Technobius, 2022, 2(4), 0030, DOI: https://doi.org/10.54355/tbus/2.4.2022.0030

Technobius

https://technobius.kz/

e-ISSN 2789-7338

Article

Calculation of the stress-strain state of highways using the finite element method

Zhanbolat Shakhmov[1,*], Jakharkhan Kabdrashit[2], Aru Kozhahmet[3]

[1]RSE on REM "National Center of Road Assets Quality", Astana, Kazakhstan
[2]Department of Algebra and Geometry, Faculty of Mechanics and Mathematics, L.N. Gumilyov Eurasian National University, Astana, Kazakhstan
[3]Department of Technology of Industrial and Civil Engineering, L.N. Gumilyov Eurasian National University, Astana, Kazakhstan
*Correspondence: E-mail: zhanbolat8624@mail.ru

Abstract. The main purpose of the examination of roads is the timely identification of areas that require improvement of road conditions, as well as the evaluation of the state of all structural elements of roads. The study of the causes of road deformations, measures to eliminate and prevent warping are the main issue of road maintenance. The survey of roads was conducted in accordance with the approved methods using standard measuring tools. PLAXIS software was used to perform the finite element analysis of deformations and stability of soil, to calculate the interaction of the pavement with the ground, the effect of heat fluxes. Processing of data on the road Almaty-Taraz has shown that stresses and deformations arise directly in the place of contact of point loads with trapezoidal shape on the depth of influence. The authors conclude that when horizontal deformations occur, the greatest stresses occur on the road shoulders, which surrounds possible slope collapses. In addition, volumetric deformations of the foundation occur under direct dynamic loading and, under its prolonged effect, contribute to the appearance of volumetric bulging deformations.
Keywords: cement concrete pavements, road defects, road survey, numerical modeling, PLAXIS.

1. Introduction

Concrete roads are not an invention of our day [1]. Concrete pavements on motorways in Europe in the 1930s were predominantly laid in two layers, with 20 to 25 cm thick freshly paved and paper lined [2]. Transverse joints, mostly as expansion joints, separated the concrete pavement at distances of 10 to 37.5 meters from each other [3]. A maximum of two transversal dummy joints were allowed between the expansion joints. The false joint was cut in the hardened concrete from 1938 onwards. Expansion dowel joints were used as longitudinal joints [4-5]. Concrete pavements were predominantly reinforced (minimum 2.5 kg/m²) and the cement content of the top concrete was approximately the same as today [6]. Dowels and anchors started to be used from around 1936 onwards [7].

Today, road construction has also aroused interest, and progressive technologies and maintenance processes for cement-bonded concrete roads are constantly being improved.

Road surfaces are heavily stressed due to dynamic influences and climatic conditions. In order to achieve high quality cement concrete roads, German road builders have defined the requirements for its paving, which include cement, aggregates, concrete strength, volume of air involved, slip resistance, surface treatment and concrete maintenance [8-9].

The total length of cement concrete paved roads in Kazakhstan is 1,628.48 km [10]. It is advisable to carry out comprehensive road inspections, serving also to accumulate a data bank on the condition of all road elements, at least once every 5 years. Road inspections are an integral part of all work aimed at ensuring high transport and operational performance of roads. Their nature is similar to that of road surveys, involving the choice of dimensions for road elements in the light of traffic flow. The results of the surveys are used as input for traffic management projects, strengthening of the pavement, reconstruction of road sections, etc. [11].

One of the deformations of roads is subsidence. The comfort and safety of travel suffers greatly from uneven subsidence. Calculations and surveys are not always up to date, so one method is numerical modelling of the pavement. Since subsidence is caused by a compressible subgrade, it is advisable to use the Plaxis calculation program for the calculation.

2. Methods

PLAXIS is a finite element analysis software system used to solve geotechnical engineering and design problems. PLAXIS is a package of computational programs for finite element calculations of the stress-strain state of structures, foundations and foundations.

The programme is suitable for those who carry out calculations of structures in industrial, civil, hydraulic, transport, underground and other types of construction, as well as for surveyors:

- Surveyors - for assessing the stability of natural slopes and preliminary analysis of landslide control structures, as well as for assessing the effects of changing groundwater levels and calculating stresses from their own weight.

- Soil laboratories to be able to calibrate and issue complete sets of soil model parameters in accordance with current regulatory requirements for geotechnical calculations.

- Design organizations to provide design justification for design solutions, which is the basis for the design process. To obtain the parameters of structures and constructions in order to make a technical and economic comparison in case of variant design.

- To construction companies in order to check the correctness of design solutions and the possibility of effective evaluation of complicated geotechnical situations at a construction site and taking decisions.

- for checking the feasibility and reliability of design decisions.

This program was used to create a model of the road section for finite element calculations of the stress-strain state of the base and road pavement.

The calculation was carried out in PLAXIS numerical simulation software, stress and strain diagrams were obtained for the road pavement and subgrade; the calculation was carried out for the Taraz Almaty section 744-806 km, since source documents (geological surveys) were available for this section.

The roadway consists of the following layers: cement concrete (27 cm thick), polyethylene film (1 mm thick), crushed stone mix with 7% cement treatment (20 cm thick), gravel-sandy mix underlay (35 cm thick). The subgrade soil is silty-clay.

The container of the mixer was wiped with a damp rag, poured with water, added cement, after which the mixer was turned on low speed.

3. Results and Discussion

As a result of the calculations in the Plaxis software package, the stress and strain isofields were obtained as shown below. The physical and mechanical properties of each pavement were determined from reference materials and laboratory results according to the project documentation.

The stress mosaic (Figure 1) shows the results of stresses in the ground from a load of 160 kN with the obtained outputs where the maximum stress occurs in the silty-clay soil layers of the road and the pavement layers. The maximum stresses reach up to 26 kN/m^2.

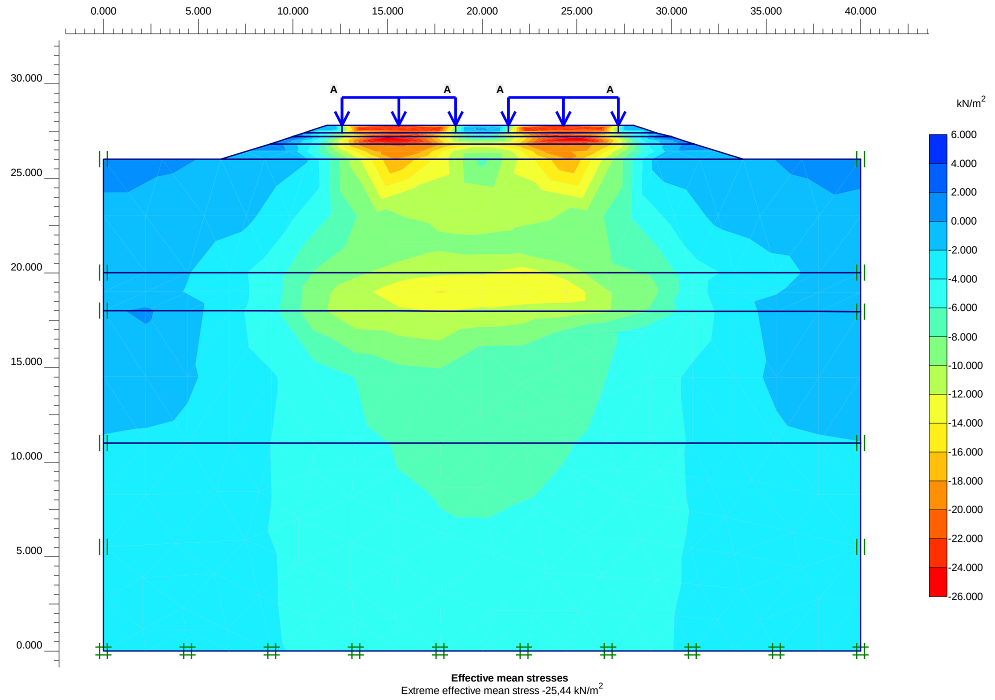

Figure 1 – Effective average tangential stress

Relative tangential stress (Figure 2) occurs directly under the road, and is distributed over the gravel soils which, because of their greater strength, carry the main load from the road. It can be seen that the stresses are not created and distributed uniformly across the layers of the subsoil.

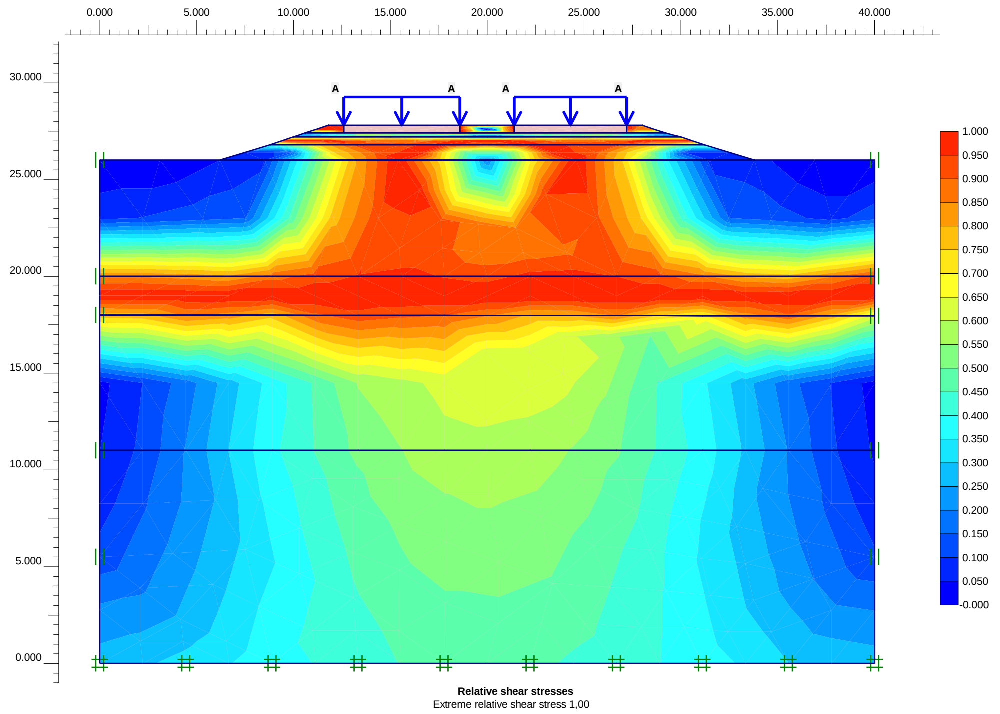

Figure 2 – Relative Tangential Stress

The Figure 3 shows that large stresses run completely through the entire pavement. The figure shows that large stresses run completely through the entire pavement. Each pavement itself distributes the load and consequently the materials withstand the load. But the important question is still that of the subgrade, which has to have a sufficient deformation modulus.

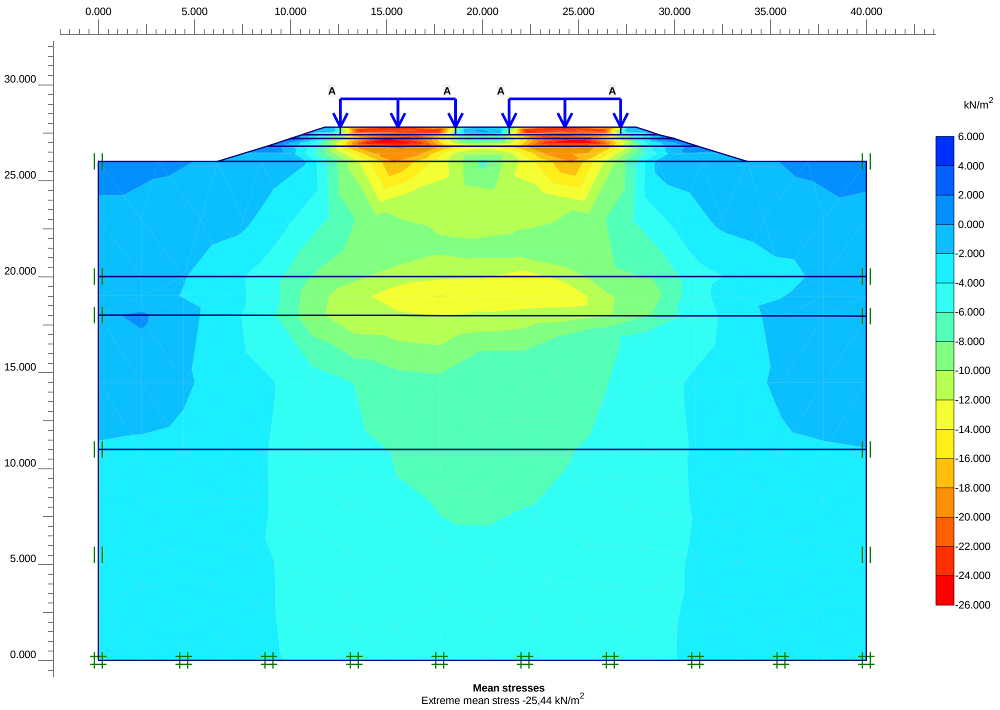

Figure 3 – Extreme Average Mean Stress

The vertical deformations (Figure 4) showed a negligible result, not more than 2 cm in total. According to the normative and technical documents it should not be more than 5 cm.

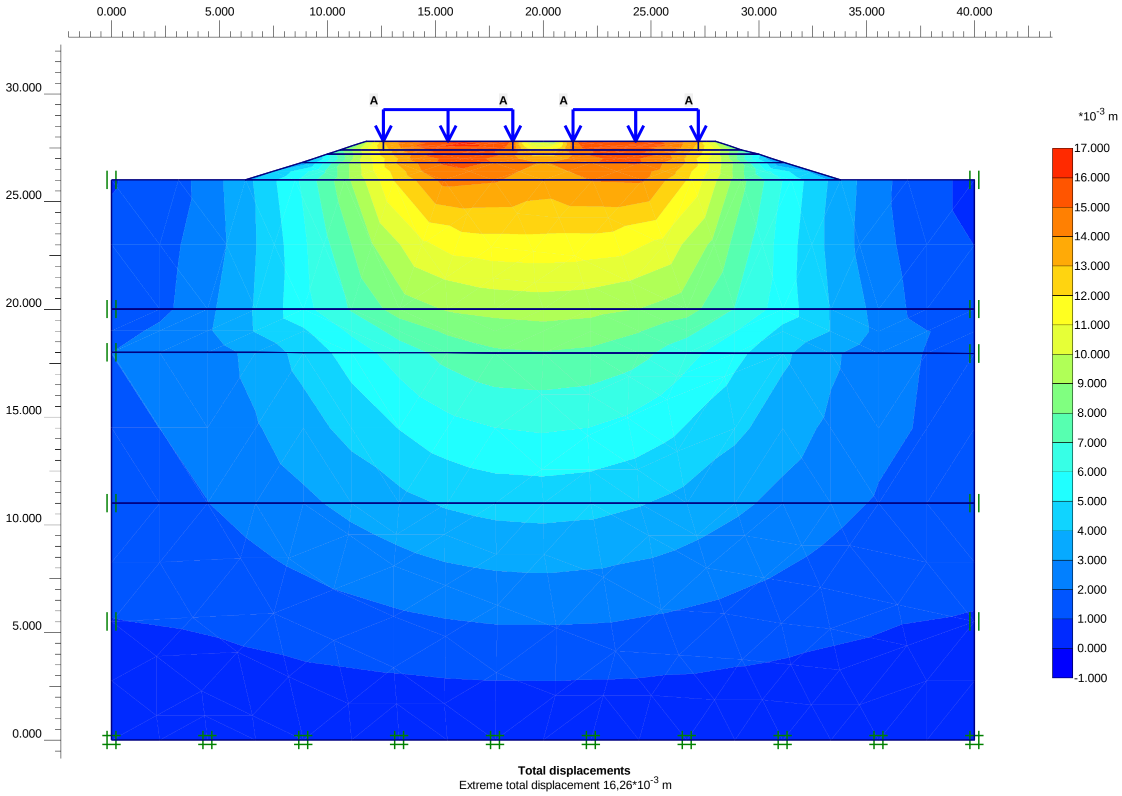

Figure 4 – Total Deformation

Horizontal deformations (Figure 5) showed a negligible result, not more than 0.5 cm in total. This result is not significant.

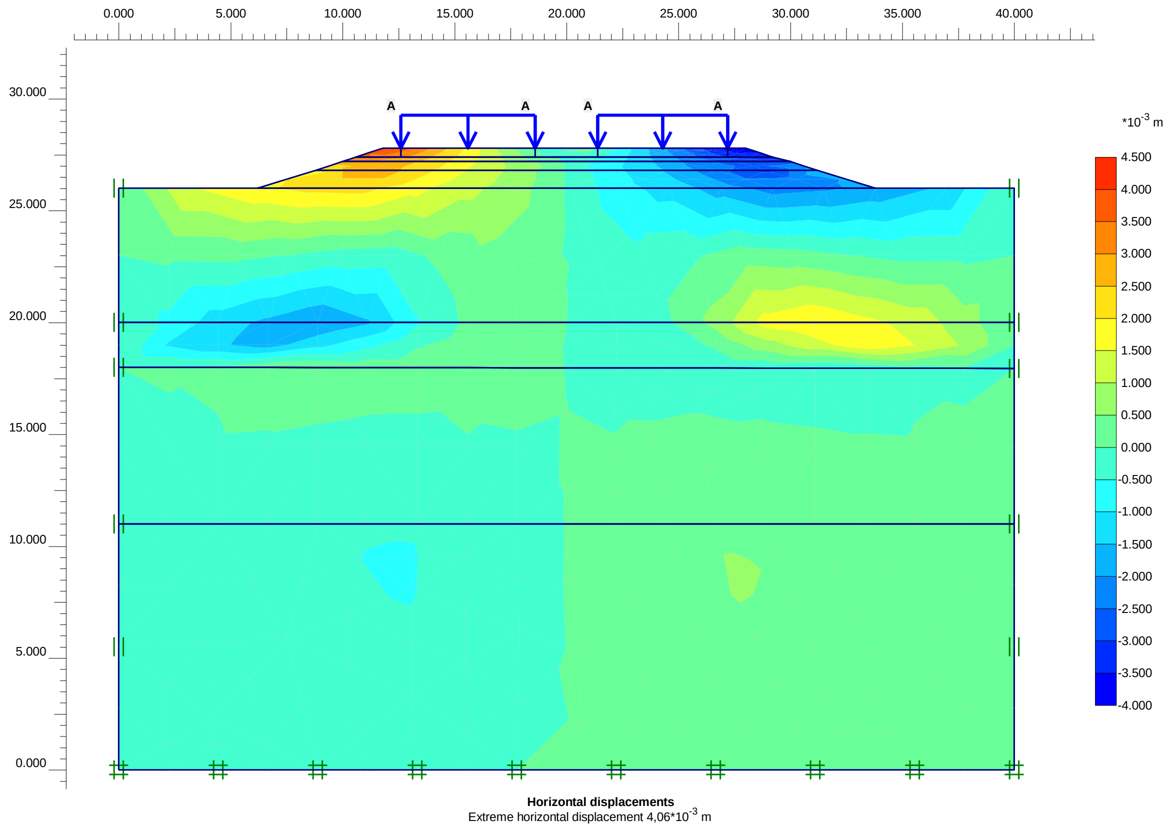

Figure 5 – Horizontal Deformation

According to the results (Figure 6,7 and 8) obtained, it can be observed that at the top of the road slope and in the gravel part of the subgrade, there are 8 m depths.

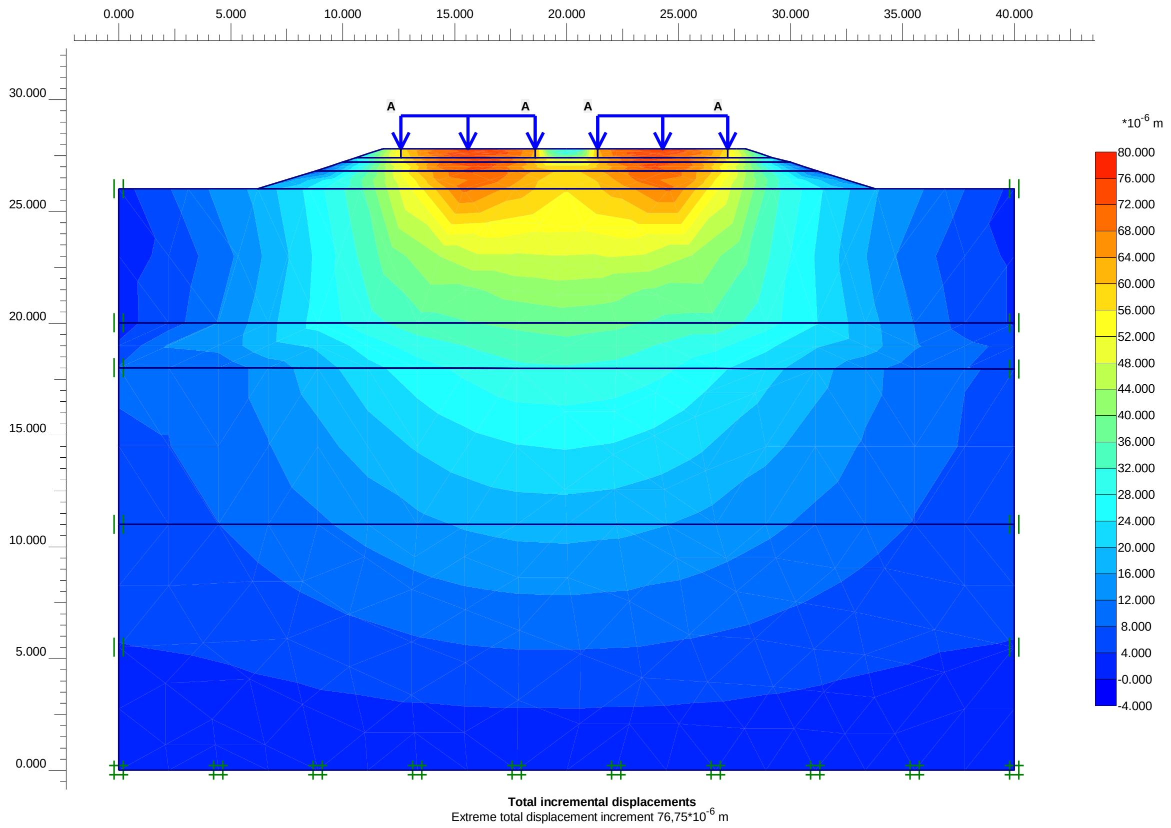

Figure 6 – Cumulative strain increments

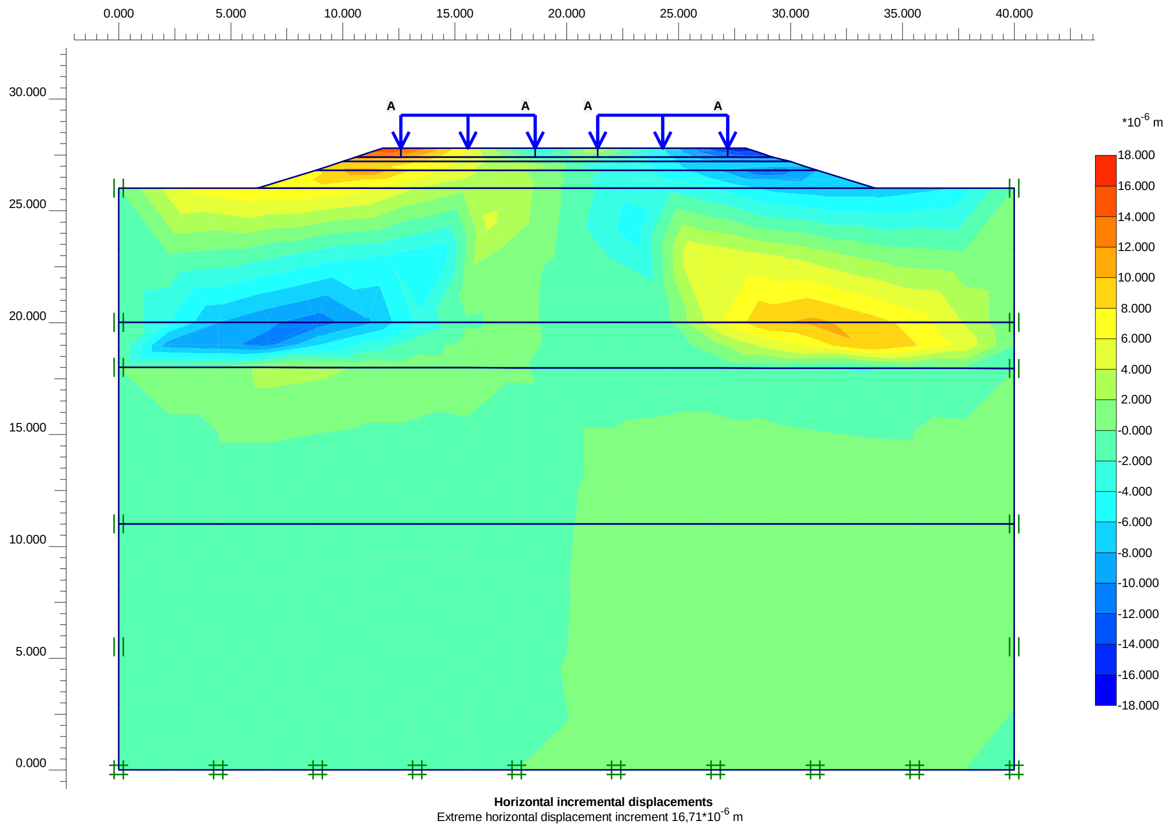

Figure 7 – Horizontal strain increments

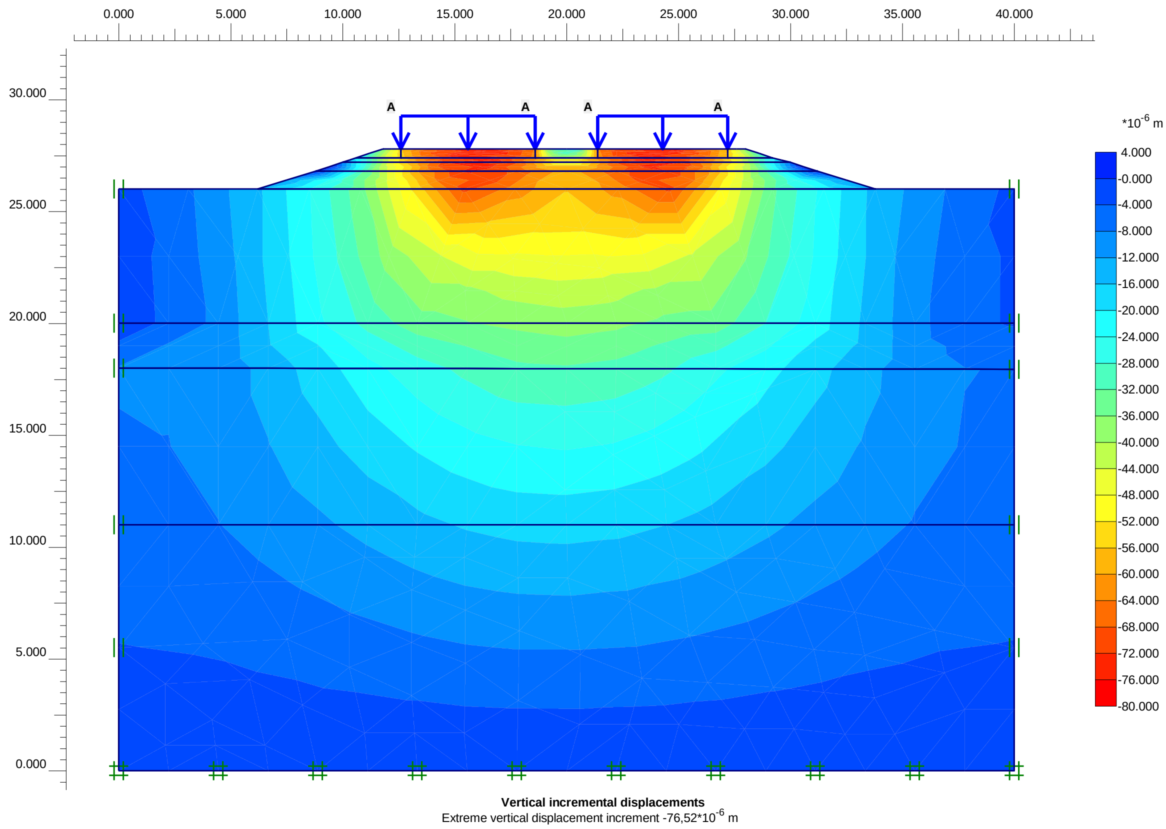

Figure 8 – Vertical strain increments

Volumetric and Tangential deformations (Figure 9 and 10) occur in the road slope areas and in the middle part in the road's median area. Maximum number is 1,4 %.

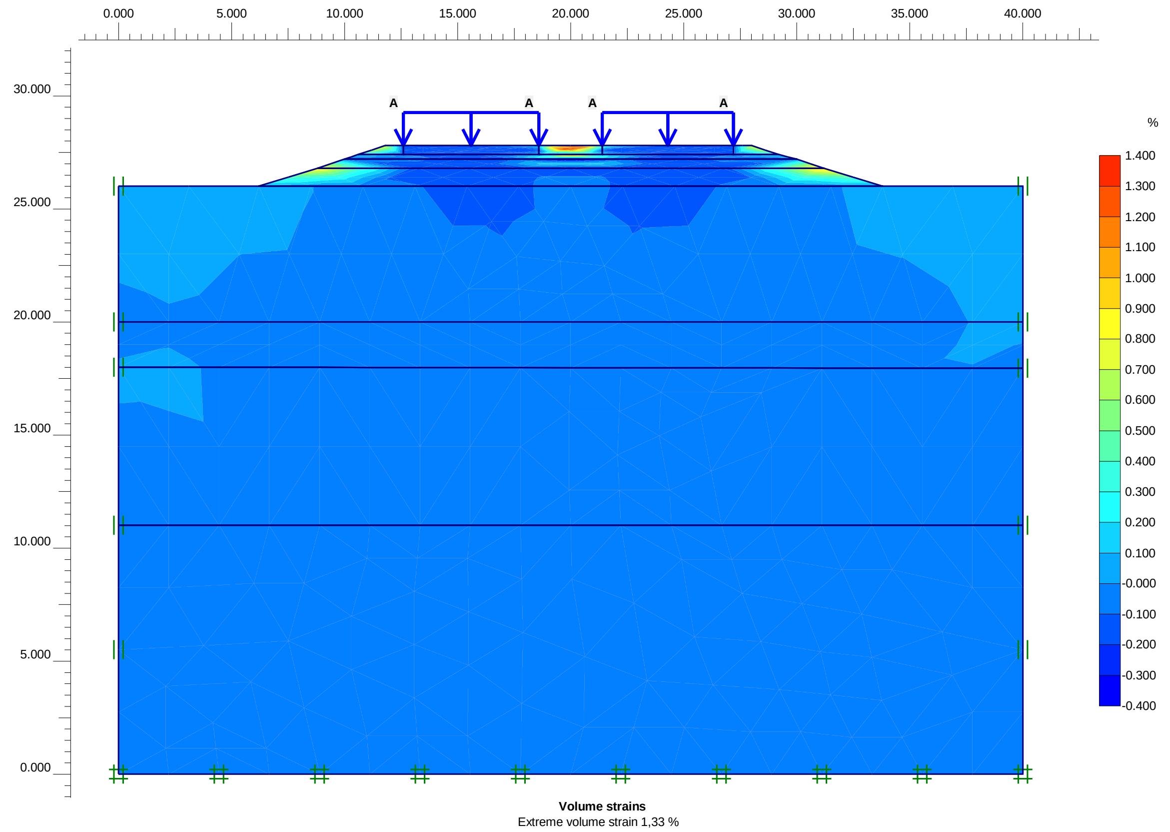

Figure 9 – Volumetric deformations

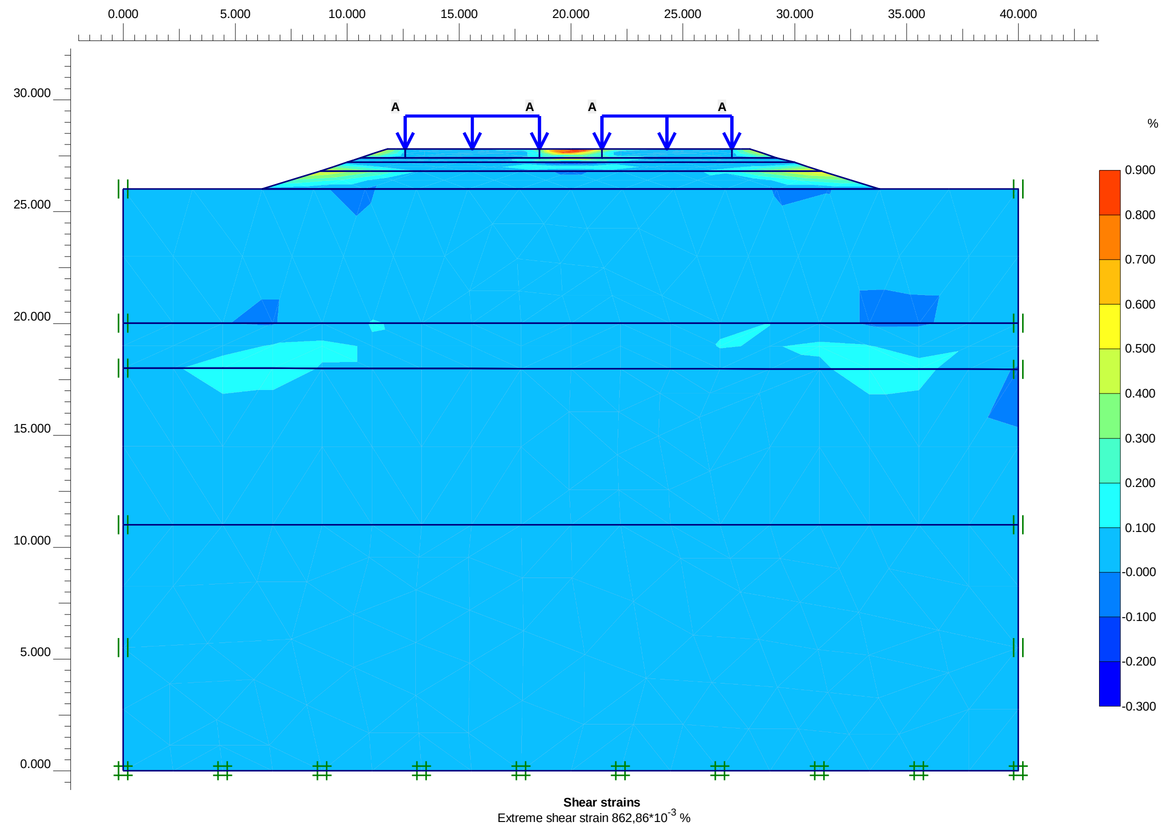

Figure 10 – Tangential Deformation

Stresses and strains occur directly at the point of contact of point loads with a trapezoidal shape along the depth of influence. The horizontal deformation isofields characterize the shear isofields towards the shoulder.

4. Conclusions

According to the calculations performed, strain and stress mosaics were obtained.

- Tangential stress mosaics show that stresses propagate linearly along road pavement with maximum 26 kN/m^2 and loam subgrade, followed by non-linear stress concentration in hard gravel subgrade;

- Relative tangential stress mosaics show that the stress isofields spreads with a widening of the influence zone in the form of a trapezoid and spreading over the gravel bed;

- The mosaics of general deformation diagrams show that subsidence occurs linearly in pavement and subgrade layers, but soil bulging occurs in road slopes due to loading of the roadbed and settlement is no more 2 cm;

- According to the mosaics of volumetric deformation diagrams, volumetric deformations are found to occur directly under the roadbed with 1.4 % and volumetric bulging deformations occur in the asphalt surface between the roadbeds.

References

1. Recycling of a Concrete Pavement after over 80 Years in Service / T. Rudnicki, R. Jurczak // Materials. — 2020. — Vol. 13, No. 10. — P. 2262–2262. https://doi.org/10.3390/ma13102262
2. Handbook of Road Technology, Fourth Edition / M.G. Lay. — Florida, USA: CRC Press, 2009. — 942 p.
3. Comparative life cycle cost analysis for gravel and pavement road (case study for gumara-kerstos-semera road project) / Setargie Mesay // Thesis. — Bahir Dar, Ethiopia: Bahir Dar University— 2020. — 96 p.
4. Expansion characteristics of concrete with free lime based expansive additives under uniaxial restraint conditions / M. Gupta, K. Pen, G. Igarashi, Y. Takahashi, T. Ishida // Construction and Building Materials. — 2022. — Vol. 356. — P. 129330. https://doi.org/10.1016/j.conbuildmat.2022.129330
5. Quality requirements of joints in rigid pavement [Electronic resource] / Suryakanta // CivilBlog.Org. — [2016]. — Mode of access: https://civilblog.org/2016/02/02/quality-requirements-of-joints-in-rigid-pavement/ (accessed date: 27.11.2022).
6. A Multiscale and Multimethod Approach to Assess and Mitigate Concrete Damage Due to Alkali–Silica Reaction - Weise - 2022 - Advanced Engineering Materials - Wiley Online Library [Electronic resource] — Mode of access: https://onlinelibrary.wiley.com/doi/full/10.1002/adem.202101346 (accessed date: 27.11.2022).
7. Precast Concrete Structures / A. Steinle, H. Bachmann, M. Tillmann. — New Jersey, USA: John Wiley & Sons, 2019. — 378 p.
8. Sustainability assessment for portland cement concrete pavement containing reclaimed asphalt pavement aggregates / X. Shi, A. Mukhopadhyay, D. Zollinger // Journal of Cleaner Production. — 2018. — Vol. 192. — P. 569–581. https://doi.org/10.1016/j.jclepro.2018.05.004
9. Low-Noise pavement technologies and evaluation techniques: a literature review / P. Mikhailenko, Z. Piao, M.R. Kakar, M. Bueno, S. Athari, R. Pieren, K. Heutschi, L. Poulikakos // International Journal of Pavement Engineering. — 2022. — Vol. 23, No. 6. — P. 1911–1934. https://doi.org/10.1080/10298436.2020.1830091
10. How Nurly Zhol program is changing Kazakhstan: Modern highways and new directions - Official Information Source of the Prime Minister of the Republic of Kazakhstan [Electronic resource] — Mode of access: https://primeminister.kz/en/news/reviews/how-nurly-zhol-program-is-changing-kazakhstan-modern-highways-and-new-directions (accessed date: 28.11.2022).
11. Ecological traffic management: A review of the modeling and control strategies for improving environmental sustainability of road transportation / B. Othman, G. De Nunzio, D. Di Domenico, C. Canudas-de-Wit // Annual Reviews in Control. — 2019. — Vol. 48. — P. 292–311. https://doi.org/10.1016/j.arcontrol.2019.09.003

Information about authors:

Zhanbolat Shakhmov – PhD, Associate Professor, RSE on REU «National Center for the Quality of Road Assets», Astana, Kazakhstan, zhanbolat8624@mail.ru

Jakharkhan Kabdrashit – Master Student, Department of Algebra and Geometry, Faculty of Mechanics and Mathematics, L.N. Gumilyov Eurasian National University, Astana, Kazakhstan, djakharkhan@gmail.com

Aru Kozhakhmet – Master Student, Department of Technology of Industrial and Civil Engineering, Faculty of Architecture and Civil Engineering, L.N. Gumilyov Eurasian National University, Astana, Kazakhstan, arukozhahmet@mail.ru

Author Contributions:
Zhanbolat Shakhmov – concept, methodology, resources, funding acquisition.
Jakharkhan Kabdrashit – interpretation, analysis, drafting, editing.
Aru Kozhakhmet – data collection, modeling, testing, visualization.

Received: 28.12.2022
Revised: 30.12.2022
Accepted: 30.12.2022
Published: 30.12.2022