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DEVELOPMENT OF A METHODOLOGY FOR STABILITY MONITORING OF A DEFENSE EMBANKMENT LOADED WITH FREQUENT TRAFFIC: THE EXAMPLE OF THE KOVIN MINE

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SUMMARY

In the present paper, the authors develop a methodology for stability monitoring of the hydrotechnical-defensive embankment that is exposed to heavy frequent traffic. The proposed methodology envisages several phases of observation, work and monitoring: (1) macroscopic observations, (2) geophysical-geoelectric tests, (3) group of exploration works, (4) model formation, (5) establishment of a monitoring system, (6) acquisition data processing and modeling. Four of the six proposed phases are illustrated by the example of the left-bank Danube embankment used by the Kovin coal mine for the needs of coal truck haulage.

The results of the performed research indicate that there are no deformations that endanger the defensive function of the embankment. In order to ensure safe coal truck haulage and preserve the function of the embankment, it is proposed to establish a system for geophysical, hydrogeological and geotechnical monitoring, to form a model for simulating the behavior of the embankment for different hydrometeorological conditions (consequently, for different consistency states and material compaction), and for different load conditions.

Keywords: *defensive embankment, traffic, stability, methodology, monitoring, modeling*

INTRODUCTION

Defensive river embankments are one of the most common forms of protection of settlements and infrastructure from high waters. Embankments are the most important regulatory structures, which narrow the riverbed for high water and thus prevent flooding of the wider coast [1]. The most common division of embankments is according to their position in relation to the main river flow, and their function, into: main, summer, peripheral, slowing down, connecting and transverse embankments. As the name suggests - the main embankments are a key element of regulation, they are the longest and they have the task of defending a large area in the hinterland from flooding during high waters.

Dimensioning of the main embankments by height is performing on the basis of the elevation of high waters, and the relevant high waters, and the authority is tied to a certain return period, which is chosen depending on the damage size that would occur due to floods. Apart from the elevation of the embankment, which must certainly be higher than the elevation of high waters, one of the most important properties of the embankment is its combined structural-filtration stability. Namely, the defensive embankment must have geometrical characteristics and physical-mechanical properties such that it can carry itself in equilibrium, to be stable for different surface and groundwater regimes in the subject area (especially in extreme cases of sudden rise or fall of surface/ groundwater levels). The defensive embankment should be also stable in relation to the possible occurrence of water filtration through the body of the embankment and the occurrence of mechanical suffusion. In accordance with the above criteria, the quality of the material for installation in the embankment is selected, ie the material is selected that will have favorable resistance-deformable properties in the compacted state (relatively high values of shear resistance parameters, low compressibility, and acceptable sensitivity to consistent change) respectively acceptable filtration characteristics (low water permeability, respectively low values of the filtration coefficient in the compacted state).

Materials that meet these properties are dusty-sandy to dusty-clayey composition, and most often build the alluvial plains of large rivers, so they are, according to the criterion of haulage lengths, an ideal material for installation in the embankment. Such materials are installed in the embankments of Kolubara, Tamnava, Zapadna Morava, Rasina rivers etc.

Defensive embankments along larger river flows are, as a rule, of large dimensions, both in the base and in the crown (up to 4-5 m), and as such are almost regularly used as roads for local needs. They are most often used by the local population for the needs of transport of agricultural machinery (motor cultivators, tractors, etc.), as well as for shorter transports by cars (Figure 1). In such cases, the traffic is usually not frequent, and does not pose a danger to the structural-filtration stability of the defensive embankment.

Figure 1. Part of the embankment on the left bank Kolubara which is used as a road for local needs (Kostić, 2019) [2].

In the case of frequent traffic, it is not uncommon for the road embankment itself (highway, regional or main road) to simultaneously perform the function of a defensive embankment. In such cases, the embankments certainly meet the condition of structural stability, given the significant loads to which the embankment is exposed during the service life of the road, but special attention must be paid to the filtration stability of the embankment, respectively the embankment must be built of low-permeability materials on the section that is used both as an infrastructure and as a defense facility.

On the other hand, it is rare for defensive embankments along some rivers to be used for frequent heavy traffic, without having previously been designed, dimensioned and built for such purposes. In such cases, one should almost certainly expect the occurrence of embankment deformations, as well as the weakening of their defensive function, both in terms of structural stability and in terms of filtration stability. Part of the defensive embankment on the Danube, near Kovin, is used for the coal haulage, and is exposed to the daily frequent traffic load from heavy machinery: trucks loaded with coal. In the present paper is establish a methodology for monitoring the stability of the defense embankment, which is used as a road of high-frequency traffic of heavy machinery, and as an example are stated the exploration works for assessing the condition of the Danube defense embankment by the Kovin coal mine.

The usual procedures for examining the condition of existing embankments include the application of combined field observations, geological and geodetic surveys, with, if necessary, the installation of appropriate equipment for continuous / periodic monitoring. During the last decades, the methodology of monitoring the existing embankments has remained almost unchanged, with the development of equipment and software solutions, which enables: (1) more accurate collection of a large amount of data; (2) continuous monitoring; (3) more complex acquisition of acquisition data, using artificial neural networks [3], machine learning methods [4,5], and numerical methods [6], etc.

In the present paper, the authors propose a methodology for observing existing embankments loaded with frequent traffic, with an illustration of the proposed methodology on the example of defensive embankment on the Danube used by the Kovin coal mine.

CRITERIA FOR CONSTRUCTION OF ROAD / DEFENSE EMBANKMENT

Designing of any type embankments includes defining the criteria of materials for installation in the embankment. These criteria are usually standardized, and this is most often the case with infrastructure embankments. As an example is possible to use the criteria for the installation of material in the embankment that were valid according to SRPS standard U.E1.010: yield strength less than 65% (flow limit), plasticity index less than 30, Proctor's number 0-0.2, minimum bulk density in the dry state for embankments up to 3 m is 1.5 t/m^3, the degree of unevenness must be greater than 9, the content of organic matter must be less than 6%, the optimal water content must be less than 25%.

However, standardized criteria for the installation of materials in the hydraulic embankment do not exist, but are determined on the basis of available material, as well as on the basis of the results of structural-filtration stability calculations. These materials do not have to meet strict criteria, in terms of load-bearing capacity and subsidence, as in the case of infrastructure embankments; but the shear resistance of the material in the compacted state and the water permeability characteristics predominantly determine the suitability of the material for installation in the defensive embankment. In domestic engineering practice, it is generally accepted that a material is suitable for installation in an embankment if it has more than 50% dust-clay particles, less than 50% sand particles, with a cohesion greater than 5 kPa, and an internal friction angle greater than 20^0, as and with a compaction filtration coefficient of less than 10^{-5} m/s..

From the mentioned analysis, it is clear that the design of defensive embankments does not take into account the frequent traffic load according to which the structure is dimensioned and the criteria of the material properties for installation in the embankment are determined. In this regard, defense embankments used as infrastructure facilities, with frequent traffic, must be the subject of research, observation and monitoring, with the task of early identification of any vulnerable locations or initial deformations, in order to timely apply adequate preventive and remedial measures.

DEFINING THE RESEARCH ALGORITHM OF THE TRAFFIC LOADED DEFENSE EMBANKMENT

Considering the impact of high-frequency traffic on embankment stability requires, as a first step, defining a research algorithm that should enable the assessment of the current state of the embankment, as well as the prediction of embankment behavior over time. In order for that to be possible, it is necessary to perform complex researches, respectively combination of different types of exploration, in order to obtain an assessment of the current condition and a projection of the embankment behavior with satisfactory accuracy and reliability. In order to achieve this, it is necessary to conduct the following researches:

(1) Macroscopic observation of the current embankment condition - this step involves a tour (field visual control) of the section of the embankment being studied and the visual registration of deformation appearance. Observation - reconnaissance is performed semi-instrumentally, using a geological compass, a geodetic bar and a ribbon and a hand-held GPS device. In addition, this phase may include the use of aerial footage by drone, especially in the case of longer sections of embankment;
(2) Geophysical tests - geophysical tests by the geoelectric method can give very precise data on the locations of leaks or less compacted material through the body of the embankment. In addition, based on the results of geophysical tests, it is possible to judge the composition of the embankment, and thus the zones of the embankment where it is possible to expect increased infiltration and filtration (embankment zones built of incoherent or poorly compacted materials), Figure 2;
(3) Geotechnical exploration works - exploratory drilling, static and standard penetration tests and laboratory geomechanical tests.
(4) Hydrogeological exploration works - installation of piezometers in the body of the embankment, in the defended and undefended part, which enables reliable calculation of the filtration stability of the embankment and formation of a hydrogeological model;
(5) Model formation - this phase implies the formation of a geotechnical model (for the calculation of structural and filtration stability) and a hydrogeological model for the calculation of filtration in a wider area. Model formation implies the formation of a two-dimensional or three-dimensional model, with defined geometric and material characteristics;
(6) Monitoring:
   a. Geodetic monitoring - involves the installation of geodetic benchmarks on the crown and slopes of the embankment, as well as periodic recording of benchmark positions (Figure 3);
   b. Geotechnical monitoring - implies periodic reconnaissance of the terrain, as well as the acquisition and interpretation of the results of geodetic monitoring (Figure 4);
   c. Hydrogeological monitoring - involves monitoring groundwater levels in built-in piezometers;
   d. Geophysical monitoring - it is possible to establish a system for geophysical monitoring by approaching the installation of electrodes that will not move during the entire monitoring period. Such a system is already established on the filled dam Vlasina (Serbia), where it is placed on the crown of the dam through fixed electrodes, which allows measurements always in the same direction, as well as the possibility of registering changes in specific electrical resistance, and thus in the properties of building materials. dam body (Figure 5);

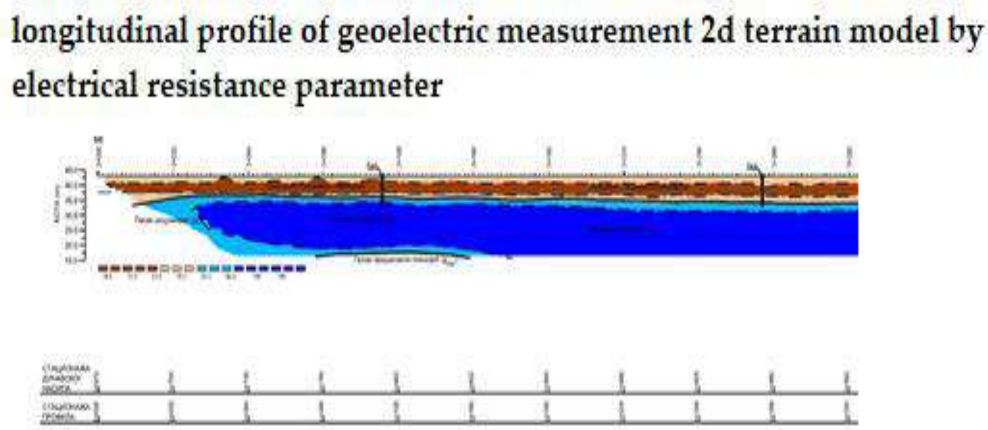

Figure 2. Results of geoelectric testing of the Grabovica defense embankment (Vasić, 2019) [7].

Figure 3. Installation and observation of geodetic landmarks, an example of observation of landslide movement in the hinterland of the Đerdap accumulation (Lazarević, 2017) [8]

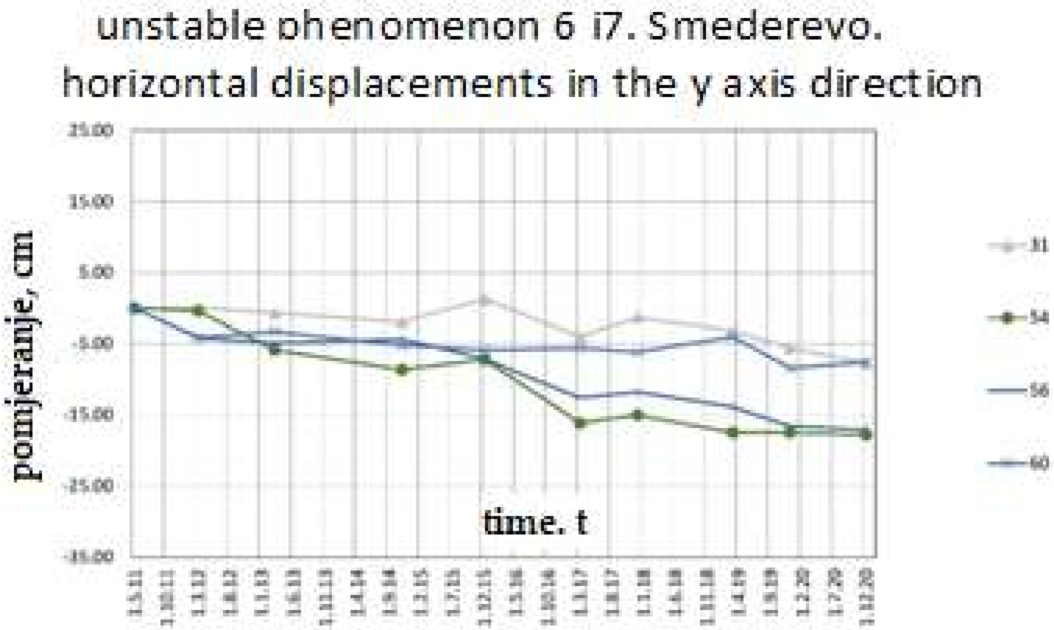

Figure 4. Analysis of geodetic monitoring results - an example of a landslide near Smederevo on the right bank of the Danube (Lazarević, 2021) [9]

(7) Modeling - implies processing of acquisition data and calculations of structural-filtration stability of embankments, using boundary equilibrium methods, or numerical methods - finite element method and finite difference method, for stationary and non-stationary conditions.

Figure 5. Fixed electrodes on the crown of the filled Vlasina dam for periodic geophysical monitoring (Vasić, 2018) [10].

Figure 6 shows the test algorithm presented in this paper.

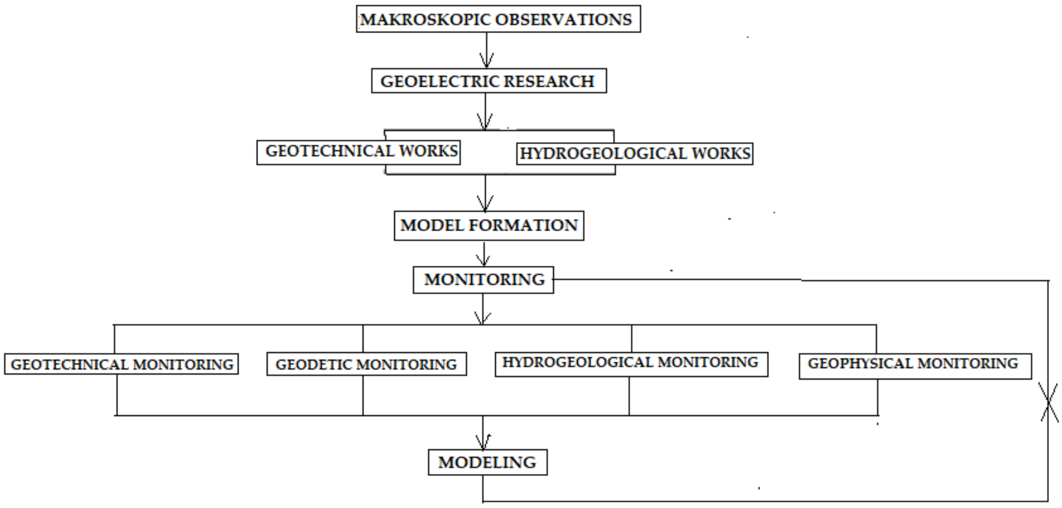

Figure 6. Algorithm for complex stability investigation of embankment loaded with frequent traffic

ILLUSTRATION OF THE PROPOSED METHODOLOGY

An illustration of the proposed methodology is given for the section of the defensive left bank of the Danube embankment (Figure 7) used by the Kovin coal mine for truck haulage of coal (Figure 8).

(a) (b)

Figure 7. (a) Location of the Kovin coal mine, (b) Section of the Danube embankment used by the Kovin coal mine for transport (taken from the Google Earth website, 29 September 2017) [11]

Figure 8. Trucks loaded with coal over the defensive embankment of the Danube near Kovin (photo Kostić, 2017) [11].

The Kovin coal mine is the only mine in the Republic of Serbia with underwater coal exploitation. Underwater coal mining is performed exclusively by the Kovin I dredger (Figure 9). By turning the cutting wheel, the material is cut off from the layer, buckets are filled which bring the excavated coal to the excavator suction zone, and then pumped, together with water, through the navigable and land pipeline to the coal drainage and grading plant. Coal is excavated by vertical cuts. The circular rotation of the excavator during coal excavation is done around the working pylon and is achieved by tightening the anchor cables to the left and right in relation to the direction of movement of the excavator. Namely, in operation, the excavator is anchored with two side anchors (Figure 10), which are in the function of the circular movement of the excavator. The center of the circular motion of the excavator and the digging radius is the working pylon located in the rear of the excavator pontoon. The rotation of the excavator in the horizontal plane (circular movement) is limited on both sides to a maximum of 40 °.

Figure 9 Dredge with buckets shown (photo documentation of Kovin mine) [12]

Figure 10. Anchoring of pipelines and dredgers (photo documentation of Kovin mine) [12]

Considering that the defensive embankment was neither designed, nor dimensioned, nor constructed to receive the loads to which it is currently exposed, it was necessary to perform a certain scope of investigative works in order to determine the current condition of the embankment and assess the possibility of further safe use of the embankment. For that cause the following working phases were performed based on the defined algorithm (Figure 6):

- Phase 1 - macroscopic observations
- Phase 2 - geotechnical works
- Phase 3 - model formation
- Phase 4 – modeling

PHASE 1: MACROSCOPIC OBSERVATIONS

Engineering geological terrain reconnaissance was done before any works on the embankment, with the aim of determining the current condition of the embankment: locating the deformation occurrence in the embankment crown - on the road, as well as deformation in the embankment slopes, which could indicate the development of instability. The reconnaissance was performed by recording the slopes towards the Danube tributary. The slopes are paved with concrete slabs, with a continuous slope of 18-22^0, and the entire length of the embankment is overgrown with vegetation. Recording was also performed according to the defended part, which is not paved with concrete slabs, but the slope is overgrown with vegetation, it has a variable slope of 20-45°. Based on the performed geotechnical reconnaissance of the terrain in 2 phases, it was concluded that the following types of deformations occur:

Type I of deformation: the overflow of the bulk sand-gravel material over the basic embankment, is characteristic of the slopes towards the undefended part. Deformations are not pronounced in dimensions and do not affect the stability of the embankment. They were formed as a result of insufficient compaction of the added material (Figure 11a);

Type II deformation: gutters - erosion furrows along the perimeter of the embankment crown. This type of deformation is more pronounced on the slopes towards the defended part, where the ravines of the largest dimensions are 0.5 m wide and 20 cm deep. These deformations do not significantly affect the stability of the embankment (Figure 11b);

Type III deformation: depressions on the road: This type of deformation is less pronounced, at more locations on the road itself. This type of deformation does not affect the stability of the embankment, but affects the safety of traffic (Figure 11c);

Type IV deformation: holes in the crown of the old embankment, which is not used for mine haulage, they are not large in size and do not affect the stability of the embankment (Figure 11g).

PHASE 2: GEOTECHNICAL WORKS

Exploratory drilling was performed in order to define the geotechnical characteristics of the embankment and engineering geological characteristics of the embankment base, as well as to take samples for laboratory geomechanical testing. Exploratory drilling was performed by rotary method with continuous coreing without rinsing. The initial drilling diameter was ∅128 mm, and the final diameter ∅ 101 mm, while the coreing was performed using a core pipe and appropriate drilling accessories. Extrusion of the core from the core tube was performed hydraulically-water, and mechanically, with hammer blows on the core accessories. Groundwater levels were monitored during drilling. A total of 4 drills were drilled (Table 1). During drilling, the occurrence of groundwater in the well was monitored, and after the completion of the drilling process, the steady groundwater level was measured.

(a)

(b)

(c)

(d)

Figure 11 Registered types of deformations on the embankment: (a) Type I of deformations: overflow of the added sand-gravel material over the basic embankment; (b) Type II deformations: gutters - erosion furrows along the perimeter of the embankment crown; (c) Type III deformations: depressions on the road; (d) Type IV deformation: holes in the crown of the old embankment.

The standard penetration (SPT) experiment was performed with blows of small hammer weighing 63.5 kg on a penetration cylinder with a cone that fell freely from a 0.76 m height. The indentation is performed in three parts to a depth of 0.45 m (0.15 + 0.15 + 0.15) where the first 0.15 m is not taken due to disturbances in the ortho of the drill during drilling. The experiment is interrupted when the number of blows is greater than 50. A total of 28 standard penetration experiments were performed (7 in each exploration dill).

Table 1: Markings, depths and coordinates of drills

Exploratory drill	Initial borehole diameter (mm)	Final borehole diameter (mm)	Drill depth (m)
GM03-17	128	101	15,0
GM04-17	128	101	15,0
GM05-17	128	101	15,0
GM06-17	128	101	14,60

Laboratory tests were performed on soil samples from exploratory drills, in order to define the physical and mechanical properties of individual lithological members necessary for further geostatic calculations. Physical-mechanical tests were performed on 24 samples from all wells (Table 2).

Table 2: Depths of sampling, types and scope of performed laboratory geomechanical tests

Exploratory drill	Sample label	Depth of sample taken (m)	Test type			
			Granulometric composition, bulk density, natural humidity	Limits of plasticity	Direct shear	Shrinkage
GM03-17	GM03-17/1	1,2-1,5	+	+		+
	GM03-17/2	3,7-4,0	+		+	+
	GM03-17/3	5,5-5,8	+	+		+
	GM03-17/4	7,7-8,0	+		+	+
	GM03-17/5	9,6-9,8	+	+	+	+
	GM03-17/6	11,3-11,6	+			+
GM04-17	GM04-17/1	2,7-3,0	+	+	+	+
	GM04-17/2	3,3-3,5	+	+	+	+
	GM04-17/3	5,0-5,4	+		+	+
	GM04-17/4	6,5-6,8	+	+		+
	GM04-17/5	8,5-9,0	+		+	+
	GM04-17/6	11,7-12,0	+			+
GM05-17	GM05-17/1	2,5-2,8	+		+	+
	GM05-17/2	5,2-5,5	+			+
	GM05-17/3	7,5-7,8	+	+		+
	GM05-17/4	8,0-8,4	+	+		+
	GM05-17/5	10,3-10,6	+		+	+
	GM05-17/6	13,5-13,8	+		+	+
GM06-17	GM06-17/1	0,7-1,0	+			+
	GM06-17/2	1,7-2,0	+	+		+
	GM06-17/3	5,5-5,8	+	+	+	
	GM06-17/4	7,6-7,8	+	+	+	+
	GM06-17/5	9,4-9,7	+	+	+	+
	GM06-17/6	13,2-13,5	+			+

PHASE 3: MODEL FORMATION

Based on the exploration results, four relevant cross-sections of the embankment were formed. The geometrical characteristics of the model were defined on the basis of geodetic survey data, while the material characteristics of the model were established on the basis of the results of laboratory tests and experience from engineering practice (Table 3).

This paper presents the calculation results for model 4, at the GM06-17 drill site (Figure 12).

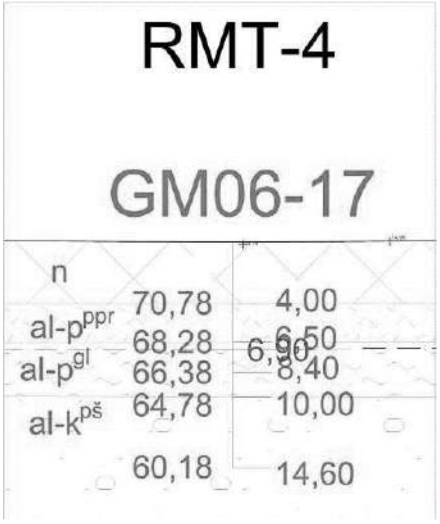

Figure 12. Geotechnical terrain model 4

Table 3. Values of parameters for physical-mechanical properties of isolated units adopted for calculations.

Environment	Parameter			
	Bulk density	Cohesion	Internal friction angle	Shrinkage module, σ=100-200kPa
Embankment	18,5	7,0	22,5	8200
Sandy dust facies flood	18,0	12,0	22,0	8300
Gray-blue clay facies flood	20,0	20,0	20,0	8500
Gravelly sands of the trough facies	21,0	6,0	25,0	15000

PHASE 4: MODELING

For the purposes of this paper, the relevant load was adopted on the basis of data on the frequency, dimensions and weight of loaded trucks, which cross the embankment:

- traffic frequency on the embankment:
  - on working days, in the height of the season, which lasts on average about 4 months (September-December), the average frequency is 100-120 trucks, and on weekends 60-80 trucks in one direction;
  - in the rest of the year, on average, about 50 trucks are loaded with finished products during the day (mostly coal and sometimes gravel);
- range - the truck dimensions are: the truck width is 2.40 m; the truck length with the box is 7.20 m (5.20 m box + 2.00 m length of the truck itself); the length of the truck with the trailer is about 16m;
- truck weight range (loaded): ranges between 25 and 40 tons of gross weight, which is the maximum permissible axle load on roads.

According to the experience from engineering practice, the calculation of stability in traffic load conditions was done for analog (equivalent) static load. Thereby the guidelines are taken from the Rule book on technical standards for determining the load sizes of bridges for evenly distributed load from vehicles type V300 (17 and 23kPa, for 25t and 40t trucks, respectively), at a width of one truck - 3m and 6m, in case of two trucks passing by.

Load calculation

The strength calculation - load limit or load-bearing capacity of the embankment was performed in two ways: by the Brinch–Hansen method [13] and by the Procedure from the Rule book on technical norms for the foundation of buildings [14]. The embankment load calculation was calculated for a traffic load of 14.1 kPa and 22.6 kPa, respectively a load of one or two trucks (Table 4).

Table 4. Load capacity results

Foundation length (m)	Foundation width (m)	Foundation depth (m)	PERMISSIBLE LOAD CAPACITY	
			Brinch-Hansen, kPa	Rule book on technical norms for the foundation of buildings, kPa
6	6	0	122,7	83,9
6	3	0	95,6	57,7

Subsidence claculation

The subsidence calculation is done by a conventional method based on the analogy of subsidence in the laboratory and in the field, from the following equation:

$$S_c = \frac{\Delta\sigma_z}{M_v}\,[\text{cm}]$$

where:

S_c – consolidation subsidence,

$\Delta\sigma_z$ – the increase of the vertical stress in the middle of the compressible layer from the additional load,

H – compressible layer thickness and

M_v – compressibility module in the middle of the compressible layer corresponding to the vertical stress increment.

The subsidence calculation results calculation are given in Table 5.

Table 5. Display of subsidence results for loading 14,1 kPa and 22,6 kPa

Load (kPa)	Subsidence (cm)
14,1	0,350
22,6	0,595

Sliding stability calculation

The calculation of the embankment stability at the drilled exploratory drill location was done by the simplified Janbu method [15]. Fadeev's procedure determined the zone within which the critical sliding circle is located [16]. In the first phase, the positions of five critical sliding circles within the zone determined by the Fadeev procedure were examined (Figure 13a). For each critical sliding circuit were considered three cases: no-load , with a 25 t load and with a 40 t load (Table 6, and Figure 13b).

Table 6. Display of safety factors for different positions of critical sliding circles, for different embankment loads

Critical circle label	No-load	With load 14,1kPa	With load 22,6 kPa
O_1	1.945	1,806	1,740
O_2	2,308	2,208	2,155
O_3	2,014	1,937	1,882
O_4	1,919	1,798	1,737
O_5	1,988	1,904	1,860

From the given table 6 it can be seen that the smallest safety factor for the critical sliding surface is O_4, and to consider the safety factor around the critical sliding surface, two sliding surfaces are added to determine the changing of the safety factor around the mentioned sliding surface O4 (Table 7).

Table 7. Display, safety factors for additional sliding surfaces

Critical circle label	No-load	With load 14,1kPa	With load 22,6 kPa
D_1	1,848	1,739	1,683
D_2	1,976	1,862	1,804

(a) (b)

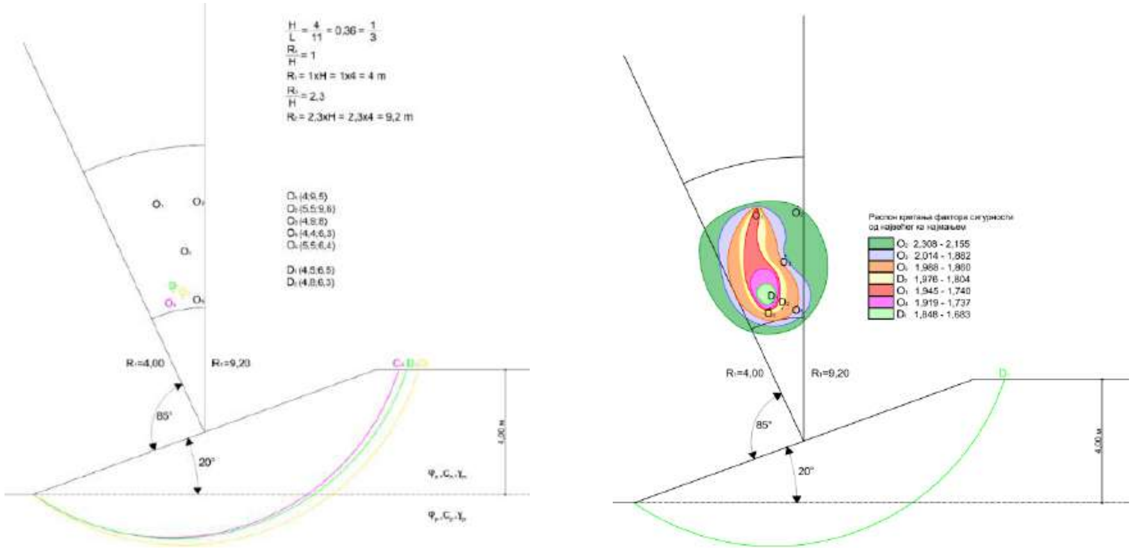

Figure 13. (a) Position of critical sliding circles within the space determined by the Fadeev method; (b) Results of safety factor calculations (Nikolić, 2018) [17]

DISCUSSION AND CONCLUSION

In the present paper, the authors propose a unique methodology for monitoring the stability of the hydrotechnical - defensive embankment that is loaded with heavy frequent traffic. The proposed methodology is in line with good engineering practice, and takes into account all possible aspects of the occurrence of instability of the defensive embankment that may occur during operation. The algorithm defined in the paper includes several phases of research: (1) macroscopic observations, (2) geophysical-geoelectric research, (3) field research (geodetic, geotechnical, hydrogeological), (4) formation of geotechnical and hydrogeological model, (5) establishment monitoring systems (geotechnical, geodetic, hydrogeological) and (6) modeling, which includes the processing of acquisition data, simulation of the current state and assessment of the behavior of the embankment in the conditions of future loads.

The authors illustrate the geotechnical works phase on the example of a defensive embankment on the Danube River, which is used by the Kovin mine for the needs of coal haulage. The frequency of traffic on the embankment on weekdays is in the height of the season (which lasts about 4 months on average), 100-120 trucks, and on weekends 60-80 trucks in one direction, while in the rest of the year on average about 50 trucks of finished products are loaded during the day. Range - truck dimensions are shown according to the specifications of the used haulage equipment (truck with box and truck with trailer). The weight range of the truck (loaded) is between 25 and 40 tons of gross weight, which is the maximum allowed axle load on our roads.

For the purpose of assessing the condition of the embankment, 4 phases of research were performed: (1) macroscopic observations; (2) geotechnical works; (3) model formation, (4) modeling. Based on the performed works, the following conclusions can be drawn:

- During the terrain reconnaissance, four types of deformations were registered: overflow of added material over the existing embankment crown, appearance of erosion furrows along the perimeter of the embankment crown, depressions on the embankment and depressions outside the embankment used for haulage. The registered deformations do not indicate the existence of an active sliding process, but can only affect the safety of vehicle movement on the embankment, and it is recommended to maintain the embankment with a grader that should align the crown of the embankment;

- The calculation of the strength or embankment load-bearing capacity was calculated by the Brinch-Hansen methods and the procedure from the Rule book on technical standards for the foundation of buildings. The obtained results show that the bearing capacity of the embankment is significantly higher than the load of 14.1 kPa and 22.6 kPa. Based on this, we can conclude that the embankment meets the needs for further transport;
- The calculation of embankment subsidence was performed by the conventional method (based on Terzaghi's theory of one-dimensional and Stteinbrenner stress distribution). The results showed that the terrain subsidence from trucks with a carrying capacity of 25 and 40 t ranges from 0.35-0.59 cm for the central point and indicates small subsidence values (maximum allowed subsidence for this type of object is 2.5 cm);
- For the calculation of the sliding stability of the embankment under traffic load, the corrected Janbu method was used, and for the determination of the critical sliding surface, on the basis of which a detailed calculation according to Janbu is made, Fadejev's procedure was used. The calculation was done for 5 critical sliding circles, for three characteristic cases: without load, with a load of 25 t and with a load of 40 t. An additional two points were examined around the critical sliding surface with the lowest Fs. In all these cases, the safety factor is above the prescribed values, Fs> 1.5.

Based on the results of the performed research works, it can be concluded that the haulage of coal across the defensive embankment does not endanger its basic function and does not lead to the occurrence of deformations that may endanger this same function in the future. However, considering that the haualge still takes place over the defensive embankment, it is recommended to establish a monitoring system, primarily the installation of fixed electrodes for geoelectric tests along the entire length of the subject section - about 3 km. After the establishment of this system, it is necessary to perform zero geoelectric tests, and then perform control geoelectric tests at least 2 times a year.

In case of registration of deformations or weakened zones, it is necessary to establish a system for geodetic monitoring, installation of geodetic benchmarks, which will serve for periodic monitoring of the movement of parts of the embankment slopes. In addition, it is recommended to install piezometer installations and groundwater levels observations on a number of transverse profiles, at least four times a year, and especially after extreme hydrometeorological conditions. It is necessary in order to form a sufficient data base for calculating the filtration stability of embankments and hydrogeological modeling. Based on the collected data and the formed base, it is necessary to start establishing a model for assessing the condition / change of the embankment condition for different load cases, and different hydrometeorological conditions.

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