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ТЕХНИКАЛЫҚ ҒЫЛЫМДАР ЖӘНЕ ТЕХНОЛОГИЯЛАР СЕРИЯСЫ / TECHNICAL SCIENCES AND TECHNOLOGY SERIES/ СЕРИЯ ТЕХНИЧЕСКИЕ НАУКИ И ТЕХНОЛОГИИ

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Simulating the process of compacting the railway bed

Akbope Karsakova[1], Adil Kadyrov[1], Igor Pak*[1], Elvira Kyzylbaeva[1]

[1] *Abylkas Saginov Karaganda Technical University, Karaganda, Kazakhstan*

(E-mail: karsakova84@mail.ru, adilkadyrov51@gmail.com, i.pak@mail.ru, elvirakiz@mail.ru)

Abstract. The article solves the problem of the interaction between sealing plate and the railway bed. Numerical results have been obtained in the process of three-dimensional modeling using the finite element method, which allow demonstrating volumetrically the stress-strain state of the railway bed and using it in the calculation methodology.

Keywords: compaction, railway bed, loose medium, viscous medium, finite element method.

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* - corresponding author

Introduction

The aim of the study is to obtain a model of the three-dimensional stress-strain state of the railway roadbed.

The objectives of the study includes:

– simulating the sealing plate operation;

– selecting the rheological model;

– substantiating the criterion of the ultimate stress state;

– selecting the numerical modeling method.

Increasing the speed of trains is one of the most important tasks for improving the operational work and development of railway transport in all industrial countries of the world. Increasing permissible speeds means reducing the travel time, improving the quality of services and attracting additional passenger traffic to rail transport. Speeds can be increased in several ways:

– constructing new lines;

– reconstructing existing railways;

– using improved rolling stock.

Experience in the construction and operation of railway transport shows that reconstruction of existing railway lines with mixed traffic of freight and passenger trains makes it possible to increase the speed to 200-250 km/h. To achieve higher speeds, it is advisable to build specialized high-speed highways, which leads to high-quality compaction of the railway bed [1].

In this regard, the modeling of the railway bed is relevant for clarifying the methodology of calculating the relative and absolute settlement of the railway bed ballast layer.

Materials and methods

The purpose of the study is to obtain a methodology of demonstrating and calculating the stress-strain state of the railway bed.

The research hypothesis is to improve the quality of assessment and calculation, and consequently the performance of the railway bed by studying the importance of legality in obtaining a three-dimensional picture of the railway bed settlement.

Practical significance consists in the use of the obtained results in engineering calculations.

Currently, high-performance complexes of track machines are used to perform track work. The work is performed in limited periods of time, the so-called "windows", at a considerable distance from the repair bases [2].

Track machines and mechanisms for compacting the ballast layer, straightening the track and finishing the ballast prism are classified according to the frequency of action, the working function performed, the number of sleepers that are simultaneously packed, etc. [3, p. 414].

Abroad there are produced straightening and tamping machines of cyclic, continuous-cyclic and continuous action designed for straightening and tamping the railway track during the construction of lines, as well as for the current maintenance and repairs of the track.

With the growth of traffic density, speeds and mass of trains, the design of the track was improved, new sets of track machines appeared, as well as a new technology of track work. For mechanization of straightening-tamping and finishing works, track renewal machines of cyclic action are used: the main type VPR; of continuous-cyclic action (PMA-1, PMA-S, "Duomatic 09-32 CSM", "Dynamic Stophexpress 09-3X", etc.); of continuous action type VPO (VPO-3-3000, VPO-3-3000S) [3, 415 p.].

During the operation the sealing working bodies of tamping and straightening machines render a horizontal and vertical impact on the ballast with forced supply (introduction) of the working bodies (horizontal or vertical vibro-compression of the ballast). When the plates are deepened into the ballast, there takes place compaction due to its vibration compression in the vertical and horizontal directions. Vertical vibro-compression is implemented in the process of inserting the plates into the ballast, and horizontal when the working platforms of the plates interact with the ballast. When the plates are compressed, horizontal vibration compression of the ballast takes place. The sealing of the shoulders of the ballast prism works according to the method of vibro-compression of the ballast (Figure 1) [3, p. 416].

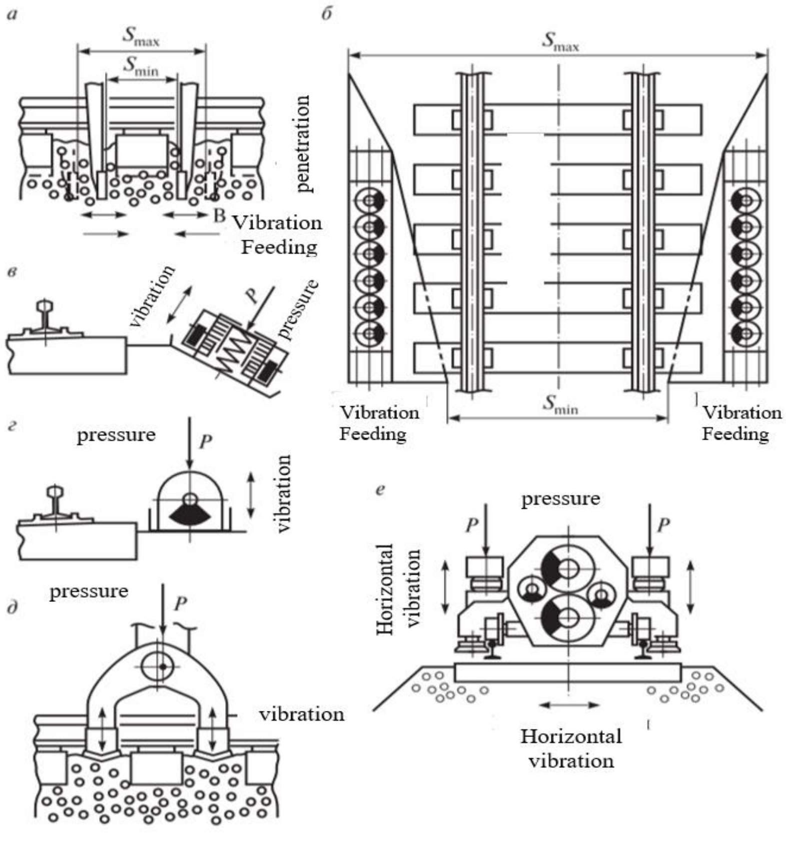

Figure 1 – Working bodies for compacting and stabilizing the ballast layer

The technological process of compacting the mass of the ballast layer is associated with redistribution under the impact of force factors (working bodies or train load) of the ballast volumes inside the layer with the formation of local zones of increased particle concentration due to compaction (under the rail threads) and reduced concentration due to decompression (in sleeper boxes, under the ends of the sleepers). The ballast, being a loose medium, exhibits its rheological properties. The picture of such distribution is conditioned by the design features of the working body and the selected modes of interaction. With each new force impact on the ballast layer by the working body, as in the case with the operation of machine complexes, the distribution pattern of the material concentration in the layer changes. Relative compaction settlement E_y after force action is determined by the formula [4]:

$$E_У = 1 - \frac{V_У}{V_H}(1 - E_H), \tag{1}$$

where V_H, V_y are the volumes occupied by the ballast before and after compaction.

The most common method of compacting the ballast layer is vibration crimping. The initial state of the ballast is characterized by the relative settlement of the E_y seal. In the calculations of sealing working bodies, the concept of a hypothetical maximum loose state and an extremely compacted state is used. They are characterized by the corresponding relative compaction settlements E_0 *and* $E_П$ [3].

The indicators for assessing the quality (degree and uniformity) of compaction and stabilization of the track ballast are given in Table 1, where σ is the standard deviation of the degree of compaction quality [4].

Table 1 – Quality indicators (degree and uniformity) of the railway track ballast compaction and stabilization [4]

Indicator	Indicator value or the calculation formula	
Compaction degree:	Practically achieved	Limit
Density, kg/m^3	ρД=(1.5…1.8) 10^3	(1.9…2.1) 10^3
Porosity	nД=0.36…0.38	0.33…0.34
Porosity coefficient	εД=0.56…0.61	0.49…0.51
Relative settlement of the sealing	$\frac{\Delta H}{H}$ =0.14…0.20	0.22…0.24
Sealing quality	$\rho \pm \sigma_P; n \pm \sigma_n;$ $\varepsilon \pm \sigma_\varepsilon; \Delta H \pm \sigma_{\Delta H}$	max min
The layer settlement speed, mm (mln. t gross)	$\frac{dh}{dT} = V_h = \text{var}$	V_h=const
Acceleration (uniformity) of the layer settlement, mm/(mln. t gross)^2	$\sigma_{УP}(W_h) \le \pm 1{,}33 мм;$ $\sigma_{УP}(W_h) \le \pm(0{,}25 \ldots 0{,}33)‰$	W_h=0

Since there is an extremely compacted state of the ballast, stabilization by compaction is modeled by the saturation process of the compaction index taken into consideration: relative settlement E.

The diagram (Figure 2) shows conditionally the positions of the rail-sleeper grid in the process of force impact on the ballast layer by a complex of machines: $E_И$ is the initial relative sediment of the layer, for example, after the operation of a crushed stone cleaning machine for deep cleaning; E_{B1} is the relative settlement of the compaction after the operation of the first straightening and tamping machine (for example, VPO); E_{B2} is the relative settlement of the compaction after the operation of the second straightening and tamping machine (for example, VPR); $E_{ДЗ}$ is the relative settlement of the compaction after passing the dynamic track stabilizer; $E_Э$ is the relative compaction settlement as a result of the operation of the ballast layer under the influence of a load from trains [4].

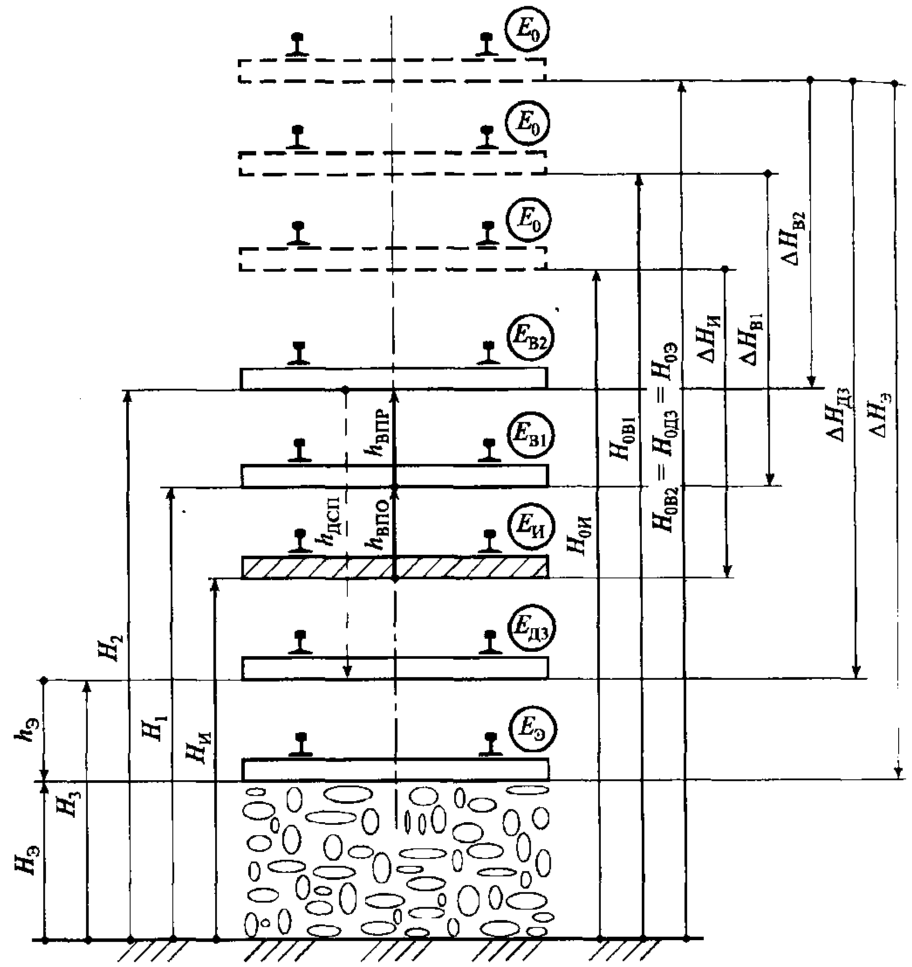

Figure 2 – The diagram of changing the ballast layer state under the compacting action of the track machine complex

After complete stabilization, it corresponds to the extremely compacted ballast layer; $H_И$, H_{B1}, H_{B2}, $H_{ДЗ}$, $H_Э$ are the thicknesses of the ballast layer after the considered impacts (indices correspond to the indices for relative settlement $h_{ВПО}$, $h_{ВПР}$ are straightening lifts of the track by the VPO and VPR machines; $h_{ДСП}$, $h_э$ are settlements of the rail-sleeper grid after and during operation; E_0 is the relative settlement of the compaction of the ballast layer in the hypothetical extremely loose state [3].

This state corresponds to different hypothetical layer thicknesses, since during the operation of the tamping machine, additional volumes of the ballast material are supplied to the area under the sleepers from the ends of the sleepers (VPO).

After all straightening and tamping works, the hypothetical layer thickness reaches the maximum value H_0. During settlement in the problem under consideration, it does not change.

The relative and absolute settlements of such a ballast layer can be calculated taking into account the above approach.

The proposed dependences make it possible to determine the loading of machine mechanisms during operation depending on the rheological properties of the medium. However, it is possible and necessary to solve the problem of changing the stress state of the railway bed prism using modern calculation methods (for example, using the finite element method (FEM).

The main environment of the railway bed is mainly composed of crushed stone. Crushed stone is a loose medium consisting of grains and spaces between them, which are mainly filled with air. A granular body has some properties that distinguish it from classical solids and liquids. It has the ability to keep the shape that it was given by the machine, and on the other hand, it can lose shape, for example, under the impact of a vibration load. Great importance in maintaining the elasticity of the form has the internal structure. A looser and less ordered texture leads to decreasing the ability to bear the load, and a less loose and more ordered texture increases the bearing capacity of the railway bed. In the loose state, the spacer properties of the ballast material are manifested to a greater extent. They are characterized by the appearance of lateral pressure perpendicular to the main pressure. If nothing counteracts the lateral pressure, the ballast bulges to the sides with the destruction of the main body.

The main properties of crushed stone are standardized in SS 7392-2002 "Crushed stone of dense rocks for the ballast layer of the railway track". Crushed stone is obtained by crushing material of igneous rocks with the density of at least 2.4 g/cm3; it consists of particles of fractions within 25...60 mm [5].

The condition of the railway bed is characterized by the quality of compaction. Assessing the settlement of the ballast layer under a force impact on it, in many calculation models there is taken into account the ballast layer located directly under the bases of the sleepers [3].

Our task is to simulate the operation of a vibrating plate.

It is known that the soil is a non-linearly deformable material, in which the relationship between load and displacement has a curvilinear character. The stress-strain state of such materials is described in more complex elastic-plastic models, which are based on the concept of yield stress. To simulate the interaction of the plate with the railway bed, the well-known Mohr-Coulomb criterion has been selected, which more accurately describes the ultimate stress state of a loose and cohesive medium. In the space of principal stresses, the yield strength forms the yield surface (Figure 3). The yield surface equation is taken depending on the strength criterion, according to which the calculation is made.

There are many numerical methods of the continuum mechanics among which the most popular is the finite element method (FEM). The FEM has the ability to take into account a variety of complex properties of soils. By this, the FEM stimulates the development of soil testing methods and new theories of their strength and deformability [6].

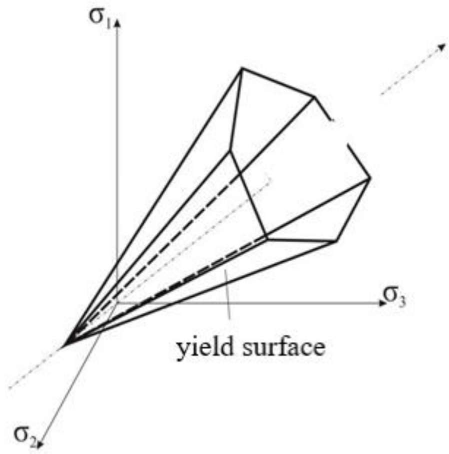

Figure 3 – Yield surface in the axes of the basic stresses of the Mohr-Coulomb criterion

Let's consider the procedure for solving the FEM problem in the Ansys WB program using a specific example: a railway bed under the impact of a vibrating plate.

There has been selected an elastic-plastic Mohr-Coulomb model with known mechanical characteristics of the pin (strain modulus, Poisson's ratio, angle of internal friction, specific cohesion and dilatation angle) (Figure 4).

Properties of Outline Row 5: gravi 2

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	1700	kg m^-3		
4	Isotropic Elasticity				
5	Derive from	Young's Modulu...			
6	Young's Modulus	400	MPa		
7	Poisson's Ratio	0.27			
8	Bulk Modulus	2.8986E+08	Pa		
9	Shear Modulus	1.5748E+08	Pa		
10	Mohr-Coulomb				
11	Yield Surface				
12	Initial Inner Friction Angle	63	degree		
13	Initial Cohesion	20000	Pa		
14	Dilatancy Angle	5	degree		
15	Residual Inner Friction Angle	2.5	degree		
16	Residual Cohesion	10000	Pa		

Figure 4 – Crushed stone mechanical characteristics

The design scheme of the railway bed is shown in Figure 5. A steel plate with dimensions corresponding to the contact area has been selected as a vibration plate.

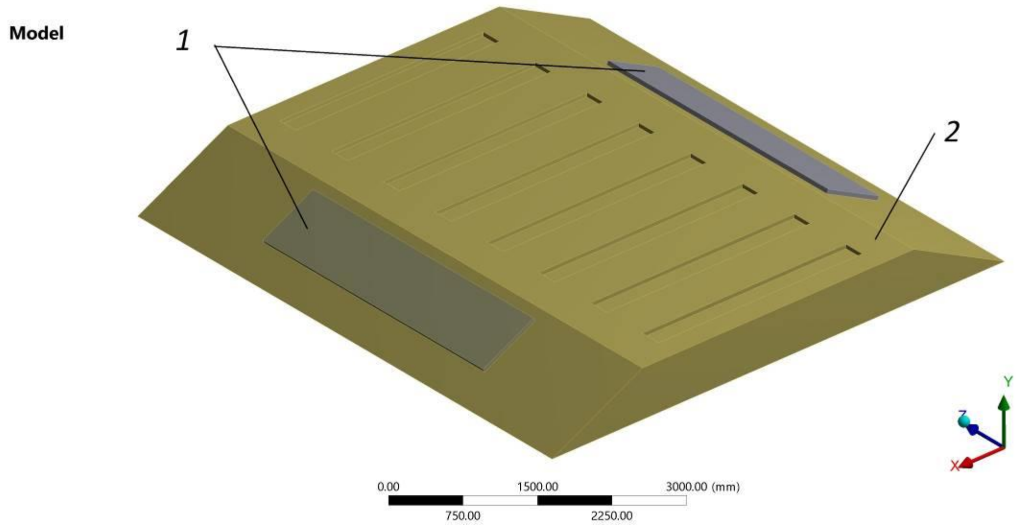

Figure 5 – The design scheme of the railway bed: 1 – vibration plates, 2 – crushed stone

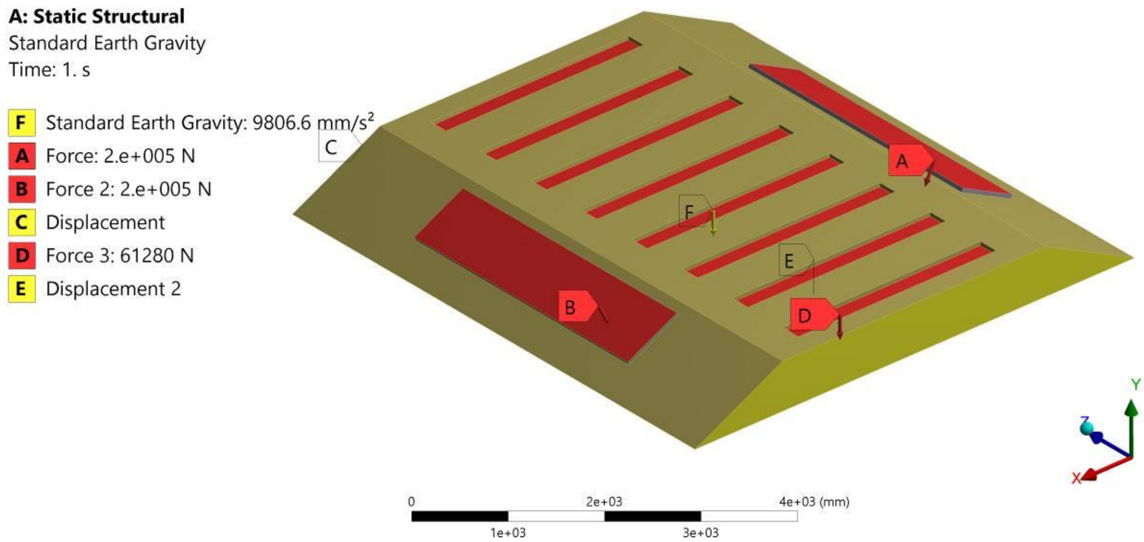

Figure 6 – The railway bed boundary conditions:

A, B – force transmitted by vibrating plates, C – limitation of movement at the ends, D – total load from reinforced concrete sleepers, rails and pairs of wheels, E – limitation of movement at the base, F – gravitational force

The load from the vibration plates is assumed to be static. The dynamic impact has been taken into account by introducing the dynamic coefficients ($k_д$=1,2).

To study displacement along the length of the sleeper base, there has been selected the studied 1-2 line (Figure 7).

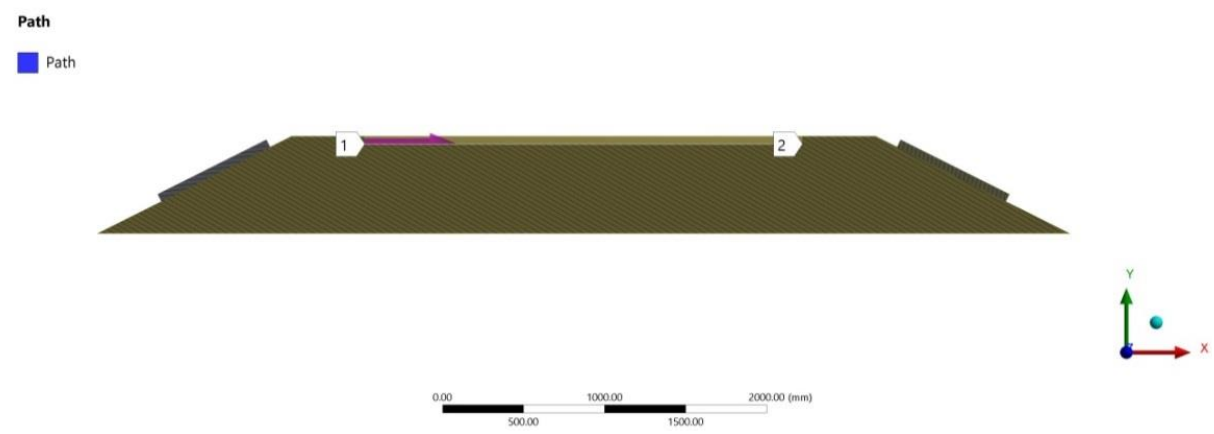

Figure 7 – The 1-2 line

The non-linear calculation of the interaction of the railway bed with the vibration plate has shown good convergence (Figure 8).

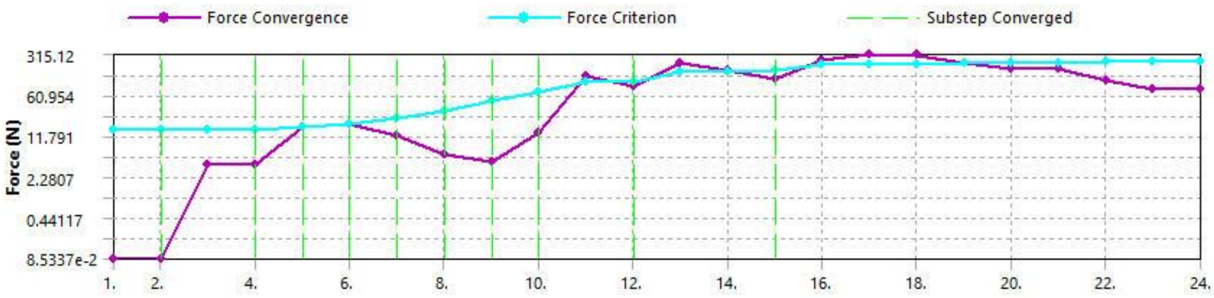

Figure 8 – Force convergence

Findings/Discussion

As a result of numerical calculations, the data have been obtained that make it possible to evaluate the performance criteria. The maximum and minimum values of stresses in the zones of impact on the railway bed, the areas of occurrence of plastic strains in soil foundations, as well as the displacement of the "undersleeper zone", which allow predicting deformation processes under vibration load, are shown.

Below there are the results of vertical movement along the length of the sleeper base (Figure 9).

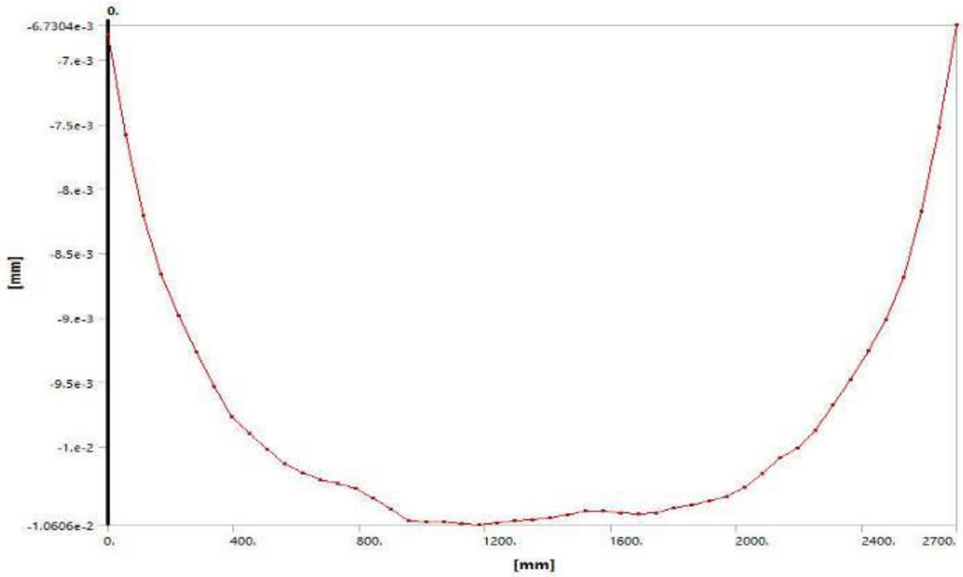

Figure 9 – Displacements along the 1-2 line

It should be noted that the largest displacements occur on the two edges of the sleeper base. Figures 10, 11, 12 show more obvious pictures of strains in various directions.

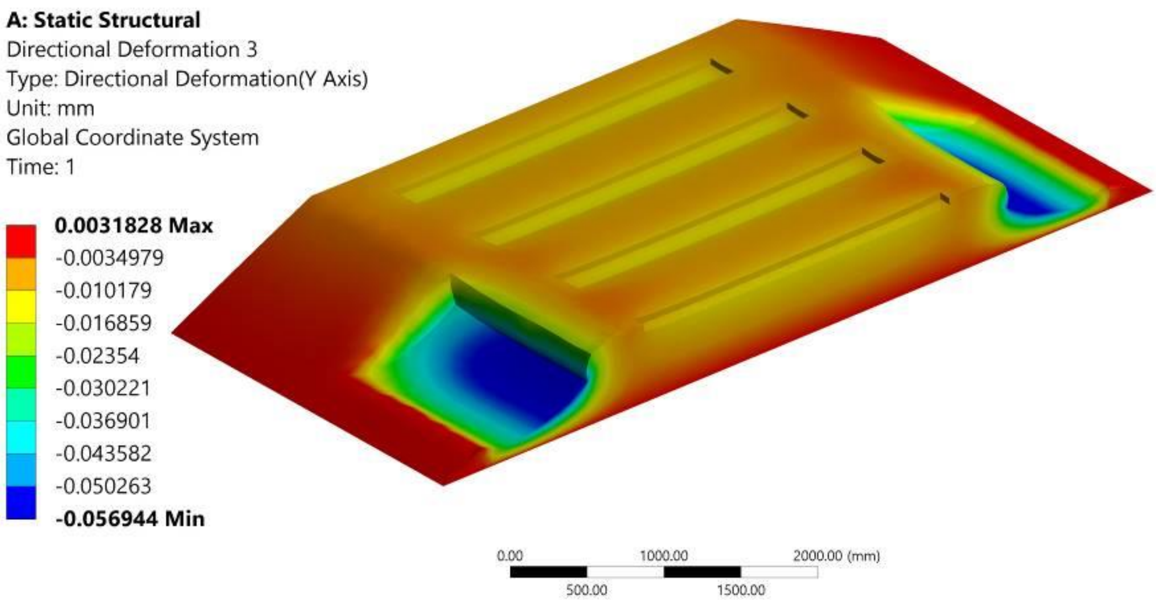

Figure 10 – The picture of strains in the vertical direction

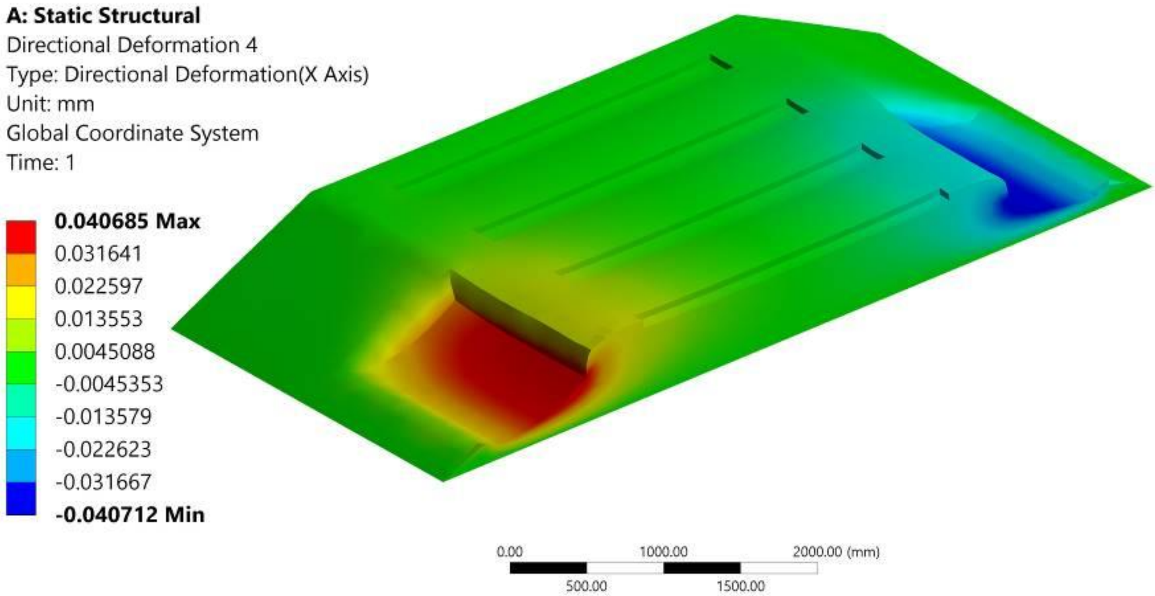

Figure 11 – The picture of strains in the transverse direction

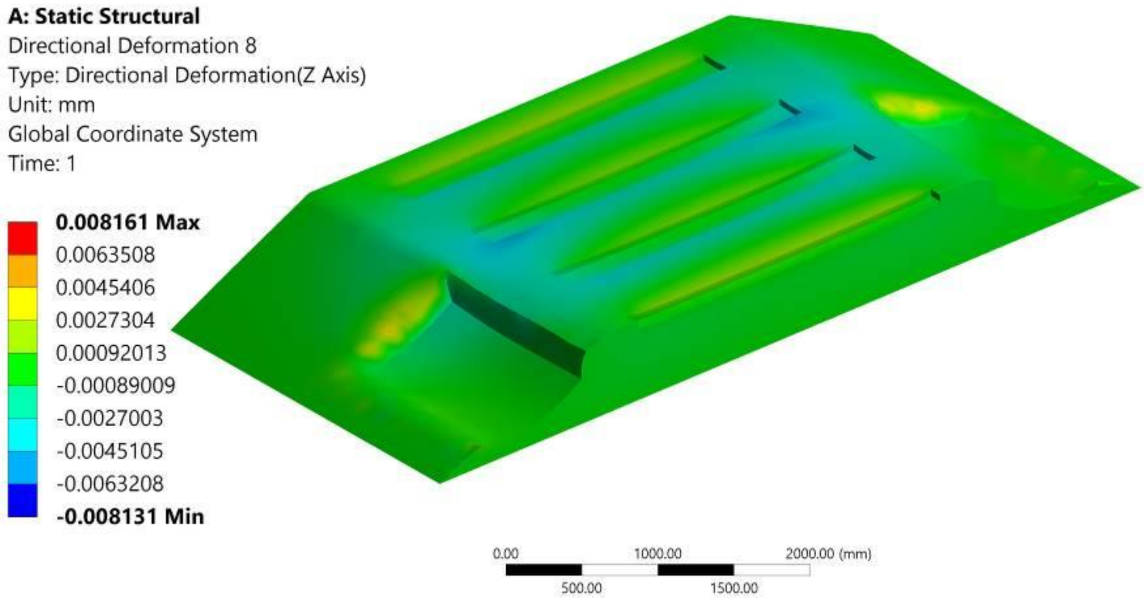

Figure 12 – The picture of strains in the longitudinal direction

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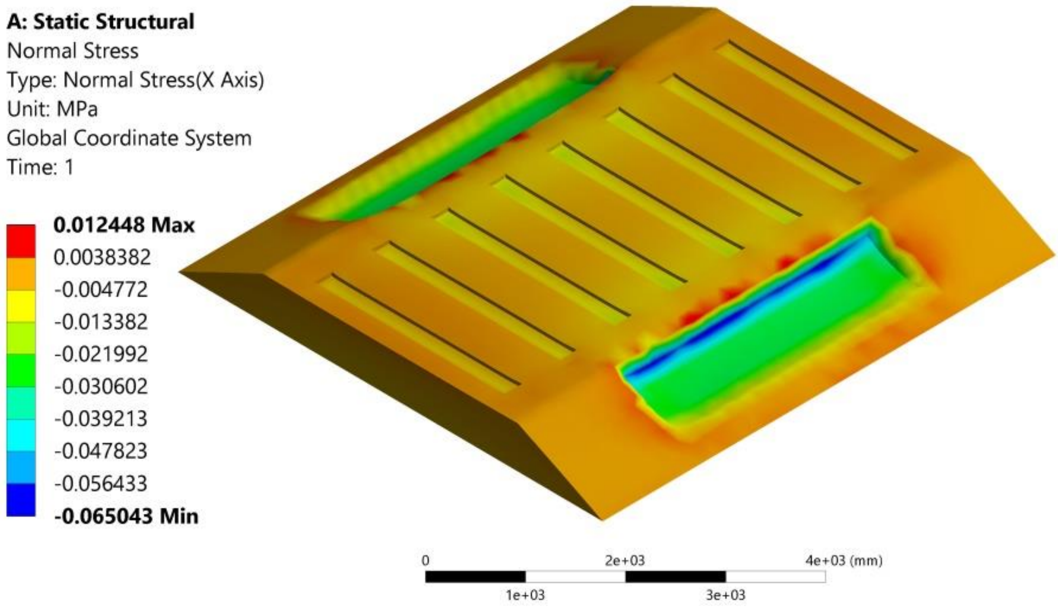
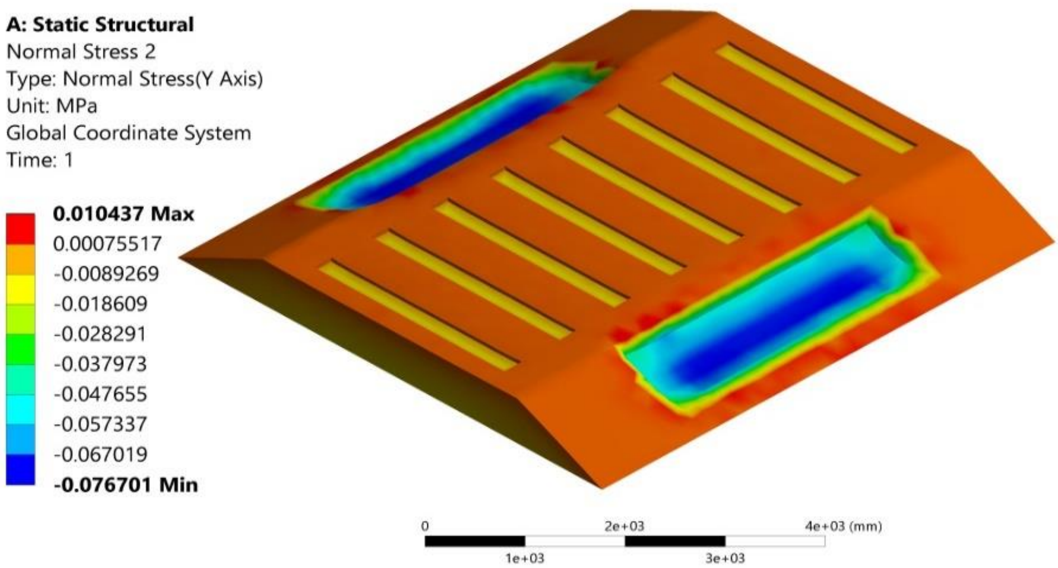
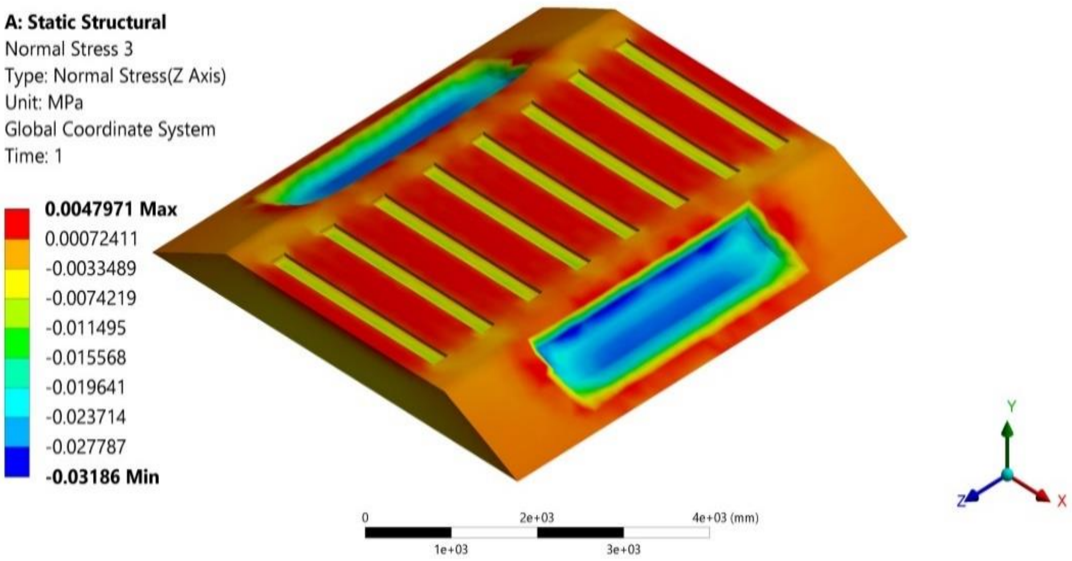
Figure 13 shows the isofields of normal stresses σ



a)



b)



c)

Figure 13 – Normal stresses isofields: a) σx; b) σy; c) σz

In this Figure there is obvious the occurrence of a high stress gradient under the loaded "slab – railway bed" system.

At the same time, plastic strains can be observed (Figure 14).

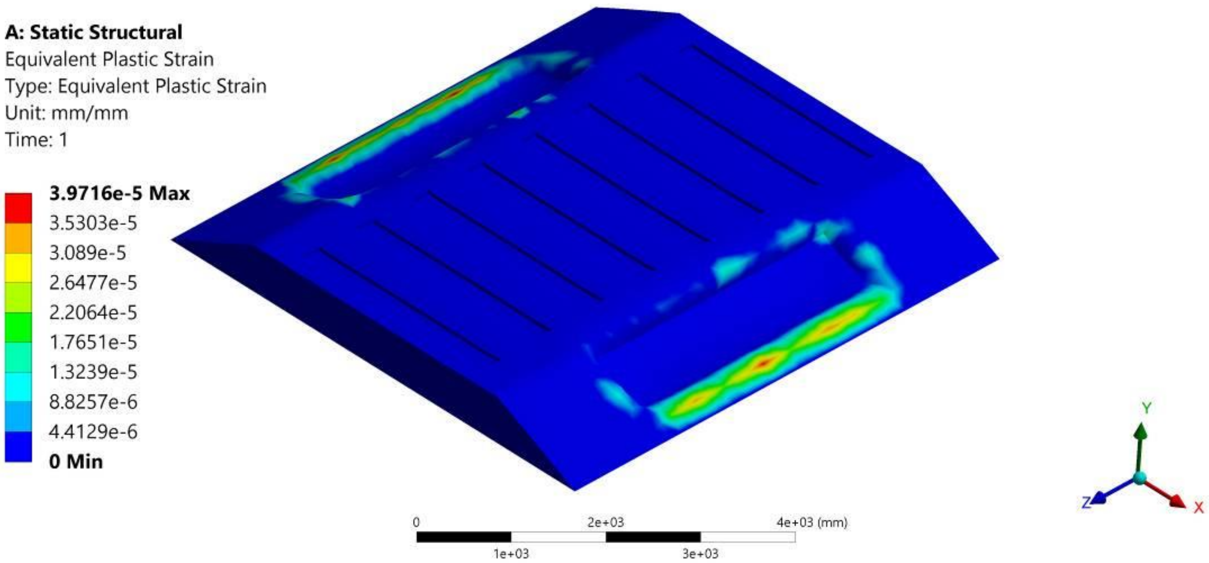


Figure 14 – Elastic strains of the earth work

Conclusion

Methods of calculating the railway bed have been analyzed.

The necessity of obtaining a picture of three stress-strain states of the railway bed by more accurate methods has been substantiated.

In order to improve the accuracy of modeling the stress-strain state of the railway bed, an elastic-plastic model should be used according to the Mohr-Coulomb strength criterion.

The precipitation along the length of the sole of the sleepers is uneven and has maximum values along the edges.

The obtained numerical results in the process of three-dimensional modeling using the FEM allow demonstrating volumetrically the stress-strain state of the railway bed.

Author contribusion:

Karsakova Akbope – consent to be responsible for all aspects of the work, proper study and resolution of issues related to the reliability of data or the integrity of all parts of the article.

Kadyrov Adil – approval of the final version of the article for publication;

Pak Igor – a significant contribution to the concept or design of the work; collection, analysis or interpretation of the results of the work;

Kyzylbayeva Elvira – writing the text and/or critical revision of its content.

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Карсакова А.Ж.[1],Кадыров А.С.[1], Пак И.А.[1], Кызылбаева Э.Ж.[1]
[1]Карагандинский технический университет имени Абылкаса Сагинова, Караганда, Казахстан

Моделирование процесса уплотнения железнодорожного полотна

Аннотация. В статье решена задача взаимодействия уплотняющей плиты с дорожным полотном. Получены численные результаты в процессе трехмерного моделирования с использованием метода конечных элементов, которые позволяют объемно демонстрировать напряженно-деформированное состояние дорожного полотна и использовать их в методике расчета.

Ключевые слова: уплотнение, дорожное полотно, сыпучая среда, вязкая среда, метод конечных элементов.

Карсакова А.Ж.[1], Кадыров А.С.[1], Пак И.А.[1], Кызылбаева Э.Ж.[1]
[1]Әбілқас Сағынов атындағы Қарағанды техникалық университеті, Қарағанды, Қазақстан

Теміржол қабатын тығыздау процесін модельдеу

Аңдатпа. Мақалада тығыздағыш тақтаның жол төсемімен өзара әрекеттесу мәселесі қарастырылды. Жол төсемінің кернеулі-деформацияланған күйін толық көрсетуге және оларды есептеу әдістемесінде пайдалануға мүмкіндік беретін соңғы элементтер әдісін қолдана отырып, үш өлшемді модельдеу процесінде сандық нәтижелер алынды.

Түйін сөздер: тығыздау, жол төсемі, борпылдақ орта, тұтқыр орта, соңғы элементтер әдісі.

Авторлар туралы мәліметтер:

Карсакова Акбопе Жолаевна **–** PhD, Әбілқас Сағынов атындағы Қарағанды техникалық университеті көлік техникасы және логистика жүйелері кафедрасының аға оқытушысы, Назарбаев көшесі, 56, Қарағанды, Қазақстан.

Кадыров Адиль Суратович **–** техника ғылымдарының докторы, Әбілқас Сағынов атындағы Қарағанды техникалық университеті көлік техникасы және логистика жүйелері кафедрасының профессоры, Назарбаев көшесі, 56, Қарағанды, Қазақстан.

Пак Игорь Анатольевич **–** хат-хабар авторы, PhD, Әбілқас Сағынов атындағы Қарағанды техникалық университеті көлік техникасы және логистика жүйелері кафедрасының аға оқытушысы, Назарбаев көшесі, 56, Қарағанды, Қазақстан.

Кызылбаева Эльвира Жанабековна **–** PhD, Әбілқас Сағынов атындағы Қарағанды техникалық университеті көлік техникасы және логистика жүйелері кафедрасының аға оқытушысы, Назарбаев көшесі, 56, Қарағанды, Қазақстан.

Сведения об авторах:

Карсакова Акбопе Жолаевна **–** PhD, Карагандинский технический университет имени Абылкаса Сагинова, улица Назарбаева, 56, город Караганда, Казахстан.

Кадыров Адиль Суратович **–** доктор технических наук, профессор Карагандинский технический университет имени Абылкаса Сагинова, улица Назарбаева, 56, город Караганда, Казахстан.

Пак Игорь Анатольевич **–** PhD, автор для корреспонденции, Карагандинский технический университет имени Абылкаса Сагинова, улица Назарбаева, 56, город Караганда, Казахстан.

Кызылбаева Эльвира Жанабековна **–** PhD, Карагандинский технический университет имени Абылкаса Сагинова, улица Назарбаева 56, город Караганда, Казахстан.

Information about the authors:

Karsakova Akbope **–** PhD, Senior Lecturer of the Department of Transport Engineering and Logistics Systems, 56 Nazarbayev Street, Karaganda city, Kazakhstan

Kadyrov Adil Suratovich **–** Doctor of Technical Sciences, Professor of the Department of Transport Engineering and Logistics Systems, 56 Nazarbayev Street, Karaganda city, Kazakhstan.

Pak Igor **–** PhD, correspondence writer, Senior Lecturer at the Department of Transport Engineering and Logistics Systems Abylkas Saginov Karaganda Technical University, 56 Nazarbayev Street, Karaganda city, Kazakhstan

Kyzylbayeva Elvira – PhD, Senior Lecturer of the Department of Transport Engineering and Logistics Systems, 56 Nazarbayev Street, Karaganda city, Kazakhstan