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## Road and Rail Infrastructure III

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## OPTIMIZATION OF GEOTECHNICAL INVESTIGATION WORKS DURING THE RECONSTRUCTION OF THE TRANSITION ZONES ON THE OLD RAILWAY LINES

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### Abstract

This paper will analyse the optimal number of required data within geotechnical investigation works with the cost estimation of performed tests and the duration of the testing (line closure). Deviation of the geotechnical parameters obtained from various research works will be shown. Special attention will be paid to the review of the quality of non-destructive methods that require a minimum of line closures. In the paper a case study of extensive geotechnical, geophysical and laboratory investigation works will be presented at the location before and after the Buna Railway Bridge (railway line M104 Novska – Sisak – Zagreb) as part of an international research project SMART RAIL. Conducted investigation works consisted of: engineering geological mapping of the location, exploratory drilling with continuous coring, performance of standard penetration testing in boreholes, field vane testing in boreholes, excavation of trial pits, testing with nuclear densimeter, cone penetration testing with pore pressure measurement (CPTU), testing with flat dilatometer (DTM) and geophysical testing methods; geoelectric tomography, seismic refraction, MASW/REMI, downhole and crosshole seismic survey and ground penetrating radar (GPR).

The works are made with the aim of defining the physical and mechanical properties of the existing geotechnical structures (embankment) and foundation soil (primarily the stiffness of individual embankment layers), and general geotechnical conditions at the site. This is essential for the assessment and valorisation of any potential geotechnical problem that arise in the transition zones, and finally to create the reliable geotechnical models and to design the reconstruction of the new transition zone between the bridge abutments and geotechnical structures (embankment).

*Keywords: transition zones, geotechnical investigation works*

### 1 Introduction

Geotechnical investigations are necessary to define the soil layers and / or rock mass at each location, and geotechnical properties of these layers. From the results, the geotechnical model can be defined which shows geotechnical layers with related parameters.

Today is in use a lot of different geotechnical investigation techniques: extraction of core samples using a drilling machine, CPT tests, dilatometer tests, field vane tests and various geophysical methods.

Exploration drilling gives us continuous and direct view of materials, but the values of geotechnical parameters, obtained from the samples that were tested in the laboratory, are point data and represent a random sample.

CPT testing gives a continuous vertical display of soil with a series of parameters, but depends on the correlations with laboratory tests and depends on the interpretation of results.

Geophysical surveys provide 2D profile cross section at the location, but also depend on the correlations with the results of exploration drilling and parameters obtained by laboratory tests. In addition to the field and laboratory works, systematized and long-time collected data can be used. This, for example is, engineering geological, hydrogeological and seismic maps. These maps provide a general, outline of specific locations, and are done for each State. If data of previously conducted researches are available, they can be used for studies or geotechnical projects. Based on the background and current data necessary geotechnical investigation works can be reduced and rationalized.

## 2 Cost and cost-effectiveness of geotechnical investigation

When the costs and benefits of geotechnical investigation works are discussed there is a wide range of personal opinions “on this issue” among investors, designers as well as among geotechnical engineers. In most cases, these opinions are derived, formed and generalized into empirical opinions, based on personal contact with geotechnical issues in certain cases from practice. Depending on the “experience” (the number of individual cases and covered range of geotechnical problems), there are evaluations ranging from “unnecessary costs” to “extremely significant need for research”. Neither of these extreme statements is applicable to all cases in practice, because there are always examples to the contrary. It can also be concluded that individual examples are generally not always adequate as arguments, because they contain a number of specific factors which generalize the conclusions.

Temple and Stukhart (1987) attempted, on the basis of data on dozens of cases in US practice, to assess the feasibility of geotechnical works by comparing the costs of inadequate investigations and additional costs during construction that they may have incurred, and the costs of additional investigations and savings in geotechnical solutions, [1].

Cases with available data showed that the savings are 2 to 30 times higher than the total costs of geotechnical investigation works. These cases also indicate that the initial extensive and more complete investigation works can reduce or completely avoid the costs and time lag of subsequent studies.

## 3 Optimal conception of geotechnical investigation works

When selecting procedures and methods of investigation works, technological possibilities and disadvantages of different methods are taken into account, but also the costs involved in obtaining the required data reliability. Soil profile and geotechnical parameters are determined by:

- Drilling, extraction and testing of samples. This method is indispensable if we want to get verifiable material facts about the soil. Quality techniques of drilling and extracting samples are relatively expensive, and also the appropriate laboratory tests on undisturbed samples. The time required to obtain the data is relatively long.
- In-situ tests usually indirectly provide information about the mechanical properties of the soil, but can also be used to determine the soil profile. These tests provide useful results faster, avoiding the need for undisturbed samples and are generally cheaper than fully implemented direct examination. The lack of them is (relatively) less reliable, indirect use of the results and for example in static penetration tests (CPT), the absence of any soil sample from a specific depth profile.
- Surface geophysical survey methods are generally the cheapest, but to obtain detailed data of soil relatively unreliable. Surface methods can quickly cover a larger area, but usually give average results, and sensitivity to changes in soil materials is usually small. Better performance is achieved with larger, more clearly differentiated environment in combination with boreholes that provide a landmark for interpretation.

The optimal strategy of investigation works seeks to use most of the advantages of the previously mentioned groups of procedures for obtaining a larger number of high-quality data with maximum rationalization of time and money. Of course, any optimization makes sense to implement in cases where the massive investigations are expected or very high demands on the reliability of the results. In cases where there is limited field research, rationalization is achieved by a more detailed processing of the soil data, using the appropriate correlation and analysis. Using the benefits of various methods of investigation works can be carried out in the following way:

- On characteristic places on site, detailed investigation works with drilling, extraction of samples and detailed, rigorously conducted laboratory tests are carried out. Close to boreholes (or in them) in-situ testing is carried out, enabling the establishment of the local correlation between the two types of tests. These correlations are limited to a specific location and specific technological procedures and are not related with potential unreliability of correlations from the literature (although those can be used in the interpretation for comparison)
- For further application in the wider area only in-situ testing are used. If with a representative surveys the extremes at the site are covered, the in-situ tests are usually the interpolation within extremes. Any deviations or significant deviations from established local trends allow rational positioning of detailed research.

## 4 Transition zones

Transition zones are defined as parts of the railway track where a change of basic characteristics that define a railway structure in its entirety takes place, [2, 3, 4]. Under the basic characteristics following parameters are considered: substructure and superstructure stiffness, deformation of each substructure layer and each superstructure part, overall value of track deformations, geometric restraints. The transition zones in general represent the appearance of discontinuity in the track structure, [5]. Within the SMART RAIL project, focus is on solving the problem in the transition zones between two different types of substructure, between the open track on embankment and the bridge, [6].

### 4.1 Negative mechanisms that occur in the transition zones

Poor condition of the transition zones is a consequence of numerous complex and interrelated mechanisms. In order to find the best possible solution for solving the problems that happen in the transition zones, all the negative mechanisms which influence the behaviour of the track structure should be taken into account and analysed. Negative mechanisms that occur in the transition zones are:

- discontinuity in the stiffness of the track structure;
- differential settlements of the rail track structure;
- influence of rail services speed;
- influence of the direction of the train.

The above-mentioned degradation mechanisms, which in fact act each on their own, may also be conditioned by each other. Cyclic repetition of these processes accelerates degradation of track geometry, with reduced quality and safety of driving as an immediate consequence, [7].

## 4.2 Role of transition zones

A certain structural solution is in fact hidden behind the term “transition zones”. The main role of transition zones is to prevent sudden changes in stiffness of the load-bearing structural elements of the track. The aim is to minimize or prevent the occurrence of additional negative dynamic loads over a part of a transition zone, which additionally accelerate the track geometry degradation, with reduced quality and safety of driving as an immediate consequence. This can be achieved by linearly changing certain properties of the surrounding structures at a reasonable distance by dividing one differential change into smaller steps, i.e. dynamically irrelevant intervals, [2,4]. Ideally these inconsistencies occurring in parts of transition zones do not influence the performance of a passing train in terms of safety but rather they more often reflect upon the quality and comfort of rail services and other dynamic occurrences, [3].

## 5 Case study: transition zones at “Buna” bridge

“Buna” bridge, situated at the railways track M104 Novska – Sisak – Zagreb at km 398+422, is selected for the case study because of the obvious problems in the transition zones, immediately before and after the bridge. In the transitions zones irregularities in the geometry have been noticed, such as track unevenness and under ballast gaps, and vertical displacements of the whole track structure. These were caused by differential settlements and by dynamic impacts of the train due to the changes in the track stiffness. In order to detect the causes of degradation in the transition zones and also to perform the appropriate reconstruction of the same area it was necessary to collect all the information’s about the existing embankment and foundation soil.



Figure 1 “Buna” bridge

## 5.1 Performed geotechnical and geophysical investigation works

An extensive geotechnical and geophysical investigations have been carried out on site in March 2012. Field tests have been supplemented by numerous laboratory tests to provide accurate information about ground conditions. Based on investigation program, the following works were conducted at the “Buna” bridge site:

- engineering geological mapping of the site;
- drilling of four geotechnical structural boreholes (B1-B4) 12 m' in depth;
- excavation of four trial pits by the railroad line (R1-R4), and nuclear densimeter
- measurement with dynamic plate load testing of embankment bed;
- cone penetration testing with pore pressure measurement, CPTU on four positions (CPT1-CPT4);
- dilatometer testing on four positions near the CPTU locations (DMT1-DMT4);
- field vane testing, FVT, in four boreholes B1-B4;
- geoelectrical tomography. The surveyed profiles are designated with the initial and the final length of geotechnical profile and their designations are GT-1, GT-2, GT-3 and GT-4.
- seismic refraction surveying. The surveyed profiles are designated SRRF-1, SRRF-2, SERF-3 and SERF-4;
- seismic tomography, characteristic in-depth cross sections SRST-1 and SRST-2, recorded perpendicular to the railway track at the position of borehole B-2 and B-3, were determined on the basis of P-wave propagation velocities;
- MASW / REMI surveys. Results of MASW surveys are shown as 2-D seismic cross sections on both sides of Bridge location;
- boreholes seismic survey, downhole in four boreholes B1-B4 and crosshole between boreholes B1-B2 and B3-B4;
- ground penetrating radar, GPR, was used for profiling along railroad line;
- laboratory testing of soil samples.

Generally, ground on “Buna” bridge location is composed of fine grained surface material – high plasticity clay, in the middle part there is mixed material – silty sand, and the substrate consists of coarse grained material – poorly graded gravel. It can be said that the stiffness of the soil increases with depth. The increase in stiffness is best seen in downhole, crosshole and MASW-SRRF tests. One can see an increase of 100 MPa in clay up to about 600 MPa in gravel. Also the difference in stiffness is seen by the number of SPT strokes, which is in lower part of clay layer  $N=7-11$  in sand  $N=5-7$  and in gravel layer  $N=15-54$ .

CPT, DMT, FVT and laboratory tests are limited to the clay and sand layers. These layers are important for determining main part of deformation under railway line. According to CPTU and DMT tests moduli for clayey materials are 20-40 MPa, while dynamic moduli are 100-200 MPa. According to the overconsolidation ratio from CPTU test, which is  $OCR=5 - <10$  for these soils, clays are mostly classified as very stiff fine grained soils. Values of geotechnical parameters are also shown graphically in Figure 2. Parameters obtained from laboratory tests, in situ testing and geophysical exploration are also shown. Material from depth 0,0 to 1,0 m, is railway embankment.

Generally it is very difficult to establish a link between non-destructive and destructive investigation works for the reason that the results of these methods are not mutually comparable. Non-destructive methods generally give us the dispersion of soil layers, and dynamic modules of deformability. What we have noticed is the relationship between the number of SPT strokes and  $V_s$  speeds. The ratio is in the coherent material ranged from 15-30 while in the incoherent material is between 5-20 what gives us the data for interesting correlations that should further be establish and verified in the future.

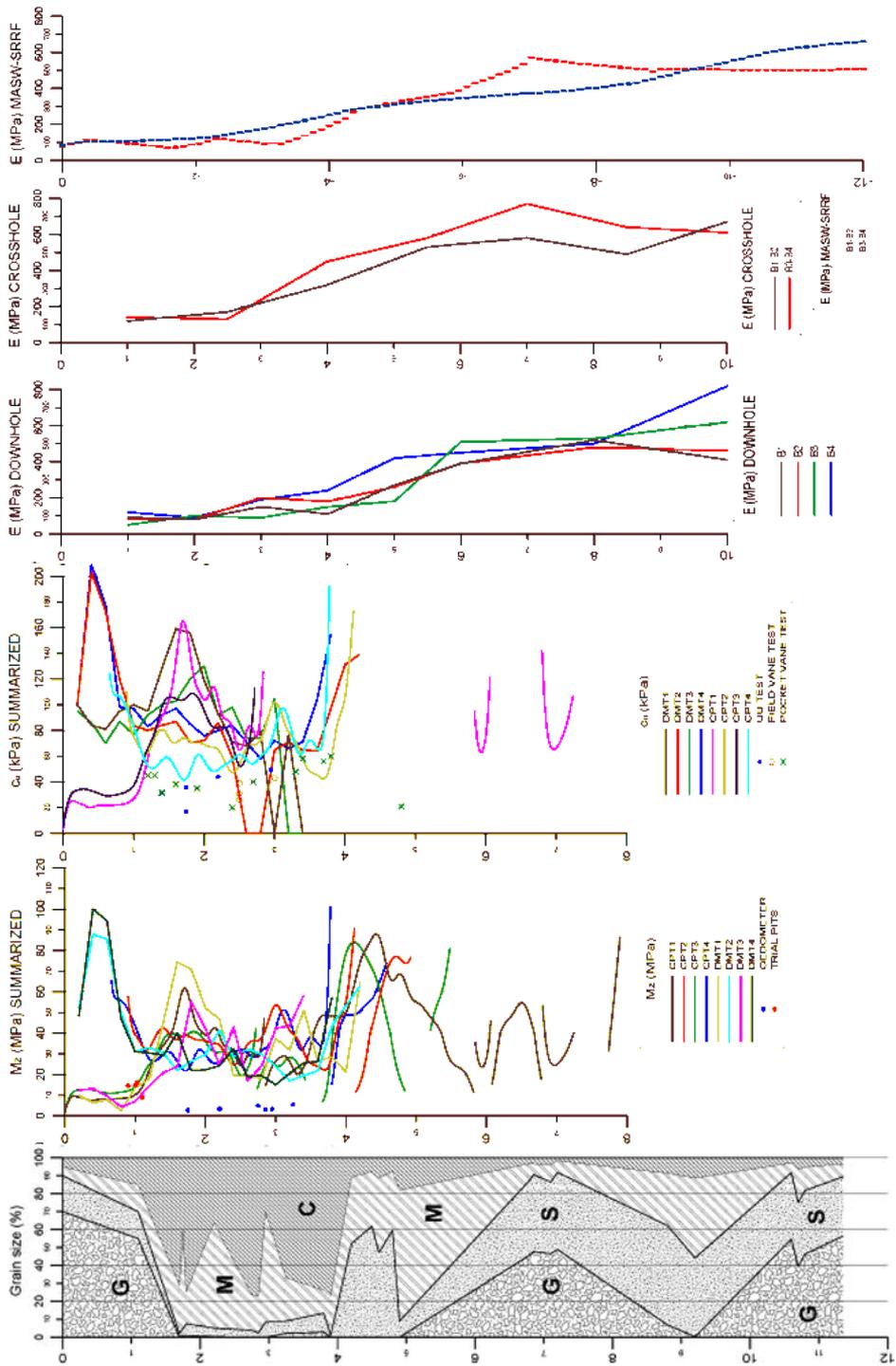


Figure 2 Obtained values of geotechnical parameters

## 6 Geotechnical investigation works optimization

Display of relationship between costs and applicability of certain geotechnical investigation works is shown in Table 1.

**Table 1** Display of relationship between costs and applicability of certain geotechnical investigation works

Geotechnical investigation work	Note	Costs (ranged from 1-20, 1 the lowest cost - 20 the highest costs)	Applicability for the determination of shear strength (score ranging from 1-5, 1 weak applicability - 5 very good applicability)		Applicability for the determination of the stiffness (points in the range of 1-5; 1 poor applicability - 5 very good applicability)		Sum (points)
			Fine grained soil	Corse grained soil	Fine grained soil	Corse grained soil	
<b>Drilling</b>	The most credible information about layers and the mechanical characteristics of the soil	1	5	5	5	5	<b>21</b>
<b>Trial pits</b>	Limited to a small depth	14	3	3	3	3	<b>26</b>
<b>Field vane test (FVT)</b>	Conducted in the borehole	18	5				<b>23</b>
<b>CPTU</b>	Without any sample	16	4	3	3	4	<b>30</b>
<b>DMT</b>	Without any sample	16	4	3	4	3	<b>30</b>
<b>Seismic refraction</b>		17			1	1	<b>19</b>
<b>Geoelectric tomography</b>		17					<b>17</b>
<b>Georadar</b>		17					<b>17</b>
<b>Downhole</b>		18			1	1	<b>20</b>
<b>Crosshole</b>		18			1	1	<b>20</b>

Evaluation was carried out on the basis of cost and applicability of the work to determine the parameters of the soil. From the evaluation can be concluded that the CPTU and DMT tests have the best ratio of costs and quality of the data obtained. All these methods have limitations and conditions conquer. Therefore, it is impossible to compare with each other. Each project and each site is specific and therefore the most important factor is the human. In other words, for good optimization of each individual situation, the most important is the experience of the person who is caring out the optimization.

## 7 Conclusion

Optimization of investigation works must achieve the following:

- optimum relationship between the quality of the data obtained and the cost of investigation works;
- if possible, carry out investigation works without closing traffic on the railroad, then again the criterion of cost reduction is present;
- in the framework of the conducted works it would be necessary to systematically monitor the investigation works on the railways, including the creation of database and continuous settlement monitoring of transitional zone.

The results of this study suggest the following:

- reduce the scope of investigation drilling and trial pits at the minimum allowed;
- conduct an analysis of all previous investigation works on railway lines;
- use to the fullest extent CPTU tests and geophysical profiling

Based on the analysis of the obtained results during the rehabilitation of the existing transition zones, the authors of this article recommend the following investigation works as optimal: drilling with laboratory testing and depending on the type of foundation soil and geotechnical structure, performing CPTU or DMT method of soil profiling and geophysical methods: geoelectric tomography or seismic refraction.

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