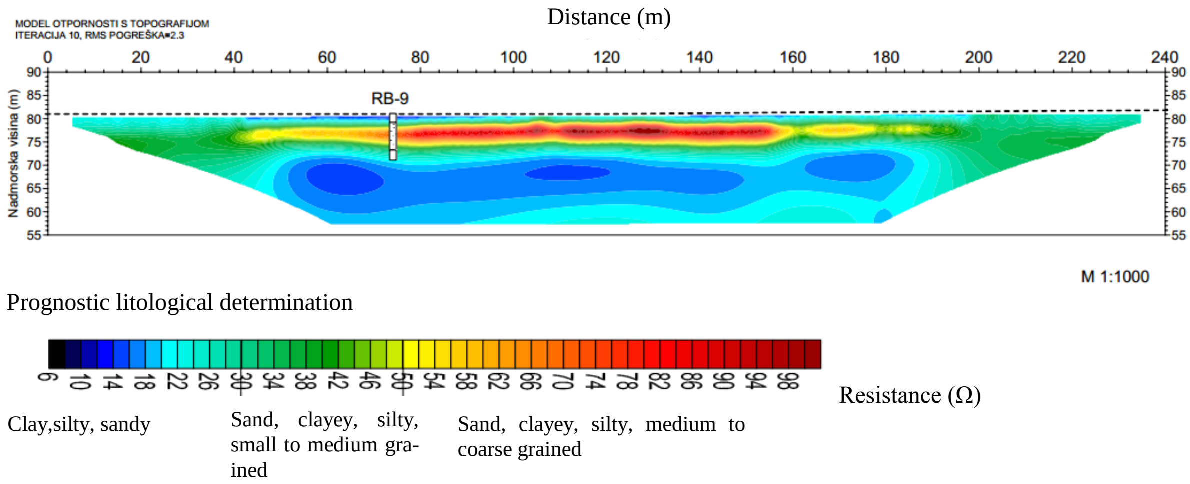

Figure 5: Geoelectrical tomography profile at levee breach

4 LEVEE REMEDIATION DESIGN

Levee remediation project in village Račinovci included landslide with length of 130 m and breach with length 120 m. On both location levee was rebuilt in full profile and part of levee in between of these two locations in the length of 340 m was reconstructed only waterside slope and crest. Along the entire section of remediation length of 500 m on the landside of levee toe drain was formed and berm that functions as an additional load on toe and was made from unselected soil material in inundation.

In the section of landslides second, temporary levee was constructed which had the function of protection against high water level up to the elevation of 84.15 m.a.s.l., which corresponds to the 25 year high water return period. Temporary levee had a length of about 160 m and was shifted about 30 m from the main levee axis. For construction of temporary levee clay material form excavation of damaged levee section was used.

On location of the levee breach it was needed urgently to close opening in the levee and the ground was saturated and partly under water. It was waited to flood withdraw to river bed and immediately temporary sheet pile wall was made (Fig.6). The length of wall was about 120 m and 12 m long sheet piles were installed. It was used steel profile Larssen 604 and it was placed near to waterside toe of former levee. Temporary cofferdam had the function of protection against high water level up to same elevation of 84.15 m.a.s.l. Steel sheet pile wall was left in place after the levee remediation at the levee toe and has a watertight function in the foundation ground in the area of breach, as additional security.

On the location of levee landslides and breach levee was reconstructed in full profiles by filling clay materials in thin layers. On landside of levee first was formed toe drain from gravel material wrapped in geotextile and over the drainage berm is constructed from unselected material which functions as an additional load on landside levee toe (Fig.7). At a distance of approximately 10 meters from the new berm is existing channel Stružac. During remediation channel was again profiled, reconstructed and covered with layer of geotextile and crushed stone. In the section between two damaged locations waterside slope and crest of levee was reconstructed. Slope was cut in 1m high steps and filled back in thin layers with clay material. The new levee crest after remediation was designed on elevation 86.2 m.a.s.l., which is about 20 cm higher and is fitted with a smooth transition to the existing levee outside the remediation area.

Figure 6: Sheet pile coffer dam at beginning of remediation

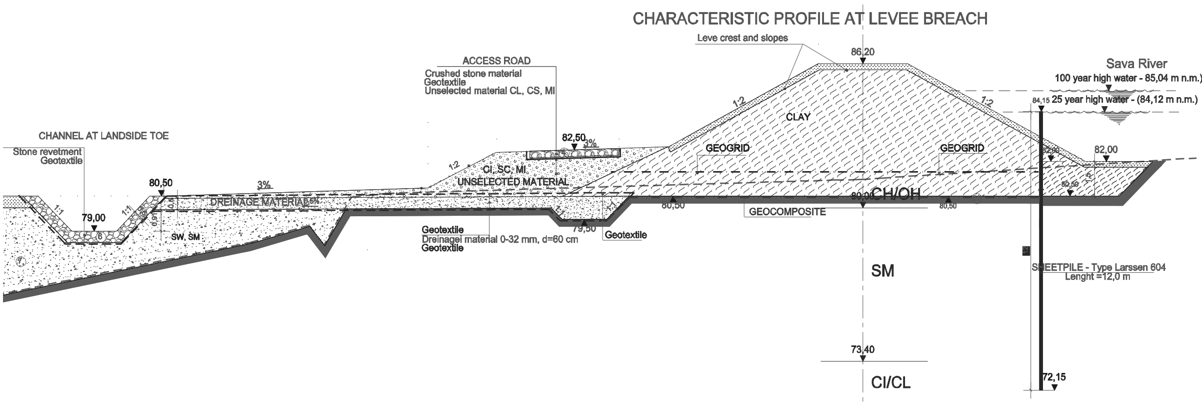

Figure 7: Characteristic profile of remediation at levee breach

5 LEVEE REINFORCEMENT

At the beginning of remediation rainy season continued and slowed down construction works. In July and August the temporary levee and cofferdam were in action in 3 occasions and the water level climbed to more than half of their height, and the clay material deposits were under water. In late August 2014, during construction, natural water content in clay material at site was measured over 30%, which is significantly more than the allowed 25% by design. During the trial section compressibility modulus was measured significantly lower than the minimum of 20 MPa, as measured by circular slab method. Contractor and Investor tried new material pit on landside of levee, but it did not help, because the ground was saturated for months.

Due to high water content in clay material, as a result, during the construction of levees with such materials settlements are expected to be higher than designed and shear strength of clay is significantly smaller. It was not possible to rebuild levee to be fully functioned in flood defence system without additional measures. We analysed a number of different solutions that are needed to enable a simple as possible construction and to restore the flood protection system to its full functionality. After analysis it was chosen solution of levee reinforced with geogrids.

This technical solution as an emergency measure proposed reinforced soil with geosynthetics. In this method, a levee or some other earth retaining structure is reinforced with geotextiles or geogrids.

Selected technical solution for the construction of earth structures reinforced with geosynthetics solved problem of reduced shear strength of clay with high water content installed in extremely rainy period with reinforcement by geosynthetics and problem of increased settlements was solved by overfilling design profile by some 50 cm. After the period of one year of levee consolidation, it was planned to make visual inspection, some in-situ investigation works and adjustments and if needed take off overfilled material and put a layer of humus and seed grass.

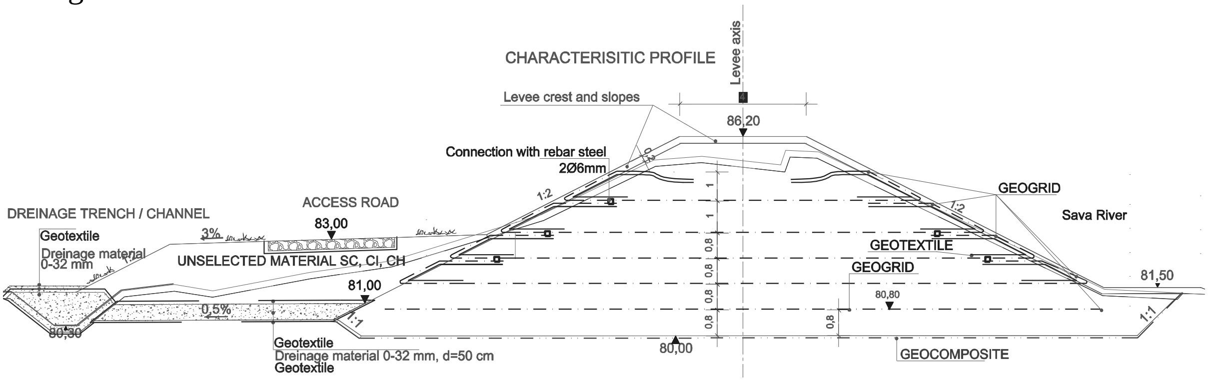

Figure 8: Characteristic profile of alternative solution

When choosing appropriate solution for levee reinforcement affected more advantages of geosynthetic reinforced retaining structures. Reinforced levee did not require special conditions for preparing foundation soil and its bearing capacity. For the weather and other conditions that prevailed at the construction site was important to use locally available material. This method had the extra advantage, because there are no special requirements for the filling material, which made it possible to work in difficult conditions. The geometry of the reinforced levee is easily adjusted to the needed height and position at current terrain. It was not necessary to change or adopt mobilised machines that were already on the construction site, and perhaps most important advantage was that the construction could be loaded immediately after completion. On the waterside of levee separating geotextile was placed within geogrids, because at the time of completion, and that was the end of the year, grass could not be seeded and the geotextile should prevent the erosion of levee in case of high water wave.

6 MONITORING

The aim of the monitoring process was to measure the settlements and observe levee behavior under loading and unloading of high water level during first two years after remediation.
In the design, numerical analysis of levee settlements was conducted in such manner that the load of levee body was applied for the first time. The analysis obtained greater values ranged from 20 to 30 cm. In the process of remediation settlements of subsoil after the completion of the levee construction was not expected, because the soil was consolidated by load of old levee and settlement of sandy layer which was loosened during the breach was accomplished during construction and as a result of numerical analysis after deducting subsoil settlement it was estimated that there will be a settlement of levee body up to 7.0 cm.
Monitoring involved using a system of horizontal inclinometer (Fig. 9), placed on the foundation soil before first layer, four piezometers and permanent geodetic points. A series of 10 measurements were carried out from September 2014 until December ~~2105~~, during which period of time high water level didn’t occurred and only settlement after remediation were measured. Measured values corresponded to design calculations. It is planned to carry out detailed analysis and publish results as part of PhD thesis.


Figure 9: Installation of horizontal inclinometer

7 CONCLUSION

Damage to the flood protection system that occurred in 2014 on the River Sava demanded the swift reaction with the aim of restoring the flood defense system and restoring security in the wider area of Županja city. Construction works with emergency measures and installment of temporary coffer dam securing the site and the village from flooding intertwined with the implementation of investigation works. In the next design stage from the beginning started preparation works for levee remediation. Bad weather condition and the beginning of autumn showed significance of interactive design and conditioned modification of design solutions that had to adapt to circumstances on site. The aim was to restore flood defense system to its full functionality on time. The temporary cofferdam and temporary levee were designed only to withstand high water level of 25 year return period, and at the beginning of the remediation temporary cofferdam and levee were 3 times in action during summer.
Modified solution with reinforced levee enabled the completion of the levee in full profile before winter. Although the clay material with increased water content was used, after one year there were no detected deformations or cracks that would require additional measures at the levee crest or slopes. Full functionality and serviceability levee will confirm only at high water level, which did not occur during this period after remediation.

REFERENCES

Buzaljko, R. et al. (1985). Basic geological map of SFRJ, Sheet Brčko, Geološki Zavod-Zagreb, in Croatian.
Chang, D.S., Zhang, L.M. (2013) Extended internal stability criteria for soils under seepage, Soils and Foundations, Vol. 53, Issue 4, pp. 569-583.
DHMZ (2014) A hundred year flood on the lower Sava River, http://klima.hr/razno/priopcenja/poplava_sava_2014.pdf
Fell, R. et al. (2003) Time for development of internal erosion and piping in embankment dams, Journal of Geotechnical and Geoenvironmental Engineering, Vol. 129, Issue 4, pp. 307-314.
Geokon-Zagreb (2014a). Geotechnical investigation works for remediation of levee breach in Račinovci km 216+300, Zagreb, in Croatian.
Geokon-Zagreb (2014a). Geotechnical investigation works for remediation of levee breach in Račinovci km 216+300, Zagreb, in Croatian.

Geokon-Zagreb (2014b) Geotechnical investigation works for remediation of levee slope sliding in Račinovci km 215+800, Zagreb, in Croatian.

Geokon-Zagreb (2014c) Detailed design for remediation of levee breach in Račinovci km 216+300, Zagreb, in Croatian.

Geokon-Zagreb (2014d) Detailed design for remediation of levee slope sliding in Račinovci km 215+800, Zagreb, in Croatian.

Meehan, C. L., Benjasupattananan, S. (2012) An analytical approach for levee underseepage analysis, Journal of Hydrology, Vol. 470, pp. 201-211.

Van Beek, V. M., et al. (2010) Levee failure due to piping: A full-scale experiment, Proceedings of the Fifth International Conference on Scour and Erosion, ICSE-5, San Francisco, California, November 7-10, pp. 283-292.

Wan, C. F., Fell, R. (2004) Investigation of rate of erosion of soils in embankment dams, Journal of Geotechnical and Geoenvironmental Engineering, Vol. 130, Issue 4, pp. 373-380.