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CONTROL OF SUBSTRUCTURE CONSTRUCTION OF RAILWAYS IN THE REPUBLIC OF SERBIA

Abstract

Control of compaction of natural soil (in excavation) or compacted in the embankment during the construction of roads is one of the basic forms of quality control of the substructure. When building high-speed roads (highways and high-speed railways), the priority is to achieve a high level of control over the performed work. In order to prevent differential settlement (during the construction of the embankment), or to change the volume due to additional compaction of the material, which inevitably leads to deformations, it is necessary to perform optimal compaction of the material. Within this paper, the technical regulations governing the control of compaction in the construction of railway infrastructure in the Republic of Serbia are presented.

Keywords: substructure, technical regulations, embankment, compaction, control

КОНТРОЛА ИЗГРАДЊЕ ДОЊЕГ СТРОЈА ЖЕЛЕЗНИЧКИХ ПРУГА У РЕПУБЛИЦИ СРБИЈИ

Сажетак

Контрола збијености природног тла (у ископу) или збијеног у насипу при изградњи саобраћајница представља један од основних облика контроле квалитета доњег строја. Код изградње брзих саобраћајница (аутопутеви и брза железница) приоритет је постизање високог нивоа контроле извршених радова. У циљу онемогућавања диференцијалног слегања (при изградњи насипа), или промене запремине услед допунског збијања материјала, које неминовно доводе до деформација, потребно је извршити оптимално збијање материјала. У оквиру овог рада приказује се техничка регулатива која регулише контролу збијености при изградњи железничке инфраструктуре у Републици Србији.

Кључне ријечи: доњи строј, техничка регулатива, насип, збијеност, контрола

1. INTRODUCTION

For many years, the railway network of the Republic of Serbia was unmaintained, technically lagging behind the railway networks of surrounding and developed European countries. With the started works of reconstruction and modernization of the railway, there was a need, for various reasons, to build substructure of the railway as high quality as possible, whether it is the reconstruction, rehabilitation of the existing or construction of a new one. As a consequence, there is a significant control of construction, especially compaction.

Taking into account the above, the technical regulations applied during construction were adopted, which are harmonized with the regulations of European countries, as follows:

In 2006, Instructions 338 were adopted for the control of compaction of the substructure of railway tracks by the dynamic method with a light falling weight (Light Weight Deflectometer) device on the JŽ railway network.

In 2012, the Regulations on the design of reconstruction and construction of specific elements of the railway infrastructure of certain main railway lines were adopted ("Official Gazette of the RS", No. 100/2012).

In 2016, the Regulations on technical conditions and maintenance of the substructure of railways were adopted ("Official Gazette of RS", No. 39/2016 and 74/2016).

The paper presents the technical conditions for compaction testing according to the mentioned regulations as well as the state of control applied in practice (during construction). Also, the paper points out the shortcomings of such application of control and the proposal of a possible solution.

2. EXISTING TECHNICAL REGULATIONS

This chapter presents the conditions for controlling the compaction of the protective layer, transition layer, embankment, foundation soil under the embankment and soil control on the part of the railway trunk in the cut.

2.1. INSTRUCTION 338

Table 1.Required values of compaction and degree of unevenness [1:12-12]

Type of railways			**Planum of the railway /on top of the protective layer /**				**Planum of the railway /on top of the transition layer/**			
			Rc*	**Ev_2 N/mm^2**	**Degree of unevenness**	**Evd N/mm^2**	**Rc***	**Ev_2 N/mm^2**	**Soil groups by AC classification**	**Evd N/mm^2**
Construction	**Main arterial route**		1,03	120	U>15	50	1,00	80	GU,GP,GW, GF,SP,SW all other soil types	40 35
Construction	**Regional railway**		1,00	100	U>15	45	0,97	60	GU,GP,GW, GF,SP,SW all other soil types	35 30
Construction	**Local railway and industrial rails**		0,97	80	U>15	40	0,95	45	GU,GP,GW, GF,SP,SW all other soil types	30 25
Maintenance	**Existing**	**V >160** km/h	0,97	80	U>15	40	0,95	45	GU,GP,GW, GF,SP,SW all other soil types	30 25
Maintenance	**Existing**	**V ≤160** km/h	0,95	50	U>15	35	0,93	20	GU,GP,GW, GF,SP,SW all other soil types	25 20

*in the Instruction Dpr

According to Instruction 338, the conditions for the installation of the protective and transition layer are given. Table 1 shows the required values of the dynamic modulus of deformation Evd together with the required values of the modulus of deformation Ev_2. Determining the correlation coefficient between the deformation modulus Ev_2 and Evd can be applied in special cases when soil homogeneity is ensured (by composition, by granulometric composition and moisture) and in statistically reliable research conditions [1:11-11].

2.2. REGULATIONS FOR MAIN RAILWAYS ("OFFICIAL GAZETTE OF RS", NO. 100/2012)

These Regulations define the minimum quality requirements for materials installed in the layers of the substructure. The minimum requirements are prescribed by the values of the degree of compaction Rc*, ie the values of the deformability modulus Ev_2 whose definition is contained in SRPS U.E1.010, ie in DIN 18134. The criteria to be met by the materials installed in the protective and transition layer are given in Table 2, while the criteria for embankments are given in Table 3.

Table 2. Minimum value of deformability modulus Ev_2 and degree of compaction Rc for the protective and transition layer of the substructure [2:37-37]*

Type of railways	**Planum of the railway protective layer**		**Transition layer**		Minimum thickness constructions safe on frost including the protective layer of the planum		
					Frost action zone		
	E_{V2} (MN/m^2)	Rc*	E_{V2} (MN/m^2)	Rc*	I (m)	II (m)	III (m)
Open track tracks, running (through) track and relief tracks	120	1,00	80	1,00	0,50	0,60	0,70
other tracks	80	0,97	45	0,95	0,30	0,40	0,50
Note: Until the detailed zoning of Serbia on frost for all railways within the Corridor X project, adopt zone III of the area of frost for calculations.							

*in the Regulations Sd

Table 3. Minimum values of deformability modulus and degree of compaction for embankment [2:37-38]

a) Embankment height H > 2,00 m		
	Railway planum level	E_{V2} = 120 MN/m^2
	Protective layer	E_{V2} = 80 MN/m^2
	Transition layer	E_{V2} = 60 - 45** MN/m^2
Below the transition layer to depth 2,0 m		E_{V2} = 45 MN/m^2 or Rc* > 100%
Below the transition layer to depth > 2,0 m		E_{V2} = 20 MN/m^2 or Rc* > 95%
b) Embankment height H ≤ 2,00 m		
	Railway planum level	E_{V2} = 120 MN/m^2
	Protective layer	E_{V2} = 80 MN/m^2
	Transition layer	E_{V2} = 60 MN/m^2
	Below the transition layer	E_{V2} = 45 MN/m^2 or Rc* > 100%
v) For the railway in the cut		
	Railway planum level	E_{V2} = 120 - 80** MN/m^2
	Protective layer	E_{V2} = 80 - 45** MN/m^2
	Transition layer	E_{V2} = 45 MN/m^2
	Below the transition layer	E_{V2} = 45 - 20** MN/m^2 or Rc* > 95%

- **in the Regulations Sd*
- *values with ** are valid for other tracks, according to the table*

- *the degree of compaction Rc* is applied here on the soil with a maximum grain size of 5 mm, and in relation to the maximum value of the unit weight in the dry state obtained by the experiment of laboratory compaction according to SRPS U.B1.038, ie according to St. Proctor Test.*

The following conditions are defined for the protective and transition layer [2:38-38]:

The protective layer is formed of coarse-grained gravelly soil with a coefficient of uniformity greater than U = 15, provided that it does not contain more than 3% of grains up to 0.02 mm in size, which achieves safety against frost. The granulometric composition should meet the filter criteria in relation to the underlying layer. The maximum grain size is up to 60 mm, water permeability coefficient $k \geq 1x10^{-4}$ m/s at the degree of compaction Rc = 1.0. The minimum thickness is 0.20 m, and together with the transition layer, it should meet the conditions of safety against frost [2:38-38].

The transition layer is formed of coarse-grained gravelly or sandy soil, provided that at a uniformity coefficient U ≥ 15 it must not contain more than 3% of grains up to 0.02 mm in size, and at U ≤ 5 it must not contain more than 10% (Casagrande's criterion). For the intermediate values of the coefficient U, the grain content of fractions smaller than 0.02 mm is determined by linear interpolation [2:38-38].

The material in the transition layer should meet the filter criteria in relation to the underlying layer or to be protected by geotextile filter plastic, defined by the project [2:38-38].

In the zones with water protection of the foundation soil and the surrounding terrain, protective sealing measures are applied both in and outside of the transition layer for the purpose of controlled drainage of polluted water (or other liquids), and according to the pollution protection solution.

The transverse slopes of the planum are 5%, with a protective layer being formed on the embankments up to the edge of the embankment, and in the cuts or railway stations to the facilities for longitudinal drainage [2:38-38].

2.3. REGULATIONS FOR MAINTENANCE OF SUBSTRUCTURE ("OFFICIAL GAZETTE OF RS", NO. 39/2016 AND 74/2016)

These regulations regulates the construction of the substructure with defined criteria.

The compaction and bearing capacity of the earth carcass layers is assessed by the static deformation modulus Ev2, which is determined by the test plate, while the control is performed by the dynamic deformation modulus Evd, which is determined by the light falling load experiment with base plate Ø300 mm. Technical conditions for the quality of the material installed in the layers of the substructure in terms of the value of the degree of compaction Rc*, ie the size of the deformation modulus Ev2, are determined by the standard SRPS U.E1.010 and SRPS U.B1.047.

When building new and improving and renovating existing railways, the installation of a protective layer is mandatory.

The surface of the protective layer meets the conditions [3:3-4]

- flatness of the soil material layer ≤ 20 mm / 4 m;
- flatness of the stone material layer ≤ 30 mm / 4 m;
- transverse slope of the layer ≥ 5% with a tolerance of up to ± 0.4%;
- the maximum deviation of the elevation from the projected one is ± 10 mm;
- the minimum thickness of the protective layer is 20 cm, and in the case of thickness > 30 cm it is installed and compacted in two layers.

Load-bearing capacity at the level of the railway planum meets the following requirements:

- for the construction and improvement of open track tracks and main tracks on main railways Ev2 > 120 MN/m^2, Ev2 / Ev1 ≤ 2.2, Evd > 50 MN/m^2, 100% ≤ Rc* ≤ 103%;
- for the construction and improvement of open railway tracks and main tracks on regional railways Ev2 > 100 MN/m^2, Ev2/Ev1 ≤ 2.2, Evd > 45 MN/m^2, Rc* ≥ 100%;
- for the construction and improvement of tracks on local railways and secondary tracks on all railways Ev2 > 80 MN/m^2, Ev2/Ev1 ≤ 2.2, Evd > 40 MN/m^2, Rc* ≥ 97%

where the ratio Ev2/Ev1 ≤ 2.2 is valid for Ev1 less than the minimum value prescribed for Ev2.

The protective layer as a filter must have water permeability, and the flow rate cannot be so high that the particles are washed away. To achieve this:

- the diameter of the grain belonging to the ordinate 15% of the granulometric curve of the protective layer must be four times smaller than the grain size in the ordinate 85%, d85 ≥ 4 x d15;[6:2-2]
- the maximum grain size should be ≤ 60 mm;
- the degree of non-uniformity must be U = d60/d10 ≥ 15;

- the water tightness coefficient should be $K \geq 10^{-4}$ m/s at Rc* = 1, which ensures that the leakage curve should end in a protective layer on the slope of the embankment or drainage ditch at maximum precipitation.

It is necessary to dimension the protective layer to protect the soil from frost. The necessary condition is that U ≥ 15 does not contain more than 3% of fractions smaller than 0.02 mm, which prevents capillary rise of water and the formation of ice lenses, which causes uplift during formation, and when melting, the track settles.

The protective layer cannot be located in the area of groundwater impact.

The transition layer is a compacted or improved layer made of coarse-grained gravel or sandy material and together with the protective layer forms frost protection [3:4-5].

Clay materials and materials that can be compacted and consolidated cannot be installed in the transition layer.

The surface of the transition layer meets the conditions:

- flatness of the soil material layer ≤ 20 mm/4 m;
- flatness of the stone material layer ≤ 30 mm/4 m;
- transverse slope of the layer ≥ 5% with tolerance up to ± 1%.

The load-bearing capacity of the transition layer meets the conditions:

- for the construction and improvement of open track tracks and main tracks on main railways Ev2 > 80 MN/m^2, Ev2/Ev1 ≤ 2.2, Evd ≥ 35 MN/m^2, Rc* ≥ 100%;
- for the construction and improvement of open railway tracks and main tracks on regional railways Ev2 > 60 MN/m^2, Ev2/Ev1 ≤ 2.2, Evd ≥ 30 MN/m^2, Rc* ≥ 97%;
- for the construction and improvement of tracks on local railways and secondary tracks on all railways Ev2 > 45 MN/m^2, Ev2/Ev1 ≤ 2.2, Evd ≥ 25 MN/m^2, Rc* ≥ 95%

where the ratio Ev2/Ev1 ≤ 2.2 is valid for Ev1 less than the minimum value prescribed for Ev2.

When creating a transition layer, the following is used:

- capillary rise resistant material;
- unbound aggregate, grain size 0/125 mm;
- percentage of aggregate grains below 0.063 mm < 12%;
- percentage of aggregate grains below 0.02 mm < 5%;
- U ≥ 15 does not contain more than 3% of fractions smaller than 0.02 mm and U ≤ 5 does not contain more than 10% of fractions smaller than 0.02 mm.

The material in the transition layer should meet the filter criteria in relation to the underlying one or be protected by the use of artificial filter materials, such as geotextiles.

The load-bearing capacity of the embankment layers, except for the load-bearing capacity at the level of the protective and transitional layer planum, for the construction and improvement of open track tracks and main tracks on main and regional railways meets the conditions [3:5-6]:

- at the level of the embankment planum below the transition layer Ev2 > 60 MN/m^2, Ev2/Ev1 ≤ 2.2, Evd ≥ 30 MN/m^2, Rc* ≥ 100%;
- at the level below the embankment planum to a depth of ≤ 2.0 m Ev2 > 45 MN/m^2, Ev2/Ev1 ≤ 2.2, Evd > 25 MN/m^2 or Rc* > 100%;
- at the level below the embankment planum for depths > 2.0 m Ev2 > 20 MN/m^2, Ev2/Ev1 ≤ 2.2, Evd > 20 MN/m^2 or Rc* > 95%;
- for railways in the cut Ev2 > 45 MN/m^2, Ev2/Ev1 ≤ 2.2, Evd > 25 MN/m^2 or Rc* > 95%

where the ratio Ev2/Ev1 ≤ 2.2 is valid for Ev1 smaller than the minimum value prescribed for Ev2.

The load-bearing capacity of the embankment layers, except for the load-bearing capacity at the level of the protective and transition layer, for other tracks and local railways meets the conditions:

- at the level of the embankment before the transition layer Ev2 > 45 MN/m^2, Ev2/Ev1 ≤ 2.2, Evd ≥ 25 MN/m^2, Rc* ≥ 100%;
- at the level below the embankment planum to a depth of ≤ 2.0 m Ev2 > 45 MN/m^2, Ev2/Ev1 ≤ 2.2, Evd> 25 MN/m^2 or Rc* > 100%;
- at the level below the embankment planum for depths > 2.0 m Ev2 > 20 MN/m^2, Ev2/Ev1 ≤ 2.2, Evd > 20 MN/m^2 or Rc* > 95%;
- for railways in the cut Ev2 > 20 MN/m^2, Ev2/Ev1 ≤ 2.2, Evd > 20 MN/m^2 or Rc* > 95%

where the ratio Ev2/Ev1 ≤ 2.2 is valid for Ev1 smaller than the minimum value prescribed for Ev2.

Embankment materials must also meet the conditions:

- maximum aggregate grain size ≤ 300 mm;

- maximum aggregate grain size ≤ 2/3 of the thickness of the layer being performed;
- chemical stabilization is used to improve the load-bearing capacity of the material.

The foundation soil planum must meet the geometric requirements [3:6-6]:

- flatness of the soil material layer 30 mm/4 m;
- flatness of the stone material layer 50 mm/4 m;
- transverse slope of the layer ≥ 5% with a tolerance of ± 1%;
- the maximum allowed deviation of the elevation of the planum of the foundation soil from the projected elevation is ± 2.5 cm for soil or improved soil, and ± 4.0 cm for cuts in the rock mass.

The required degree of compaction of the foundation soil Rc* should be higher than:

- 98% for a layer ≤ 0.5 m below the planum of the railway;
- 95% for a layer 0.5 ≤ 2.0 m below the planum of the railway;
- 92% for a layer > 2 m below the planum of the railway.

The load-bearing capacity of the foundation soil under the embankment meets the conditions:

- below the upper surface of the embankment to a depth of ≤ 1.0 m Ev2 > 45 MN/m^2, Evd > 25 MN/m^2;
- below the upper surface of the embankment for depths ≤ 2.0 m Ev2 > 20 MN/m^2, Evd > 20 MN/m^2.

If the embankment is not made, usually on the part of the railway body in the cut, at the level of the foundation soil, the conditions prescribed by Article 7a para. 3 and 4 of this regulation for the transition layer.

*in the Regulations Dpr

3. ADOPTED PRACTICE OF CONTROL OF COMPACTIONS, SHORTCOMINGS AND PROPOSED SOLUTION

In the last few years, the Republic of Serbia has been working on the reconstruction of existing railways, construction of new high-speed railways, and especially on the construction of a large number of industrial tracks for the economy needs. Almost as a rule, the control of embankment construction is performed only by determining the dynamic deformation modulus Evd, and without determining the degree of compaction Dpr and determining the correlation coefficient between Ev2 and Evd as well as the ratio Ev2/Ev1. Also, when testing with a light drop weight, the required moisture is not checked, and testing of layers is not performed in the same height profile, so the obtained results cannot be compared by layers.

This practice of compaction control and substructure construction is not in line with existing regulations. The consequences of such tests often lead to the degradation of the substructure, which results in the need to repair and reduce the speed.

It is an indisputable fact that this test method is used as faster one in the world, but it is carried out with other tests: determination of Dpr, water content, correlation relations Ev2/Ev1, correlation between Ev2 and Evd, determination of degree of unevenness, coefficient of water resistance (for protective layer) .

In the Republic of Serbia, this test method is not yet standardized (so the ASTME 2835 standard is used) and can be applied only in correlation with standardized methods. According to the provisions of the mentioned Instruction and the Regulations of testing, determination of the dynamic modulus of deformation, Evd is obligatorily performed along with other tests and the stated correlation relations. Due to the fact that it is not standardized in the Regulations for main railways, tests by determining the dynamic modulus of deformation Evd are not even listed, so based on the application of these Regulations, they are not even authoritative. Applying only this method, which has a high percentage of subjectivity (depending on the expertise of the examiner) can have a number of negative consequences, some of which are listed. This should be especially kept in mind when building high-speed railways (with speeds higher than 200 km/h) because here the consequences can be much greater.

In order to speed up the testing process, the authors of this paper propose the following methodology:

- determine profiles for testing according to the standard and technical conditions (harmonized with the standard)
- determine in examination process the zone where soil homogeneity is ensured (by granulometric composition and moisture) and in statistically reliable research conditions. Perform the necessary tests and correlations and, based on them, perform further tests with a

light falling weight (determination of the dynamic modulus of deformation Evd) in that zone, and with constant monitoring of moisture.

- enter the results of the on-site test in Table 4, which is signed by the responsible contractor, the responsible expert supervision and the test executor. This is a document that is an integral part of the construction site documentation and is attached to the official certificate. The table gives the possibility of re-examination if the result does not correspond to the required (prescribed) values is not good, but also lists the measures taken to achieve the required value (material replacement, application of geosynthetics, chemical stabilization, etc.).

Table 4.Proposed presentation of compaction test results

OBJECT : ____________________

LOCATION : ____________________

TESTING OF EMBANKMENT/CUT

Station	Position towards the axle D-right L-left	Type of construction	Material	Soil moisture humidity w	Ev2		Meets requirements	Evd		Meets requirements	Evd /Retested/		Meets requirements	Remediation measures /replacement stabilization other/	Ev1/Ev2		Meets requirements	Dpr		Meets requirements	Final assessment /meets requirements/		Test date
					Achieved	Required		Achieved	Required		Achieved	Required			Achieved	Required		Achieved	Required		Yes	No	
km				%	MPa	MPa		MPa	MPa		MPa	MPa			-	-		%	%				

Note: ____________________

He questioned: Responsible contractor: Supervisory authority:

4. CONCLUSION

The aim of the author of this paper is to present the state of regulations related to the construction of the railway substructure in the Republic of Serbia. In addition, the paper points out the increasing practice of non - compliance with existing regulations and the possible consequences.

Therefore, it is necessary that the tests of embankment construction, especially for high-speed railways, are clearly defined in the project documentation (geotechnical study, technical report, technical conditions, bill of quantities and estimate of works and graphic details).

During the construction, internal and external control tests are required, based on the stated technical documentation. The important role of the responsible contractor and responsible professional supervision should be emphasized.

Very often in practice (in court disputes), designers, responsible contractors and professional supervisors are prosecuted for the consequences of a poorly constructed facility. It is necessary to add controllers to this list, because it often happens that all test results are in accordance with the required values, and the facility is poorly built and requires repair work. The question is how this is possible. There are several answers to this question: the use of inadequate materials that do not meet the required criteria, so the results are often falsified, not enough control tests are performed, which are often not adequate. Therefore, the responsibility of the control performer is great.

In this paper, the authors proposed the possibility of speeding up the testing process with a clear procedure that includes compliance with existing regulations.

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