# Multiscale Modelling in Railway Engineering

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The article presents the design and operation of selected types of physical simulation models of the railway track subgrade and transport earthen structures. These models include:

- model section of railway track for testing vertical displacements,
- test bench physical simulation models of reinforced railway track subgrade,
- multiscale physical simulation model of the retaining wall made of reinforced ground stabilizing the transport embankment,

The paper discusses the research of the displacement state of the models constructed. The results of research can be the foundation for designing subgrade reinforcements in modernised railway tracks.

**Keywords:** subgrade, earthen structures, physical simulation models.

## 1. NOTES ON SIMULATION RESEARCH

The paper describes the physical simulation models of railway track subgrade functioning and earthen structures as well as the method of deformation tests. The results of such experiments may be useful as a verification of computer simulations. These models can be constructed in laboratory scale (these include the group of giant-size models) and full-scale models. Measurements performed on simulation models have several advantages [Surowiecki 1988, 1989, 1991, 1994, 1998, 2004; Mazur, Surowiecki 1989; Surowiecki, Wysocki 1990; Surowiecki 2011]:

- they allow to adopt selected variables with a fixed scope of value changes and thereby the analyzed course of physical phenomena is controlled,
- the assumed variables apply not only to the model, but also to the environment (e.g. the influence of ambient temperature, the influence of climate),
- due to the possibility of continuous monitoring of the modelled object, exposed to external factors (e.g. operational load), modelling is more versatile and less expensive than research in uncontrolled conditions (e.g. railway track deflection measurements on an operating track),
- in certain cases, the only suitable solution is a simulation of a phenomenon (e.g. estimating the state of stress and deformation of an insert strengthening the subgrade of a railway track).

The paper focuses on three simulation models regarding the evaluation of:

- vertical displacement of railway track sections, treated with vertical pressure, which reflects the impact of dynamic operating load;
- the state of deformation and stress in the subgrade layer with reinforcement,
- the characteristics of the limit value of active earth pressure (soil wedge) in embankments.

## 2. SITE TESTS OF VERTICAL DISPLACEMENTS OF RAILWAY TRACK SECTIONS

The aim of the study was to determine the size of settlements of track sections, which were under the influence of long-term operational load. The desired operating conditions of the track are approximately simulated through the method of dynamic pulse loads. The equipment used, which can be found in the Railway Institute in Warsaw

[Mazur, Surowiecki 1989; Surowiecki 2011], allowed to introduce any chosen dynamic load into the simulation model of the track. The dynamic load can be equivalent to the gross transport load in a specific time interval.

Three models of track sections were constructed out of rails type 49 E1 on wooden sleepers with the wheelbase of 0.65 m:

- model 1: 25-meter long span (model- for the purpose of comparison) on a coarse sand bedding layer with a layer thickness of $h_p$ =0.5 m;
- model 2: 1.5-kilometre long track section, constructed on three sleepers and a coarse sand bedding layer with layer thickness of $h_p$=0.5 m;
- model 3: 1.5-meter long track section, constructed like model 2, with the exception of the sand bedding layer, where at the depth of $z$ = 0.25 m a horizontal reinforcing cylinder was installed. It is a steel mesh with rod diameter $d$ = 3,. mm and 12 mm x 12 mm net mesh.

The scheme of the test stand is shown in Figure 1. The device in the operating part consists of a frame structure, in which pillars *(a)* are anchored in oblong beams, embedded in the subgrade through concrete foundation. The operating device, which transmits the contact pressure onto both rails is fixed to the crossbeam *(b)* in an elastic way, allowing the centric application of the vertical load onto the vertical axes of the rails. The ends (*e)* of cylinders *(c)* transmitting the load onto rails *(d)* resemble the rims of the railway vehicle wheels. The controlling part is equipped with devices applying the static load and pulsating dynamic load. The device enables the application of static load of 0-200 kN on a single rail and dynamic load of 0-160 kN on a rail. The dynamic and static load with the value of $Q$ = 200 kN was introduced in the process of research. The pulsator was working on the frequency of 4,17 Hz, which equals the vehicle moving at the speed of 75 km/h at the wheelbase of 5,0 m. The functioning of the track section in the conditions similar to operational (real) was reflected through the introduction of a long-term cycle of pulsating dynamic loads in the range of 0-50 million kN. The load achieved in one hour was 3 million kN (0.3 Tg). Thus, the state of the total load of 50 million kN (5 Tg) was achieved after 16.7 hours. A static force (initial load) was applied onto all the models in order to achieve the initial compaction of the subgrade. Next the dynamic load was applied.

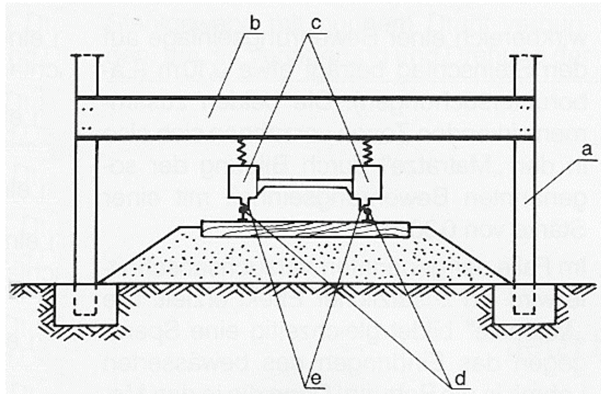


Fig. 1. Traverse section of the test bench, done in CNTK [Mazur, Surowiecki 1989; Surowiecki 2011]: *a* - pillars of framework structure, *b* - crossbar, *c* – cylinder generating vertical load on the rails, *d* - rail, *e* - the ends of cylinders transmitting the load onto the rails

Figure 2 shows the plan of rail section model of the length of 1.5 m, consisting of three sleepers. The measurements of permanent subsidence were taken through levelling, based on the changes in the height of test points placed on both rail tracks. The amplitude of vibrations was estimated after installing a special vertical screen on the end of the cylinder (*e*). The amplitude readings were made on the screen in the form of a millimetre grid with the use of a stationary recorder.

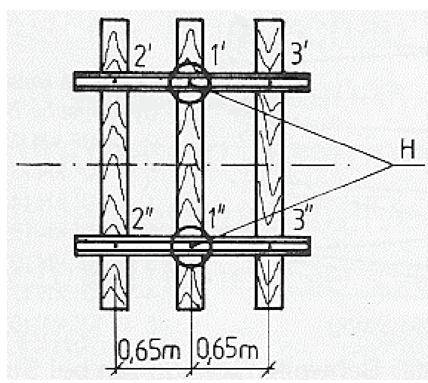


Fig. 2. The plan of track section model, consisting of three sleepers [Mazur, Surowiecki 1989, Surowiecki 2011]: H - hydraulic cylinder pressure points which generate the vertical load on rails

## 3. THE TEST BENCH OF THE SUBGRADE LAYER OF REINFORCED RAIL

Figure 3 presents the test bench, where physical simulation models were constructed in order to estimate the strength characteristics of the subgrade layer of reinforced rail. Rectangular models with dimensions of 0.54 x 0.54 and height $h$= 0.42 were constructed in a container, which is an essential element of the test bench (Fig. 3) [Surowiecki 1988; Mazur, Surowiecki 1989; Surowiecki 1989]. Special design of steel walls and the container bottom enabled to construct a three-dimensional models of deformation, exposed to static pressure in the range of $Q$=0-20 kN, generated by a non-deformable vertical square plate with the side length of 0.32 m.

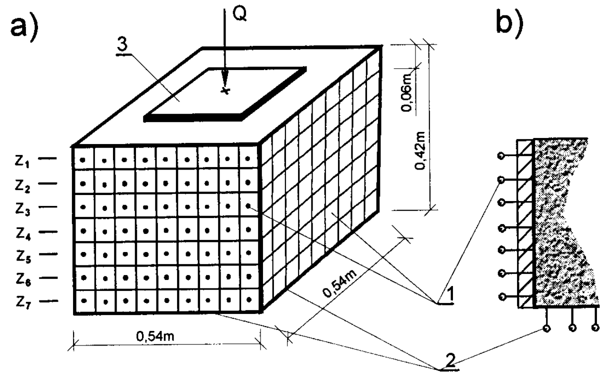


Fig. 3. Basic parameters of the test bench [Surowiecki 1988; Mazur, Surowiecki 1989; Surowiecki 1989]: *a* - general view; *b* - vertical section through the wall, *1* –horizontal pressure sensor, *2* - vertical pressure sensor, *3* - plate transmitting the load onto the model; $z_1$ = 0.03 m; $z_2$ = 0.09 m; $z_3$ = 0.15 m; $z_4$ = 0.21 m; $z_5$ = 0.27 m; $z_6$ = 0.33 m; $z_7$ = 0.39 m - measuring levels

The model matrixes were made of coarse sand with a moisture content of 3% and with medium density. Strength properties of models were defined in the function of the amount of reinforcement. Reinforcement inserts in the form of grids made of plastics (Fortrac geogrid) were arranged horizontally, i.e. perpendicularly to the surface of research load, in order to achieve the maximum effect of anisotropic cohesion, expressed by the relationship presented in publications [Surowiecki 1998, 2004, 2011].

## 4. SIMULATION MODEL OF THE VERTICAL WALL OF THE REINFORCED SOIL EMBANKMENT

Multiscale physical model of the functioning (in terms of horizontal displacement) of reinforced soil embankment allows the study of horizontal earth pressure and the estimation of the position of the slip surface in the limit state of the active earth pressure.

The model was constructed in a rectangular container, shown in Figure 4 [Surowiecki 2004, 2011]. The subject of the study is the horizontal displacements of the externally loaded mound measured in the plane of the model measuring wall (*1*). The measured displacements enable the estimations of the following:

- unitary horizontal active earth pressure,
- the position of the slip surface in the limit state of the active earth pressure,
- the size of the soil wedge in the limit state of the active earth pressure.

In the model, dry coarse sand constitutes the ground medium. The reinforcement inserts in the form of strips or lattices (in variants) were placed horizontally with vertical spaces of $e_z$ = 0.195 m. In each layer strips were located parallel to the longitudinal axis of the container, while maintaining the same horizontal spaces, which were adopted in the following sequence (axial spacing): $e_x$ = 0.11; 0.17 and 0.23 m. The following strips reinforcement systems (with smooth or corrugated strips) were used in the individual tests:

- system I (5 layers with 9 inserts each; together $n_{a,c}$ = 45 inserts; insert length $l_a$ = 1,8 m; horizontal spacing $e_x$ = 0.11 m);
- system II (5 layers with 6 inserts each; together $n_{a,c}$ = 30; $l_a$ = 1.8 m; $e_x$ = 0.17 m);
- system III (5 layers with 4 inserts each; together $n_{a,c}$ = 20; $l_a$ = 1.8 m; $e_x$ = 0.23 m).

The designed load on the ground mound results from the applied research method and is mainly the factor forcing the occurrence of the soil wedge. To some extent, however, the load imitates the vertical load of the axle of a stationary vehicle. The static load $q$ is realized vertically onto the surface of a rigid rectangular loading plate (*2*) placed crosswise (on the model width of $B$ = 1.20 m), assuming a minimum distance from the edge of the inner surface of the front measurement wall (*1*) as $l_y$ = 0.30 m. The value of load (within the range of $q$ = 0-61.69 kPa) is identical for all tests and minimal, yet necessary to create the soil wedge in the reinforced ground mound model.

The following two compaction states of the mound building granular medium were analyzed: loose and pre-compacted.

Among the research results, the following should be highlighted:

- the estimation (in terms of percentage) of the degree of horizontal earth pressure reduction in the mound due to reinforcement,
- determining the quality of the cooperation between the ground medium and the reinforcement.

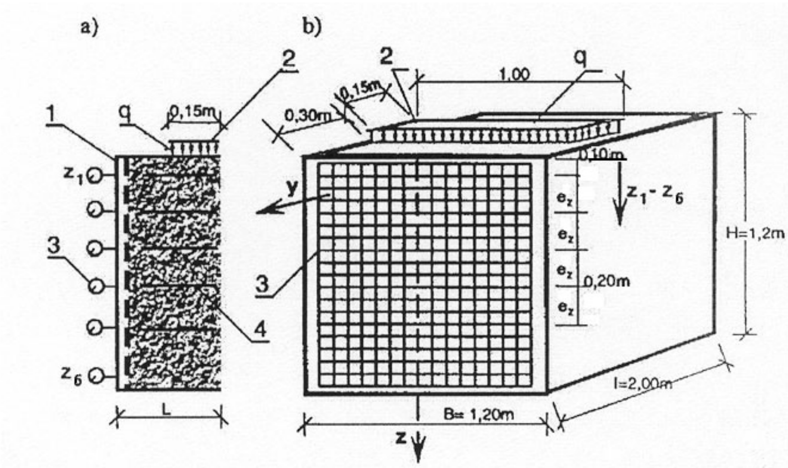


Fig. 4. The scheme of the test bench [Surowiecki 2004, 2011]: *a* - vertical cross section; *b* - general view; *1* - retaining wall (measurement) model, *2* - loading plate 0.15 x 1.0 m, *3* - horizontal displacements sensors; *4* - reinforcement inserts; $z_1$-$z_6$ - measuring levels

# 5. CONCLUSIONS

The paper presented three types of simulation physical models, which constitute the basic tools of the scientific research work carried out by the author in the field of road and railroad engineering. Both the area of application and the goals achieved in the process of research were described in the paper.

In addition to the already given advantages of the preferred models, it is necessary to emphasize the following issues:

- the possibility of eliminating the adverse influence associated with tests on real objects (e.g. the train movement on a currently used railway track)
- the possibility of controlling the behaviour of models in the range of the assumed variables values

The discussed models do not constitute a target solution. For example, in the model of track subgrade layer, the container bottom imitating the ground area constitutes a one-parameter Winkler model. It is known that geotechnical engineering uses two- and multi-parameter models. Therefore, it is possible to modify the presented models and develop research so as to make the research more detailed and obtain more specified data regarding the credibility in depicting physical phenomena.

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