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ROAD AND RAILWAY EMBANKMENTS AS FLOOD-CONTROL DIKES

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Abstract

When designing roads and railways in the vicinity of river flows, it is a common situation for road embankments to serve as flood-control embankments as well. Such solutions are not the best ones; however, they are often imposed. This paper presents examples of embankments designed in this way, considering both roads and railways. Geostatic calculations of slope stability are performed for the designed solution of a railway embankment. Based on the analyses, some recommendations and guidelines have been given, emphasising the aspects on which particular attention should be paid if there is a necessity to design this type of embankments.

Keywords: road and railway embankments, flood-control dike, slope stability, geostatic calculations

1 Introduction

The construction of contemporary roads and railways, in particular at high speeds, imposes the design of the route using larger radii of line curvatures. In addition, the routes of these traffic lines are often laid along river valleys, even up to the riverbed itself. In these cases, the road embankment represents, at the same time, a flood-control dike as well. Design of this type of structures is very complex and requires solution of many problems.
The first problem that needs to be comprehensively considered when designing these types of embankments is of hydrotechnical nature, i.e. the water level regime in the riverbed as well as in the hinterland. It is necessary to analyse in detail the flood wave over a period of time from the beginning of the flood to return to normal stage. The problem of sudden change of water level and its influence upon the embankment stability (settlement, stability of slopes of the embankment, and suffusion) is of particular concern in these cases.
Another problem related to the impact of water is the flooding of the embankment and withdrawal of water from the embankment, which can often lead to subsequent settlement. When it comes to high-speed roads and railways, the occurrence of subsequent settlements of embankments is considered to be unacceptable, in particular for the case of high-speed railways when not even the slightest settlements are allowed.
When designing an embankment as a traffic object and a flood-control structure, it is necessary to analyse in detail the stability of the embankment slopes, the settlement of the embankment, and the load from the embankment and the traffic to the subsoil. In addition, it is necessary to investigate the possibility of the occurrence of liquefaction, since saturated sands appear quite often in the vicinity of the riverbed.

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2 Design of embankments

When a roadbase (embankment) partially enters a riverbed (i.e., the road embankment is also the river bank protection), special measures should be taken to protect the embankment:

- The embankment toe must be secured against undercutting and erosion. There are several technical solutions as shown in Fig. 1. The embankment toe is secured up to the low water level. These are just examples of how the protection of an embankment can be performed. In principle, there is no essential difference in the protection of these embankments considering the railway and road embankments. The only differences are related to the type and intensity of load, as well as to the construction of pavement structure (permanent way).
- In addition to securing the toe, the protection of the slope of an embankment is also important. Ensuring the slope of the embankment should extend up to a minimum of 1.0 m above the high water level. In view of the data on the floods that have taken place in recent years and of the global warming, it is necessary to revise the high water levels (1 in 100 years' water event).

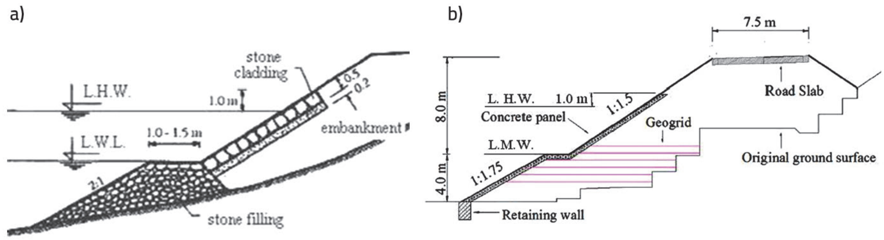

Figure 1 Protection of the embankment toe: a) on railways [1]; b) on roads [2]

When designing capital traffic lines (high-speed railways, highways, and roads of huge significance), in addition to the above mentioned measures, it is necessary to prevent water from entering the body of the embankment either from the protected or unprotected side of the embankment. In the present conditions, it is achieved by the application of waterproof foils. Nevertheless, in practice, when constructing these roads and railways, this is done in part or not at all, which can cause a number of negative consequences for the stability of the embankment and the safety of traffic. Therefore, in the design, it is necessary to analyse several factors in order to provide a safe solution from the aspect of the stability of the slopes of the embankment and its settlement. Factors influencing the design solution of a traffic communication embankment as a bank protection are:

- River morphology;
- Sudden decrease in water level;
- Embankment loading;
- Earthquake impact;
- Embankment settlement.

2.1 River morphology

The shape of a riverbed (cross-sections, longitudinal profile, river course) depends on the basic natural factors (hydrological, hydraulic, psamological, and other factors). The aforementioned forms are interdependent.

When designing an embankment, the impacts under which the riverbed is formed (water flow, properties of the material in the riverbed) should be analysed first.

The most significant influence is the flow of water. In addition to the basic flow of water in the river, which takes place under the influence of gravity, there are secondary flows in natural streams. The most important are centrifugal, frictional, and vortex flows.

Centrifugal flow occurs in curvity of river channel as a consequence of the uneven distribution of base flow velocities across the cross-section, as well as the uneven amount of water movement along the width and depth of the river stream. The flow is transverse to the base flow, so that with the longitudinal ones it creates a helical flow, as shown in Fig. 2. This flow plays a primary role in creating meanders and moving them downstream. At the bottom, the velocity of this stream is 1.5 higher than the velocity of the longitudinal stream, and at the surface it is much lower (about 15 % of the velocity of the longitudinal stream). Surface currents in the curvature plunge along the concave coast (downward flow), and they erupt to the surface in the convex coast zone (upward flow).

Friction flow is backflow, occurring at places of sudden widening of the river stream, behind sudden change in the longitudinal grade. The velocity of this stream reaches 30-50 % of the velocity of the basic stream, so that it also plays a very important role in the formation of the riverbed.

Vortex current is a consequence of friction flow. This stream draws the water with the deposit onto the surface of the stream and significantly influences the movement of the river deposit in the zones of the stabilisation structures – embankments. The velocity of the vortex current is the same order of magnitude as the velocity of the base stream, but may also be higher.

The properties of the material in the riverbed are also very significant. The geomechanical and geological composition of the material in which the riverbed was formed significantly influences its development and the morphological forms that occur. Therefore, geomechanical and geological data, obtained through proper investigations, are very important for the design of embankments.

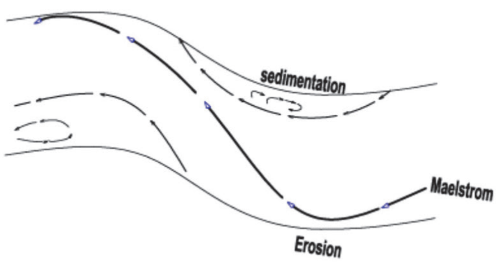

Figure 2 Helical flow in curvity of riverbed [3]

2.2 Sudden drop of water level

A sudden decrease in the water level has multifold effects: on the safety of the slope of the embankment, on the occurrence of suffosion, and on the settlement of the embankment.

The effect of a sudden decrease in water level on the stability of the slope of the embankment was considered by Morgenstern [4]. When the water level drops rapidly, the water from the embankment does not flow as fast as in the riverbed. Figure 3a shows a sudden decrease in water, based on which a diagram of values of the safety factor is given (Fig. 3b). The diagram is presented for one angle of inclination of the embankment slope.

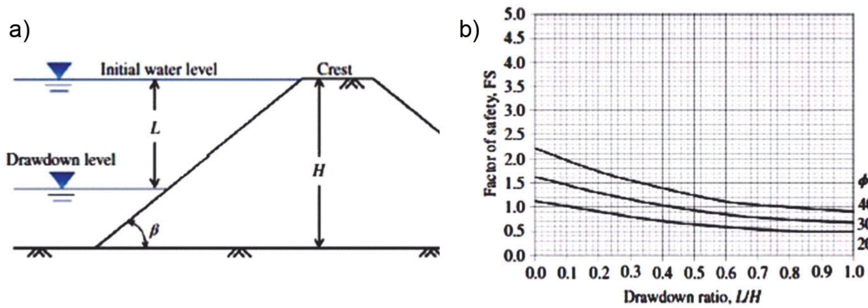

Figure 3 a) Illustration of rapid drawdown; b) Morgenstern charts for rapid drawdown for $c'/\gamma H$ = 0.0125 and β = 2:1 [4,5] (c' is cohesion, γ is volume weight, and H stands for the height of embankment)

Suffosion of the soil (internal and external) can also be caused by a sudden decrease in water level. Internal suffosion is the redistribution of small particles that alter the local hydraulic conductivity of the material. External suffosion represents the extraction and evacuation of small particles, which yields an increase in hydraulic conductivity. This often leads to the degradation of the embankment, as well as to its settlement. Accordingly, when designing, it is necessary to analyse the criteria for the evaluation of suffusion, starting with the study of the size of the soil grains. The grain size distribution criteria should be linked to the hydraulic load rating. The hydraulic approach consists of estimating the load produced by the fluid flow to initiate the suffusion [6].
A sudden decrease in water level influences quick changes of the pore pressures in the embankment body, which in case of some embankment materials can lead to subsequent settlements of the embankment.

2.3 Embankment loading

In addition to constant load (embankment weight, traffic load), there are also incident loads (earthquake, flood). All these loads affect the stability of the slope of the embankment and the additional settlement of the embankment. Here, too, is necessary to emphasise the difference between road embankments which also serve as a river bank protection and embankments which are designed exclusively for protection against water. The former are characterised with significant traffic loads – static and dynamic, in which case no subsequent settlements are allowed. In case of latter ones, there is no traffic load, and the criterion for settlements is not so strict.

2.4 Influence of earthquake

The first impact of an earthquake is on the stability of the slopes of an embankment. Accordingly, in the design of roads and railways, it is necessary to take this influence into account. The effect of an earthquake reduces the coefficient of safety of the slope of the embankment. Another effect of an earthquake is possible occurrence of liquefaction. The soil, on which the embankment is located along the riverbed, is in most cases saturated and made of cohesionless material, and in some cases of soft loose materials. With this in mind, it is necessary to check all the criteria for the occurrence of liquefaction and to provide a solution in the design for its prevention.

2.5 Embankment settlement

One of the evident problems associated with the construction of an embankment is its settlement. Larger settlements are allowed in the case of flood-protection (bank-protection) embankments. In order to prevent settlements that would jeopardize the functionality of the embankment, the subsoil should be specially treated. The subsoil on the riverbank itself is usually soft soil, so it is necessary to take additional measures to improve it (soil replacement, construction of gravel piles, etc.). In addition, the quality of the material that is placed in the embankment must be in accordance with the required criteria. However, in the case of embankments–bank protections that are also used as embankments on roads or railways, settlements are not allowed (or possibly small values of settlements are allowed), which is especially true for railway embankments. In order to prevent their settlements, it is necessary to take the following steps:

- To ensure the subsoil of the embankment with the appropriate geotechnical measures that would prevent settlements of the subsoil due to the weight of the embankment, the impact of load, the impact of an earthquake excitation, as well as the effects listed in the second chapter of this paper;
- To build-in materials into the embankment body according to the technical criteria in terms of the quality of the material and the method of its placing;
- To protect the embankment from the effects of flooding and saturation of the embankment with water (especially for settlements, the predominant effect is a sudden drawdown of water level if water has infiltrated into the embankment body). This problem can be solved by installing waterproof foils in the toe and along the slopes of the embankment.

3 Geostatic calculations of slope stability

Due to the limited space of the paper, only the slope stability analysis is presented.
This section presents an analysis of the slope stability of an embankment on the Belgrade–Budapest railway line. In the Final Design of the railway line, a complete analysis was conducted based on an embankment model, which represents only one part of the route of the given railway line along the Danube River. The embankment is also a flood-control dike. This part of the analysis and the technical solution are not presented in this paper for the sake of the authorship protection. This paper presents a model of an embankment next to the Danube River that is not given in the Final Design of the railway. Information on the cross-section profile of the railway and soil characteristics was obtained from the Investor.
A cross-section of the embankment on one part of the Belgrade–Budapest railway line is depicted in Fig. 4. The slope stability calculation is shown for one case of water status in the Danube River, taking into account the total loading including earthquake effects. The seismic impact is considered for the 8th degree of seismicity (seismic coefficient $k_s = 0.06$).

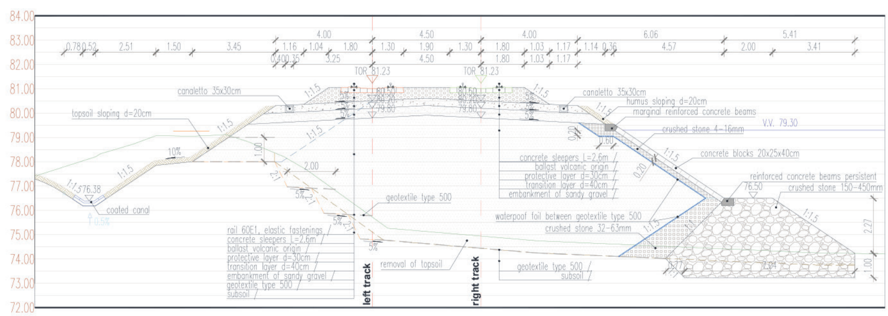

Figure 4 Embankment on the Belgrade–Budapest railway [7]

The designed embankment is ensured on the unprotected side (towards the river) by a waterproof foil, up to 20 cm above the high water level. In the analysis, two cases are considered: the case of the embankment with two loaded tracks and the case of one loaded track towards the river (Fig. 5). The earthquake action was taken into account in the calculation. The presented analyses are given for one water level in the river and the embankment, with a deeper slip surface, whereby different calculation methods were applied. The safety factor for the slope of the embankment considering two loaded tracks is in the range from 0.98 (Fellenius–Petterson) to 1.18 (Bishop). For the slope of the embankment loaded on a single track, the safety factor ranges from 0.94 (Fellenius–Petterson) to 1.22 (Bishop). The analysis of the slope stability of the embankment indicates that the safety factors are not satisfactory, i.e. an insufficient height of the embankment slope above the high water level was protected by a watertight foil.

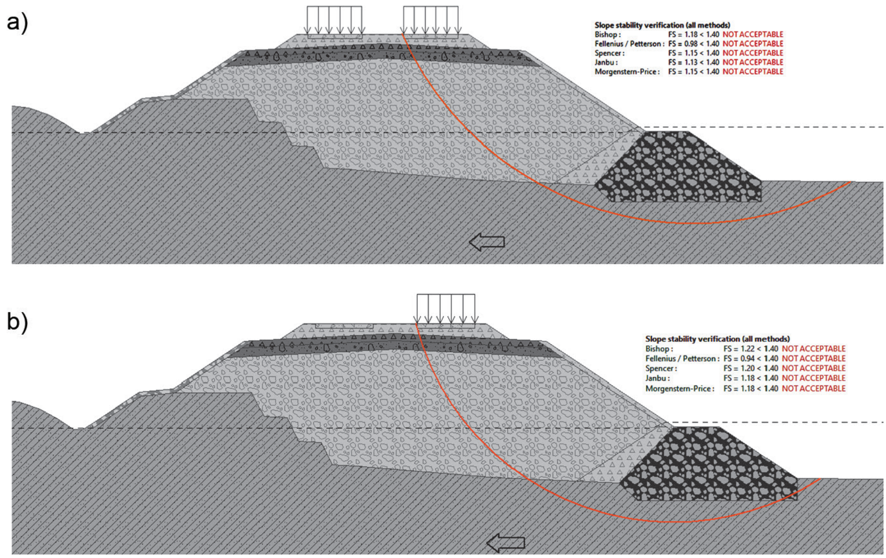

Figure 5 Slope stability analysis of railway embankment: a) two tracks loaded; b) one track loaded

This is the designed embankment solution within the Design of the high-speed railway line, for which the slope stability calculation has not been done in the designing stage. When the slope stability was checked within this study, as shown above, unsatisfactory safety coefficients were obtained. In order to achieve satisfactory safety coefficients, it is necessary to undertake the following:

- Redesign the geometry of the embankment by replacing the subsoil to the required depth and increasing the dimensions of the gabion in the riverbed;
- Install a waterproof foil on the unprotected side of the embankment, under the embankment, and on the protected side up to the required height;
- Provide a protection on the unprotected side up to the height of 1.0 m above the high water level with proper structures.

The presented example is highlighted with the aim of indicating to the designers that each type of embankment has to be analysed separately and comprehensively. Due to the limited length of the paper, the modified solution of the considered embankment is not shown here.

4 Concluding remarks

When designing roads and railways, in particular capital ones such as high-speed rail lines and highways, solutions of the road embankments that will also serve as flood-control dikes should generally be avoided. If, however, this cannot be avoided, the body of the embankment should be completely protected by watertight foils up to a height of minimum 1.0 m above the high water level. In addition, it is necessary to analyse all relevant factors, which affect the embankment stability and traffic safety on any basis.
The designed embankment of the railway line, presented in this paper, is only partially protected on the side down the river by a watertight foil of the height of only 20 cm above the high water level. The fact on inappropriately performed protective measures was confirmed by the slope stability analysis of the embankment, whose results indicate that the safety factors are not satisfactory. It is pointed out that it was necessary to redesign the embankment, but more importantly, the designers are told that each type of embankment on railways or roads that also serves as a bank protection should be analysed in detail, and not just make a cross-section of the embankment.
The presented analyses indicate the necessity for the comprehensive approach when designing this specific type of embankments.

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References

[1] Marusic, D.: Design and construction of railway lines, University of Split, Faculty of Civil Engineering, 1994.

[2] Wang, J., Li, Q., Yang, C., Zhou, C.: Dynamic response and damage character of road embankment under strong earthquake, International Journal of Distributed Sensor Networks, 14 (2015) 9, pp. 1-12, doi: 10.1177/1550147718794611.

[3] Mladenovic, B.M.: Arrangement watercourse, Institute of Water Management "Jaroslav Cerni", Serbia, 2018.

[4] Morgenstern, N.R.: Stability charts for earth slopes during rapid drawdown, Geotechnique, 13 (1963) 2, pp. 121-133.

[5] Xiao, M., Barreto, D.: Geotechnical Engineering Design, John Wiley & Sons, 2015.

[6] Marot, D., Benamar, A.: Suffusion, transport and filtration of fine particles in granular soil, Erosion of geomaterials, (2012), pp.39-79.

[7] General design of the railway line Belgrade–Budapest, section Stara Pazova – Novi Sad, CIP, 2016.