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GEOTECHNICAL CHARACTERISTICS OF EMBANKMENT ALONG THE RAILWAY ROUTE OF ENTITY BORDER OF FEDERATION OF BIH – MAGLAJ, SECTION km 103+500 MAGLAJ

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ABSTRACT

Railway route from entity border to Maglaj is on corridor V of railways that connects Adriatic sea with European Union countries. More precisely, it is on the railway Samac – Sarajevo that was built during the fifties. From Doboj to Zenica exist two tracks, one built in 1947. and the other thirty years later. In time, the railway worn out, since it was not maintained properly during its exploitation, so allowed train speed is 40 km/h. Reconstruction of railway had previously started on sections with aim to achieve the level of train speed to 120 km/h.

Terrain research in order to overview quality of material on which the railway is laid, and immediate environment that has effect on railway route, were conducted by sections, from which section km 103+500 – Maglaj is one of the most important considering characteristics of the terrain on which the route passes. Research along railway route were conducted by using research trial pits from both sides and in between tracks, to depth of entry in basic soil. Depth of research works is different for old and new track, considering the way of construction in time period of 30 years. Beyond narrow corridor of railway route research of characteristics of the terrain were not conducted, because of inability to access due to mining. Results of terrain and laboratory tests showed geotechnical characteristics of material, based on which were given quality improvement measures for deposited materials, and base for reconstruction of railway.

Key words: *railway route, track, terrain, research trial pits, embankment*

INTRODUCTION

Within revitalization of railways in Bosnia and Herzegovina, priority was given to railway route Samac – Sarajevo, that represents corridor V and connects Adriatic sea with European Union countries. Revitalization was planned in phases, and special priority was given to section Doboj – Zenica, on which is railway with two tracks. The first track was built in 1947, and the second 30 years later. At some time they were maintained enough for normal railway traffic, whose speed was reduced to 40 km/h.

New demands in increase of train speed up to 120 km/h, demanded reconstruction of railway, along its entire route. Complexity of geological structure of the terrain along the railway route, mining, poor maintenance during exploitation, especially parts of the railway that are outside of narrow route corridor, demanded detail research of embankment characteristics, as well as terrain that has an effect on railway route. Section of railway route from Doboj to Zenica on chainage km 103+500 – Maglaj, figure 1, represents one of more complex for research, and for reconstruction, because of inability to move outside narrow route of corridor, due to terrain being mined.

Figure 1. Section km 103+500 – Maglaj on route of corridor V

Along the railway route were conducted research works with trial pits, depth to basic soil. Their depth is different depending from height of embankment and track next to which were conducted. Old track is characterized with smaller embankments, while the new is built by more modern regulations, that resulted with higher height of embankment. Open profiles of trial pits were mapped, dynamic circular plate Evd tests were conducted and disturbed and undisturbed samples for laboratory tests were taken.

CONDUCTED RESEARCH WORKS AND LABORATORY TESTS

Railway has two tracks that go parallel along the route, except one part where they separate in length of about 100 m, with the biggest distance, between them being 40 m. Research works were conducted on sides and between tracks to depth of about 0,2 – 0,3 m in basic soil [1,2,3,4,5,6,7]. Average depth to basic soil ranges from 0,7 – 1,2 m, and smaller number of trial pits is of bigger depth, from 2,5 m, figure 2.

Figure 2. Cascade making of research trial pit IJ – 16

Different depths of trial pits are related to period of construction of railway track, because the embankment of old track is considerably smaller, figure 3.

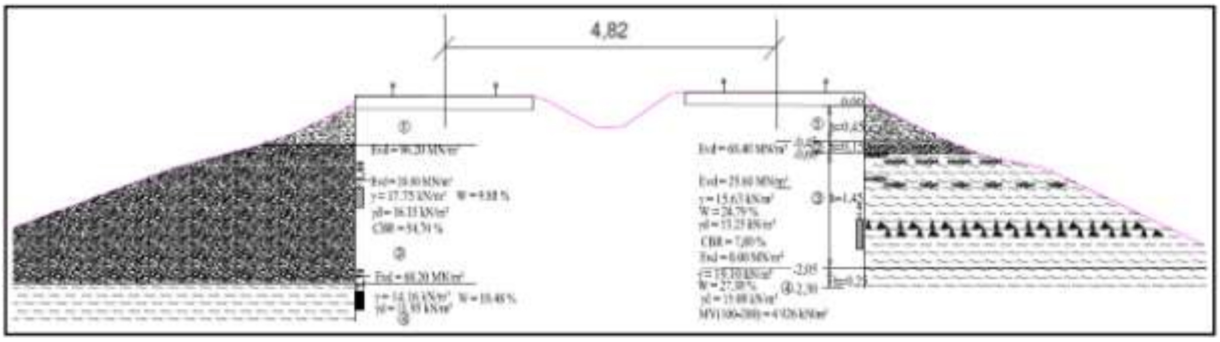

Figure 3. View of embankment along new and old track of railway route

On researched section were done 46 trial pits. In every trial pit was conducted minimally one dynamic plate (Evd) test, and in more depth trial pits test was repeated with depth, so on some, were done four (4) tests. In total were done 88 tests, table 1.

Table 2. The dynamic deformation modulus in research trial pits

Test depth (m)	Total	Track		Between tracks	The dynamic deformation modulus (MN/m^2)
		Right (old)	Left (new)		Evd
< 0,5	34	8	9	13	21,18-75,41
0,5 - 1,0	47	12	15	12	19,76-82,50
1,0 - 1,5	10	3	2	3	13,34-66,11
1,5 - 2,0	3	-	1	1	14,32-47,91
> 2,0	10	1	3	5	<10-63,43
Total	88	24	30	34	

From every trial pit was taken one disturbed or undisturbed sample, and from deeper trial pits two, in total 52 samples, from which were processed 46, table 2. Undisturbed samples were taken from basic soil, immediately below the embankment.

Table 2. Overview of conducted terrain research works

Trial pits depth (m)	Total	Track		Between tracks	Samples	
		Right	Left		Disturbed	Undisturbed
< 1,0	18	4	10	4	16	2
1,0 – 2,0	21	3	13	5	19	1
> 2,0	7	1	2	4	6	2
Total	46	8	25	13	41	5

Laboratory tests on samples covered determination of physical - mechanical characteristics. Identification - classification, resistant - deformable tests and compactness tests were done, table 3.

Table 3. Laboratory tests on taken samples

Trial pits depth (m)	Total	Granulometric content	Bulk density	Atterberg limits	Direct shearing	Compressibility	Proctor test and CBR
< 1,0	18	18	18	2	2	2	17
1,0 – 2,0	21	21	21	1	1	1	19
> 2,0	7	7	7	2	2	2	3
Total	46	16	17	5	5	5	39

Identification – classification tests, covered natural moisture (ω), granulometric content, bulk density in natural state of moisture (γ), bulk density of dry sample (γ_d), Atterberg limits of consistency (ω_l, ω_p, I_p, I_l i I_c) on samples of basic soil [5,8,9,10].

Deformability tests were conducted in conditions of oedometer compression with prevented lateral spreading. The initial load is σ = 100 kN/m^2, and every following load is twice the size of previous and is σ = 200 kN/m^2, σ = 400 kN/m^2 ie σ = 800 kN/m^2.

Direct shearing tests were conducted on samples of soil, dimensions 6 x 6 x 2 cm, with consolidation of 24 hours, for load values σ = 50 kN/m^2, σ = 100 kN/m^2 and σ = 150 kN/m^2.

Proctor's and CBR tests were performed on standard quantity of disturbed samples taken from research trial pits. Characteristics of load capacity of embedded material in existing embankment were analyzed, with evaluation of lower layer load capacity, ie railway embankment.

GEOTECHNICAL CHARACTERISTICS OF EMBANKMENT

Represent materials that build deposited part of the terrain over which the railway is laid. Embankment is laid along the route on basic soil of different lithological content whose basic characteristics are:

Dusty sandy, gravelly clay is a natural soil with values of basic parameters:
natural moisture ω = 27,11 – 29,01 %, optimum moisture by Proctor $\omega_{opt.}$ = 12,37 %
values of laboratory CBR = 16,70 %

Dusty sand is a natural soil of modern sediments, has the following parameters:
natural moisture ω = 15,33 – 18,48 %, optimum moisture by Proctor $\omega_{opt.}$ = 11,83 %
values of laboratory CBR = 18,20 %

Delluvial dusty sandy clays are the natural soil with parameters:
natural moisture ω = 23,59 – 30,48 %, optimum moisture by Proctor $\omega_{opt.}$ = 11,83 %
values of laboratory CBR = 18,20 %
Atterberg limits of consistency:
flow limit ω_l = 63,54 %, plasticity limit ω_p = 28,39 %, plasticity index I_p = 35,47 %,
flow index I_l = 0,059, consistency index I_c = 0,941

Deluvial dusty sand is a natural soil of modern sediments with parameters:
natural moisture ω = 19,86 %, optimum moisture by Proctor $\omega_{opt.}$ = 10,68 %,
values of laboratory CBR = 28,50 %

Jurassic-Cretaceous sand, dusty sand is a natural soil, characterized by the following parameters:
natural moisture ω = 15,57 %, optimum moisture by Proctor $\omega_{opt.}$ = 11,88 %,
values of laboratory CBR = 21,80 %

Characteristics of deposited materials, obtained with terrain and laboratory tests are the following:

Superstructure consists of crushed stone surfacing, built from limestone debris, dirty, with traces of other materials, size 8,0 – 10,0 cm. It has relatively good physical – mechanical characteristics. Depth of surfacing prism per tested chainages is from 0,2 – 0,9 m. Values of dynamic deformation modulus Evd are the following:

The dynamic deformation modulus (MN/m^2)
Evd = 20,03-76,27, Ev_1 = 19,29-75,50, Ev_2 = 45,66-140,00

Foundation consists of protective buffer layer built of sandy gravel and layer of embankment built of different mixture of material such as natural soil from material borrow pits (dusty sandy clay, sand, gravel) and technogenic materials (crushed aggregate with clayey sandy filling).

Protective (buffer) layer is built of sandy gravel. Grain diameter that corresponds to ordinate 60% - d_{60} goes from 1,415 to 19,990, and grain diameter that corresponds to ordinate 10% - d_{10} goes from 0,0599 to 0,825, which indicates that material embedded in buffer layer is of similar granulometric content on all tested sections. According to Allen Hazen degree of soil unevenness C_u goes from 24,68 to 355,33, which indicates that buffer layer is of moderately evenly to unevenly content. Basic parameters are the following:

natural moisture $\omega = 2{,}26 - 9{,}41$ %, optimum moisture by Proctor $\omega_{opt.} = 7{,}41 - 10{,}16$ %,
values of laboratory CBR = 31,60 - 71,12 %, dynamic deformation modulus (MN/m^2)
Evd = 19,15-82,50, Ev_1 = 10,50-63,16M, Ev_2 = 18,00-136,80

Depths at tested chainages where protective layer was possible to separate from embankment layes, goes from 0,06 m - 0,6 m, and on some sections was not embedded.

Embankment on new railway track is built of different mixture of materials such as natural soils from material borrow pits (dusty, sandy clay, sand, gravel) and technogenic materials (crushed aggregate with clayey sandy infill), figure 4.

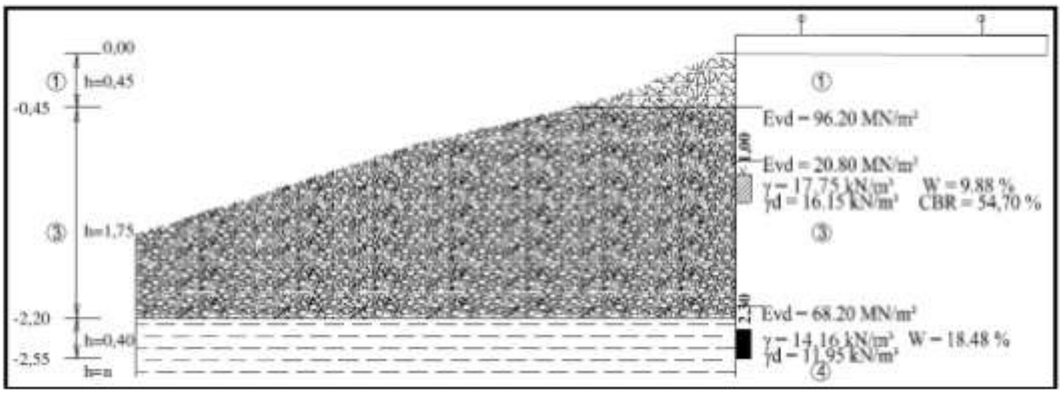

Figure 4. View of embankment on new track of railway route
1. crushed stone surfacing, 3. embankment, 3.basic soil

Grain diameter that corresponds to ordinate 60% - d_{60} goes from 0,951 to 29,13, and grain diameter that corresponds to ordinate 10% - d_{10} goes from 0,0031 to 1,994, which indicates that material embedded in embankment is of similar granulometric content on all tested sections. Grain diameter in earth embankment that corresponds to ordinate 60% - d_{60} goes from 0,0301 to 0,0722, and grain diameter that corresponds to ordinate 10% - d_{10} goes from 0,0015 to 0,0028 According to Allen Hazen degree of soil unevenness C_u goes from 4,50 to 688,60 which indicates that embankment material is of uneven content, and in earth embankments level of soil unevenness C_u goes from 25,62 to 31,79, which indicates that material of earth embankments is of even content [7,8,9]. Basic parameters are the following:

natural moisture of
technogenic materials $\omega = 2{,}54 - 32{,}20$ %, earth embankments $\omega = 15{,}51 - 24{,}79$ %
optimum moisture by Proctor of
technogenic materials $\omega_{opt.} = 7{,}02 - 10{,}69$ %, earth embankments $\omega_{opt.} = 12{,}35 - 15{,}22$ %
values of laboratory CBR-a

technogenic materials CBR = 27,40 - 75,30 %, earth embankments CBR = 7,80 - 13,60 %
The dynamic deformation modulus by depths of embankments has the following values in MN/m^2

1,0 - 1,5 m	Evd = 14,40-64,30, Ev_1 = 11,00-62,30, Ev_2 = 19,10-138,60
1,5 - 2,0 m	Evd = 14,90-47,07, Ev_1 = 11,23-42,84, Ev_2 = 19,70-104,00
> 2,0 m	Evd = < 10-68,20, Ev_1 = 18,50-66,20, Ev_2 = 15,05-146

Embankment on old track is almost not present or is present in morphologically more developed parts of the terrain along railway route. Crushed stone surfacing is set on basic soil, figure 5. In part where there is embankment, is of similar characteristics as the embankment of new track, considering that material was taken from the same borrow pits that are in the immediate proximity.

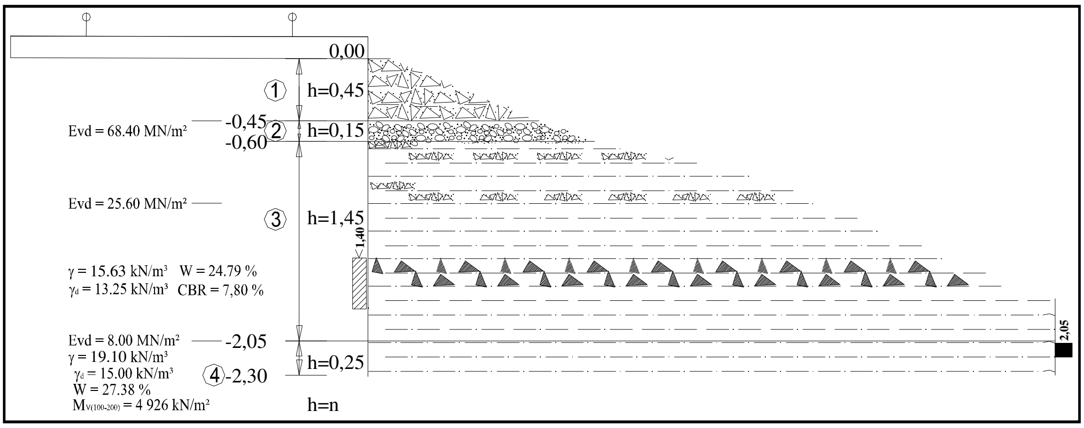

Figure 5. View of embankment on old track of railway route
1. crushed stone surfacing, 2. embankment, 3, 4. basic soil

Crushed stone surfacing is built of limestone debris and other materials, size from 8,0 – 10,0 cm, goes around 0,6 m. Values of dynamic deformation modulus Evd are the following:

The dynamic deformation modulus (MN/m^2)

$Evd = 26{,}56\text{-}60{,}50$, $Ev_1 = 29{,}79\text{-}58{,}50$, $Ev_2 = 49{,}79\text{-}131{,}00$

GEOTECHNICAL CONDITIONS AND MEASURES FOR RAILWAY RECONSTRUCTION

On two track railway section Inter entity boundary line – Maglaj, chainage km 103+500 – km 108+900, total 5,4 km, should be done a railway reconstruction, that would include the following:

- on superstructure of the railway removal of old surfacing built from limestone crushed stone,
- on foundation of railway removal of old protective (buffer) layer, on sections on which it is embedded,
- on certain sections replacement of damaged parts of embankment

In planum, embankment will be compacted by valid technical regulations to the predicted values for the embankment layer, and transitional layer, then will be performed embedding and compacting of new protective layer, and embedding of new crushed stone surfacing [1,2,4,8,9,11]. The following conditions will be satisfied:

- for conducting sanation of railway foundation is needed minimal deformation modulus $E_{vd} \geq 55\ MN/m^2$.
- railway planum– buffer of gravel for needed thickness compact till the achievement of values $E_{vd} \geq 55\ MN/m^2$.
- railway planum – transitional (improved) layer make from materials for embankment construction, by regulation required value where is respected filter rule, that needs to be embedded in layer, thickness of 30,0 cm with compression of layer, till the achievement of dynamic deformation modulus $E_{vd} \geq 40\ MN/m^2$.
- Embankment hull – gravel for needed thickness compact till the values regulated by standards $E_{vd} \geq 25 – 30\ MN/m^2$.

- subsoil – natural terrain should be done according to by regulation demanded values, in zone of notch and low embankments, and it should be respected the rule of exchange of certain depth with material that should be altered, so it could be achieved dynamic deformation modulus $E_{vd} \geq 25 - 30$ MN/m^2.

During conduction of reconstruction, independent from technology with which will be conducted sanation of foundation, including the procedure of „screening“ of surfacing and machine embedding of protective layer below surfacing, it is necessary to plan and do detail geotechnical research of foundation (especially earth planum) and determine its characteristics, and condition in which it is.

Considering that reconstruction will be conducted, independent from the technology, recommendations refer to classical reconstruction which will be conducted. With screening and mechanical embedding of buffer and crushed stone, compaction of earth planum, and making of inclination (3 – 5%) of planum for dewatering cannot be properly done. Parts of embankment, where „gravel sacks“ and „crushed stone sacks“ are bigger, also cannot be sanitized on this way, which represents a significant problem in this method.

For improvement of railway condition, especially at old embankments that were made from less load capacity soil from local material trenches, repaired several times by crushed stone filling for maintenance of grade level, should be paid attention on places where are detected demages of track. Damages refer to delevelling – subsidence, lateral movement of track, high humidity of earth planum, impressing of surfacing in hull, deformation of foundation hull, loss of transverse inclination of planum, bulged out inclinations at embankments, mass sliding on inclinations, nonfunctioning of dewatering system of surface and especially groundwater. All mentioned deformations are possible, on some parts of the railway.

Basic task of protective layers (buffer) is maintenance (protection) from traffic load and exogenous factors. This layer should protect crushed stone surfacing from penetration („pumping into“) small particles from foundation. On section are possible constant deterioration of altitudinal track position, which demands increase of maintenance costs. Appearances of „pumping into“ (suction of water and small particles), muddying of crushed stone surfacing, impressing of crushed stone surfacing in earth planum (creating of crushed stone sacks), softening of earth planum at unfreezing (because of creating ice lenses during frost) are possible on this part of the railway.

It is necessary to test material for making of protective layer, aggregate (sandy gravel or crushed stone aggregate) before the embedding. Testing should be done from the aspect of mineralogical characterization (strength and constancy), granulometric content (granulometric curve, level of unevenness participation of small muddy and clay fractions and coarse fractions of gravel and debris).

It is mandatory to respect the criteria of filter stability, ie prevention of small particles penetration from foundation in crushed stone and its muddying, due to water influence and dynamic load caused by traffic. In order to test the stability of the filter buffers, it is necessary to conduct granulation of buffers and earth planum.

In addition to these general remarks, during the research were defined and allocated all zones per chainages with a specific proposal for reconstruction. Considering that reconstruction will be done without traffic jam, it is necessary to harmonize dynamics of reconstruction of certain tracks.

CONCLUSION

Researched section of railway belongs to corridor V that connects Adriatic sea with European Union countries. It is located on old route Samac – Sarajevo, that was built in two time periods. The first track was built in 1947, and the second 30 years later. Different period of construction characterizes also the way of construction, primarily in part of material over which the railway is laid. Forty years later both tracks are dilapidated to the extent that traffic speed on them about 40 km/h. New demands are the increase of speed to 120 km/h, which demands complete reconstruction of railway, which will be done per sections.

Railway reconstruction demanded previous research of its route, characteristics of embedded material, level of damage, and characteristics of the terrain over which passes the railway. From research works were conducted research trial pits on sides and between tracks to depth of 0,2 – 0,3 in basic soil. Average depth to the basic soil is from 0,7 – 1,2 m, and smaller number of trial pits is deeper than 2,5 m. In researched trial pits were conducted dynamic compressibility modulus and were taken samples for laboratory tests. Terrain research beyond narrow part of the railway route was nod conducted because of inaccessibility of terrain due to mining.

Characteristics of embankment determined on terrain and in laboratory are different, especially in part of old and new track, but gave sufficient indicators to which extent and on what section should conduct a replacement. Allocated were all sections with characteristic occurrences and way of reconstruction with quality embedding of material and its compactness, all with aim to create conditions for required speed.

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