The Operational Safety of the Railway Track in the Area of a Bridge Structure Made of Corrugated Sheets

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The subject of the article is the assessment of effectiveness of the cooperation between the railway track pavement with a pass of the flexible ground-coating construction made of corrugated sheets, in terms of traffic safety. The object of the research is the track surface, located within the said structure, under operational loading conditions. The article contains the discussion of the concept of the research project currently being prepared by the authors. In particular, there are presented: the object of research, the purpose of the project, its thematic scope and the method of research, as well as theoretical models of research, the specification of tasks implemented in the project, the way of the field verification of the theoretical approach to the issue in question and the expected results of the research.

Keywords: bridge structure, ground-coating construction, railway track, operational safety.

1. INTRODUCTION

This paper touches on the effectiveness of the cooperation of the railway track pavement with a bridge facility of the flexible ground-coating structure made of corrugated sheets, as well as the impact of the correlation quality between operation of these railway components and the traffic safety. Tendencies observed for many years in the European Union aiming at improving the rail transport comfort and the related constant growth of scheduled train speed are the result of, inter alia, the optimization of the existing railway infrastructure quality and increasing the operational reliability of traffic control systems.

A significant problem with the quality of track way operation relates to tracks within the area of engineering facilities and results from occurring in many cases the so-called threshold effect, that is the change of stiffness during the entrance of a vehicle from the embankment on the object, and vice versa. This article proposes a solution to this problem by means of ground-coating bridge structures. These objects are designed in such a way to ensure the long-term beneficial co-interaction of the steel coating made of corrugated sheets supported on the foundation, with the ground backfill located between the coating and the track construction. The main operational value of a ground-coating object is the foundation continuity of the railway surface, which means providing the identical subgrade under the surface in the bridge area and on access roads. When designing ground-coating bridge objects, the ground backfill and the surface (roads or railway tracks) are treated as elements of the supporting structure.

The article contains the discussion of the concept of the research project currently being prepared by the authors on the operational safety of railway track exploitation in the zone of a bridge structure made of corrugated sheets.

2. THE RESEARCH OBJECT

The object of the research is the railway track pavement located within the ground-coating bridge structure treated with operational load. The main subject of research, as regards the surface, is a sleeper being the surface fundamental load-bearing element. In actual conditions the rolling stock impacts the track grate covering the number of sleepers specified in the solutions of the pavement theory. However, in the studies programmed within the scope of this project, the authors made use of a simplification and restricted themselves to a single sleeper in the track along a straight section (there is no the so-called cant). The authors envisage more detailed specification of the research subject and consideration of the load distribution along the track over the length covering a number of sleepers. In this way, the cooperation between sleepers will be taken into account when adopting the operational load.

3. THE THEMATIC SCOPE, THE PURPOSE OF THE PROJECT AND THE TEST METHOD

The cooperation effectiveness between the railway track surface and the susceptible engineeing construction made of corrugated sheets is being analyzed in terms of traffic safety.

The main research objective is to assess the state of stresses and strains in a sleeper and a bridge structure made of corrugated metal as a function of variable parameters relating to:

- a railway sleeper (material characteristics),
- subgrade (the state of ballast bed density under a sleeper, the location of zones of ballast bed density along the length of a sleeper, thickness and strength characteristics of ground backfill material above a bridge construction)
- a bridge structure (the geometric characteristic of the coating and the strength characteristic of material which the coating is made of).

The test method includes:

- the numerical analysis of theoretical models of railway tracks (within the state of stresses and strains)
- the experimental studies performed in relation to real objects (measurements of deformations during the exploitation process).

4. TEST MODELS

Theoretical models were classified to two groups, which are characterized below.

1. Reference models: the railway pavement (a sleeper built on the ballast bed layer) + subgrade, called track substructure or backfill. There were adopted variable parameters relating to:

1.1) the construction of the track:

- kinds and types of sleepers (wood: hardwood and softwood, pre-stressed concrete PS-83 and PS-94.). Sleepers were treated in simple terms as rectangular beams, which were subsequently numerically modeled with a disc member.
- schemes of ballast bed density under a sleeper (ballast bed density characterized by the density index I_s, the distribution of heterogeneous density zones along the sleeper length, or homogeneous density). The adopted indicator of the ballast material density I_s is contained in the set of values: 1.00 (the variant of full density); 0.98; 0.96; 0.94; 0.92; 0.90 (the minimum acceptable for railway lines in accordance with Technical Specifications Id-3 [1]); 0.88; 0.80; 0.50; 0.40; 0.30 (a crisis situation).
- the ballast bed thickness (there was adopted crushed granite of the fraction of 31.5 / 63 mm; the layer thickness comparatively in two variants: h_{min} = 0.35 m, in line with the requirements for main line tracks with the pavement on the pre-stressed concrete sleepers h = 0.40 m).

1.2) the ground substrate:

- physical and mechanical properties,
- the water flow in the track substructure (there are considered model systems taking into account three key directions of the water movement found in nature: horizontal, vertical down, vertical up); the influence of the hydrodynamic pressure on the track substructure specific weight,

1.3) the operational load:

There was applied the static load of the axial thrust Q = 221 kN (a stationary vehicle). The sleeper was loaded with two vertical concentrated forces of the value of $0{,}5 \cdot Q = 0{,}5 \cdot 221$ kN, which were transformed to the uniformly distributed load of intensity q = 750 kN / m, working on the width of the feet of rails of the 60E1 type. Additionally there were introduced:

- two horizontal forces of the value $H_{transversal}$ = (0.15 - 0.40) Q, applied in the running plane of the rail heads parallel to the longitudinal axis of the sleeper, acting outwards from the track, imitating the so-called side impact of the rolling stock (these forces generate the occurrence of the bending moment in the plane of the rail cross-section);

– two horizontal forces $H_{longitudinal}$, imitating the impact of the vehicle braking process on the track, applied in the running plane of the rail heads parallel to the longitudinal axis of the rails (these forces initiate torsion of the sleeper in the plane perpendicular to the longitudinal axis of the sleeper).

The problem of modeling the initial compression of pre-stressed concrete sleepers was solved with the use of simplification involving the introduction of the centrically pre-stressing force. The total pre-stressing force on the basis of the producer's technical documentation ((Wytwórnia Podkładów Strunobetonowych in Goczałków/Strzegom), having losses taken into consideration, is P_c = 300 kN for the sleeper PS-83 and P_c = 310 kN for PS-94.

2. Models of the railway track pavement with a ground-coating engineering facility. There were adopted the following variable parameters:

2.1) in the track construction: as in the case of reference models.

2.2) characterizing the ground backfill:
– the thickness of the layer,
– the type of ground backfill (physical and mechanical characteristics) and its density,
– the phenomenon of water flow in the area of the backfill (there will be considered model systems including three main directions of water movement in nature: horizontal, vertical down, vertical up); the influence of the hydrodynamic pressure on the track superstructure specific weight.

2.3) for a bridge construction made of corrugated sheets:
– the cross-sectional shape parameters (Table 1 [2, 3, 4]).
– the structure geometry in the longitudinal section,
– the load-bearing capacity of an object (the strain of the coating depending on the sheet corrugation).

2.4) relating to the operational load: as for standard models.

Note on modeling the test object work phases:
– the FEM model of an object in the construction phase, taking into account the deformation and the coating susceptibility during the phase of the ground backfill stacking;
– the model including the effect of prolonged exposure to permanent loads,
– the object model in the exploitation phase.

Table 1. Shapes of cross-sectional constructions made of corrugated sheets [2, 3, 4].

Shape	Span range (mm)	Common use
Round	150 ÷ 15800	Culverts, bridges, drainage pipelines, rain water sewers, storage reservoirs, service tunnels, relining
Vertical ellipse (5%)	1500 ÷ 6700	Culverts, sewage systems, service tunnels, relining
Arc-wheeled (drop-shaped)	1200 ÷ 12000	Culverts, bridges, animal passages, relining
Tunnel	1700 ÷ 12000	Underground passes, relining
Arced	1500 ÷ 21000	Bridges, viaducts
Horizontal ellipse	1600 ÷ 12000	Culverts, bridges, viaducts, tunnels, animal passages
Pear - shaped	7200 ÷ 8600	Viaducts, tunnels (particularly rail ones)
High-profile arc	6300 ÷ 23000	Bridges, tunnels, viaducts, animal passages
Low-profile arc	6100 ÷ 23000	Bridges, tunnels, viaducts, animal passages
Box-shaped	6100 ÷ 23000	Bridges, viaducts, relining
Others	Variable	In accordance with a designer's requirements

5. TASKS IMPLEMENTED WITHIN THE PROJECT

5.1. The development of numerical models of the track pavement (the system: sleeper + ballast bed):
– a wooden sleeper: a rectangular beam supported over the entire length in the granular center of the ballast bed type,
– a pre-stressed concrete sleeper: its form was simplified by treating a sleeper as a beam with the constant cross-section over the length,
– a ballast bed as the foundation for a sleeper.

5.2. The development of reference models of the system: sleeper + ballast bed + track superstructure, with no water flow in the subgrade and, optionally, with the water flow in the subgrade.

5.3. The development of track models with a ground-coating engineering object, excluding the water flow in the subgrade and, optionally, with the water flow in the subgrade [6, 7, 8, 9, 10].

5.4. The analysis of the state of normal and tangential stresses, stress amplitudes and the state of strain in a sleeper, in the function of changes in the sleeper material parameters and changes in the conditions of the sleeper placement, characterized by the ballast bed density index and the location of zones differing in density index values. The state of deformations, like the stress state, will be described by movements, the values of which will be estimated in the specific points of a sleeper: on vertical side edges, at selected vertical planes and in the vertical axis of the sleeper symmetry.

5.5. The evaluation of the strain of the ground-coating structure shell in the function of: the geometry of the cross-section, the sheet corrugation type and the ground backfill thickness in the key, operational load parameters. There will be considered the cases as follows: with no water flow in the area of the ground backfill and with the water flow in the area of the ground backfill.

The design methods (theories) listed below will be applied in order to estimate the value and distribution of internal forces [2, 3, 11]:

- Marston-Spangler (Iowa Deflection Formula),
- of the ring compression by White and Layer (Ring Compression Theory),
- the Ontario Highway Bridge Design Code (OHBDC),
- the American Association of State Highway and Transportation Officials (AASHTO),
- Duncan,
- Vaslestad,
- Sundquist-Petterson,
- the Canadian Highway Bridge Design Code (CHBDC).

The Marston-Spangler method is based on the assumption that the upper and lower part of the structure are evenly vertically pressed by the ground center, while the side parts are loaded with horizontal ground pressure of the parabolic distribution (Figure 1 [11]). The maximum ordinate of the horizontal pressure is 35% higher than the ordinates of the vertical pressure p_c. Given these assumptions, the values of bending moments M_c and M_h are obtained in the construction wall (Figure 2 [11]):

$$M_c = 0{,}02\, P_c\, R^2, \quad M_h = -\,0{,}02\, P_c\, R^2 \qquad (1)$$

where: P_c –the vertical pressure of the ground backfill, R –the radius of the pipe / the shell structure.

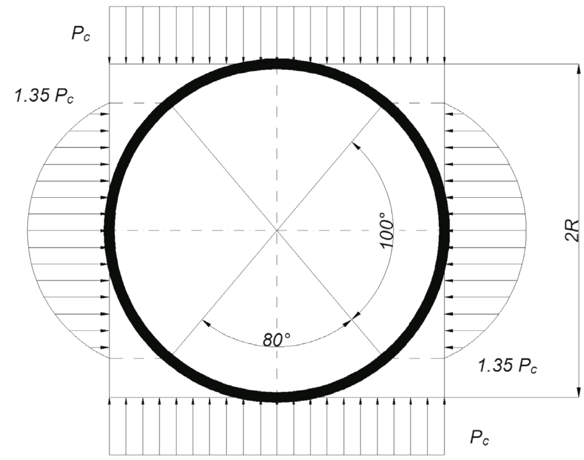

Fig. 1. The distribution of the ground pressure on the shell structure according to Marston-Spangler [3, 11] .

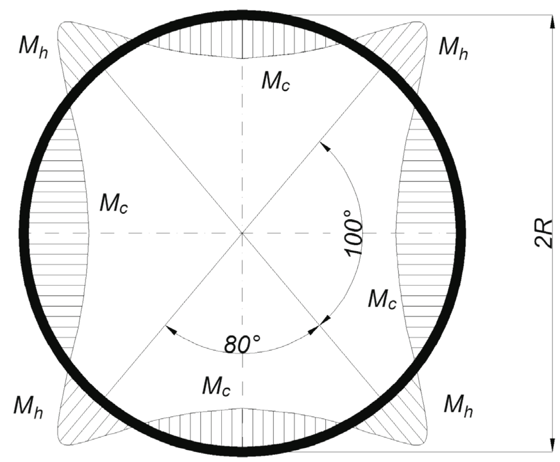

Fig. 2. The diagram of bending moments M_c and M_h in the wall of the shell structure [11] .

Figure 3 shows schemes of the distribution of the ground backfill pressure on the shell structure according to the White and Layer theory of the ring compression [2, 3, 11]. The structure is analyzed as a ring subjected to the even compression. The method may be properly applied if the height of the ground surcharge (backfill) is at least 1/8 of the shell diameter (design span) over the construction.

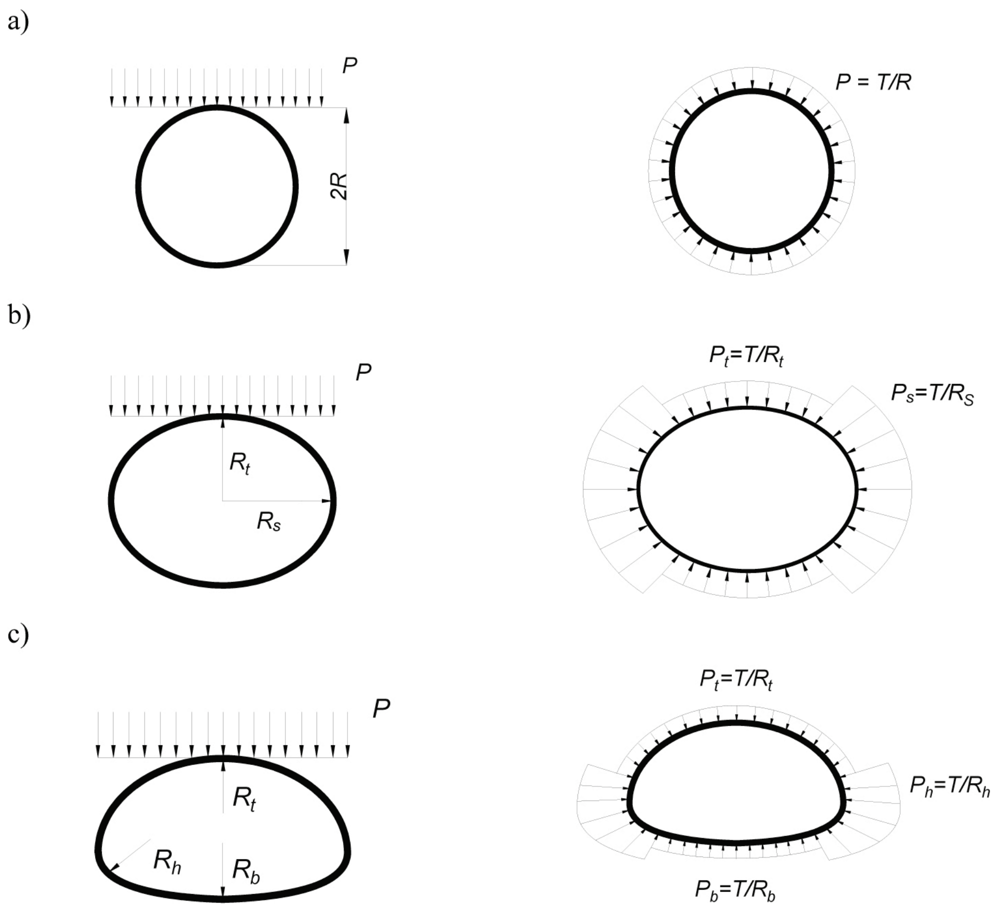

Fig. 3. The distribution of the ground pressure on susceptible shell structures of cross-sections: a) circular, b) elliptical horizontal and c) elliptical oval [2, 3, 11].

5.6. Modeling and the analysis of filtration and consolidation processes in the ground center of the backfill over an object made of corrugated metal. The task will be to:

1) determine parameters for efficient models of the filtration flow based on the theory of homogenization, considering:
   - track reference models (without an engineering object made of corrugated sheets)
   - track models with an object of corrugated metal,

     o
2) using the analytical method to solve the issue of the classical filtration flow through the incompressible or slightly compressible ground center of the backfill [6, 7, 8, 9] (the case of the flood wave occurrence)
3) using the analytical method to solve the issue of the consolidation of the porous center of the ground backfill over an object made of corrugated metal.

The problem of the consolidation generated by the complex nature of the operational load will be analyzed.

5.7. The safety assessment of a ground-coating facility with the application of selected methods of the theory of structural reliability, taking into account the impact of changes in parameters: a sleeper (foundation), the ground backfill and pavement of passages on the value of reliability measures. A measure of reliability will be expressed as the ratio of reliability or probability of failure.

5.8. Operational tests carried out on a real object. The aim of the field tests will be to estimate the state of deformations of real objects exposed to the operational load. The state of deformations of these objects will be determined on the grounds of monitoring movements of individual elements of an engineering facility during the exploitation process. The measurement results will provide the basis for verification of theoretical analyses.

5.9. The safety assessment of the usage of a real object with the solutions of the reliability theory applied [5].

6. CONCLUSIONS

One of the most important tasks planned within the framework of the project is to evaluate the safety of a ground-coating facility with the use of selected methods of the theory of structural reliability. The task will be implemented by means of computer simulation, taking into account the impact of changes in parameters: a sleeper (foundation), the ground backfill and the pavement of passageways on the values of reliability measures. The anticipated results of the task include:

a) the probabilistic description of parameters of the ground subgrade under the railway track (ground parameters as random variables, parameters of the subgrade as random fields)
b) reliability measures:
   - torque reliability measures described in the form of indicators,
   - the probability of the non-compliance of the boundary condition, that is, the probability of failure,
   - reliability measures calculated with approximate methods: the first order reliability method FORM, the second order reliability method SORM,
   - estimating the reliability of the system: railway track + sleeper + object made of corrugated metal, assuming a model in which the entire structure is a set of components, each of which has distinct failure criteria characterized by separate functions of the border state,
   - reliability measures calculated with simulation methods: the Monte Carlo classical method, the weighted simulation, the conditional expectation method, the adaptive conditional expectation method

c) measure of reliability in the event of occurrence of the ultimate border states of the ground bearing capacity under the railway track construction,
d) the probability of failure in the event of the vertical displacement (settlement) of the railway track structure over a bridge facility made of corrugated sheets.

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