CETRA[2018]

5th International Conference on Road and Rail Infrastructure

17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

IRF GLOBAL

FEHRL

Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation

CETRA[2018]
5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

TITLE
Road and Rail Infrastructure V, Proceedings of the Conference CETRA 2018

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

ISBN
978-953-8168-25-3

DOI
10.5592/CO/CETRA.2018

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
"Tiskara Zelina", May 2018

COPIES
500

Zagreb, May 2018.

Proceedings of the
5th International Conference on Road and Rail Infrastructures – CETRA 2018
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

CETRA[2018]
5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

ORGANISATION

CHAIRMEN

Prof. **Stjepan Lakušić**, University of Zagreb, Faculty of Civil Engineering
Prof. emer. **Željko Korlaet**, University of Zagreb, Faculty of Civil Engineering

ORGANIZING COMMITTEE

Prof. Stjepan Lakušić
Prof. emer. Željko Korlaet
Prof. Vesna Dragčević
Prof. Tatjana Rukavina
Assist. Prof. Ivica Stančerić
Assist. Prof. Maja Ahac
Assist. Prof. Saša Ahac
Assist. Prof. Ivo Haladin
Assist. Prof. Josipa Domitrović
Tamara Džambas
Viktorija Grgić
Šime Bezina
Katarina Vranešić
Željko Stepan
Prof. Rudolf Eger
Prof. Kenneth Gavin
Prof. Janusz Madejski
Prof. Nencho Nenov
Prof. Andrei Petriaev
Prof. Otto Plašek
Assist. Prof. Andreas Schoebel
Prof. Adam Szeląg
Brendan Halleman

INTERNATIONAL ACADEMIC SCIENTIFIC COMMITTEE

Stjepan Lakušić, University of Zagreb, president
Borna Abramović, University of Zagreb
Maja Ahac, University of Zagreb
Saša Ahac, University of Zagreb
Darko Babić, University of Zagreb
Danijela Barić, University of Zagreb
Davor Brčić, University of Zagreb
Domagoj Damjanović, University of Zagreb
Sanja Dimter, J. J. Strossmayer University of Osijek
Aleksandra Deluka Tibljaš, University of Rijeka
Josipa Domitrović, University of Zagreb
Vesna Dragčević, University of Zagreb
Rudolf Eger, RheinMain Univ. of App. Sciences, Wiesbaden
Adelino Ferreira, University of Coimbra
Makoto Fujiu, Kanazawa University
Laszlo Gaspar, Széchenyi István University in Győr
Kenneth Gavin, Delft University of Technology
Nenad Gucunski, Rutgers University
Ivo Haladin, University of Zagreb
Staša Jovanović, University of Novi Sad
Lajos Kisgyörgy, Budapest Univ. of Tech. and Economics
Anastasia Konon, St. Petersburg State Transport Univ.
Željko Korlaet, University of Zagreb
Meho Saša Kovačević, University of Zagreb
Zoran Krakutovski, Ss. Cyril and Methodius Univ. in Skopje
Dirk Lauwers, Ghent University
Janusz Madejski, Silesian University of Technology
Goran Mladenović, University of Belgrade
Tomislav Josip Mlinarić, University of Zagreb
Nencho Nenov, University of Transport in Sofia
Mladen Nikšić, University of Zagreb
Andrei Petriaev, St. Petersburg State Transport University
Otto Plašek, Brno University of Technology
Mauricio Pradena, University of Concepcion
Carmen Racanel, Tech. Univ. of Civil Eng. Bucharest
Tatjana Rukavina, University of Zagreb
Andreas Schoebel, Vienna University of Technology
Ivica Stančerić, University of Zagreb
Adam Szeląg, Warsaw University of Technology
Marjan Tušar, National Institute of Chemistry, Ljubljana
Audrius Vaitkus, Vilnius Gediminas Technical University
Andrei Zaitsev, Russian University of transport, Moscow

CETRA2018 17–19 May 2018, Zadar, Croatia
5th International Conference on Road and Rail Infrastructure

GEOSYNTHETICAL MATERIALS IN DESIGNS OF HIGHWAYS IN COLD REGIONS OF FAR EAST

Sergey Kudryavtsev, Tatiana Valtseva, Elena Goncharova, Zhanna Kotenko, Anastasiya Peters, Semen Bugunov
Far Eastern State Transport University, Russia

Abstract

The results of scientific researches and engineering calculations of rational structures parameters of highways are presented in the paper. All the calculations and researches done were carried out relatively to a highway section in the Russian Far East. This road is being built in severe climatic and complex engineering and geological conditions. This is the area of permafrost occurrences and widely spread deep season freezing. The usage of a geosynthetic integral two-axis gird in the structure allows to lessen considerably the volume of expensive hard mineral volcanic filling of high quality. Numeric modeling of the structure behavior was done using a programming geotechnical complex, an “FEM model”. This allowed to give a quantitative and qualitative assessment of freezing and thawing processes in conditions of annual cycle construction. Effective measures to provide operational reliability for the rational engineering solutions for highways in Northern territories of the Russian Far East were worked out on the basis of the achieved results.

Keywords: geomaterial, strengthening, modeling, deformations, permafrost soil, deep freezing, thawing.

1 Introduction

This work represents a number of engineering, scientific and applied calculation solutions. The goal of the given researches is a rational design of a highway using modern geotechnologies and promising geosynthetic materials that provide the necessary supporting power and operational reliability at the given loads and intensive traffic in complex engineering, geological and severe climatic conditions of Northern territories of Russia. During the researches the numerical geotechnical modeling tests of stress deformed conditions under traffic loads as well as thermodynamic processes in an annual cycle of freeze-thaw were carried out for different variants of highway structures. To confirm the results of the theoretical researches a test ground was designed on the operating section of a highway under construction. The test ground had permanent points equipped with monitoring devices that were to measure the dynamic parameters of the structure under traffic loads. The engineering and geological conditions corresponded to those in the calculation researches. The tests of the pavement structure with an integral two-axis geogrid and less thickness of crushed stone layers were carried out. The field die, a loading device determining the supporting power of a road structure, was used in the tests.

DOI: https://doi.org/10.5592/CO/CETRA.2018.953

2 Methods of numerical modeling

2.1 Method of numerical modelling of stress-strain state

The design geotechnical modeling was performed using software package “FEM models”, which was developed by geotechnical engineers from Saint-Petersburg. The elastic-plastic model with the yield criterion was used to describe the work of variable stiffness design. This elastic-plastic model was chosen because its parameters can be taken from existing material of engineering and geological surveys [10-17]. Numerical methods are in good correspondence with the traditional engineering methods of calculating the settlement in such formulation. They provide accurate description of deformations in structures. Figure 1 shows a scheme of determining the theoretical stresses in the elastic-plastic model of the soil. The ultimate stresses in the tension field are restricted by the tensile strength σ_p. Area I in the tension field is restricted by the stress $\sigma_3 = \sigma_p$, while in the compression area it is restricted by the Coulomb strength criterion according to:

$$\sigma_1 = R_c + \sigma_3 ctg\Psi \tag{1}$$

Where R_c is the uniaxial compression strength.

The element stiffness matrixes and the ones for the whole system are formed once and stay the same in the procedure of elastic-plastic solution. The load is applied in small portions as it happens in its real sequence in nature. If the point M occurs within the limits of the elastic region I, it means the element is in the elastic state and there is no need to correct the stresses.

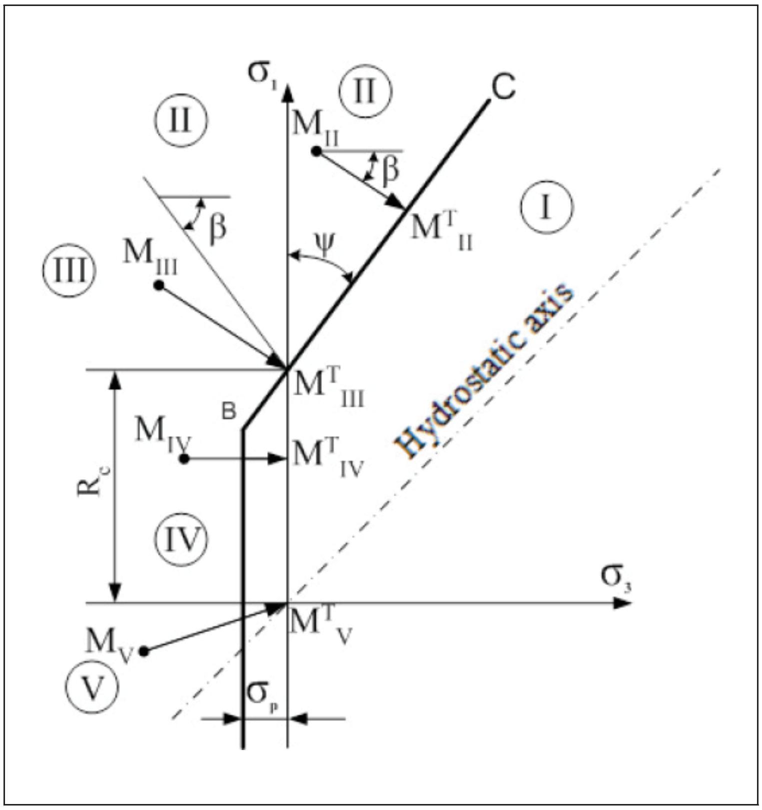

Figure 1 Scheme of determining theoretical stresses in elastic-plastic model of soil

If the point M occurs beyond the yield behavior contour, the theoretical stresses are calculated in the following order. If the point of total stress occurs in the area II (the basic plastic zone), the theoretical point lies at the intersection of the plastic yield and the right line. If the point of total strength occurs in area III, the element breaks in the direction of the stress, while the stresses go down to the level of the soil strength to the uniaxial compression. In the FEM Models program the natural stress state is substituted by the hydro engineering tensor for pressing the soil of the "characteristic volume" that is summarized with the actual stresses in situ:

$$\left\{\sigma_{1,3}\right\}=\left\{\sigma_{1,3}^{\Phi}\right\}+\left\{\sigma_{1,3}^{r}\right\} \tag{2}$$

The assumption reflects a real picture of the natural stress state in weak soils. The used method and the software package "FEM models" are developed by the authors for the projects under construction in Russia and the Far East. Application of the methods and approaches for the calculation and design of geotechnical structures using software package "FEM models" show its accurate and objective performance in the most rational calculations of geotechnical constructions.

2.2 Method of numerical modelling of freezing and thawing processes

Investigation of the processes of freezing and thawing of the soil base of the thermopiles foundation is expedient to carry out the methods of numerical simulation. Numerical simulation of the thermopile foundation in permafrost performed in the software package "FEM-models", developed by Geotechnics St. Petersburg under Professor V.M. Ulitskogo. Integral part of "FEM-models" is a program "Termoground", which allows you to explore with the help of numerical simulation in the spatial setting processes of freezing, frost heaving and thawing in the annual cycle of the finite element method. General equation describing the freezing and thawing processes for a transient thermal regime in a three dimensional soil space can be expressed as following:

$$C_{th(f)}\rho\frac{\partial T}{\partial t}=\lambda_{th(f)}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right)+q_V \tag{3}$$

Where $C_{th(f)}$ – specific heat of soils (frozen or thawed), J/kgK; ρ – soil consistency, kg/m³; T – temperature, K; t – time, c; $\lambda_{th(f)}$ – thermal conductivity of soil (frozen and thawed), W/mK; x, y, z – coordinates, m; q_v – internal heat source capacity, W/m³.

The core of a mathematical modeling of thermophysical processes in "Termoground" program is the model of high ice, thawed and frozen soils offered by N.A. Tsytovich, Y.A. Kronik and V.F. Kiselev. The major factors determining the defined surface temperatures on the embankment elements and the adjacent territory are the atmospheric air temperature and the heat exchange conditions between the air and the structure surface that depend on the wind conditions, solar radiation, evaporation, and others. The thermophysiscal characteristics of the roadway and roadbed soils in thawed and frozen states are taken in accordance with the SR 25.13330.2012 – Permafrost Foundation Engineering Standards.

3 Results of numerical modeling of stress deformed conditions and freeze-thaw processes

The elastic plastic model with the ultimate surface of Coulomb-Moore was used in the geotechnical modeling of the structures. The original data was taken from the materials of engineering geology studies. The studies of the stress deformed conditions of a non-reinforced highway (with crushed stone in a full amount) and a highway reinforced with a geogrid (47 % of crushed stone layers less), Figure 2. The maximum vertical deformations (buckling) on the surface of the highway are 1.44 mm (Figure 3). While the values of vertical live-load stresses under a wheel do not exceed 174 kPa that meet the long-term durability parameters of the pavement structure, Figure 4.

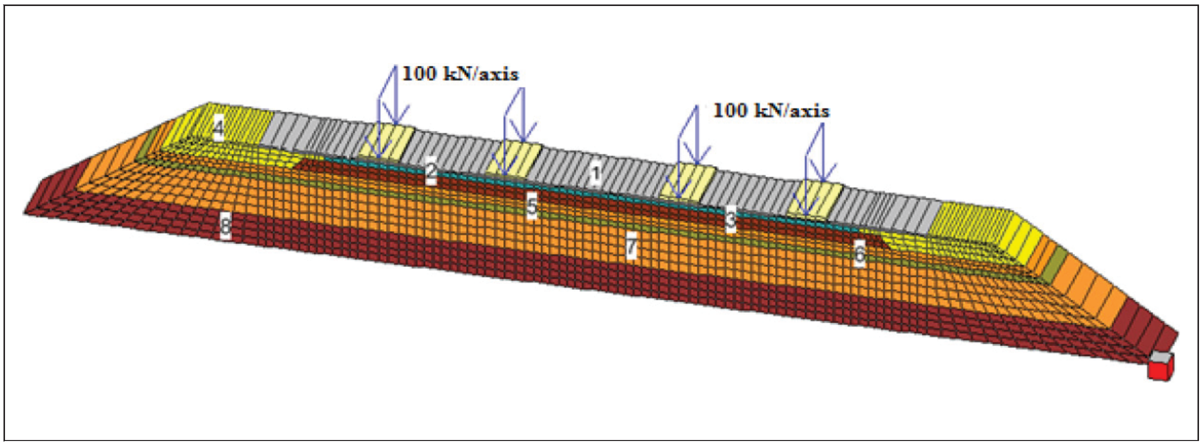

Figure 2 Design scheme of structure reinforced with integral geogrid of determining theoretical stresses in elastic-plastic model of soil: 1) dense asphalt concrete; 2) porous asphalt concrete; 3) crushed stone and sand mixture; 4) crushed stone fractions of 5-40mm with a geogrid being laid on the surface of crushed stone mixture; 5) crushed stone mixture; 6) equalizer layer; 7) ballast ground; 8) light stiff ballast sandy loam

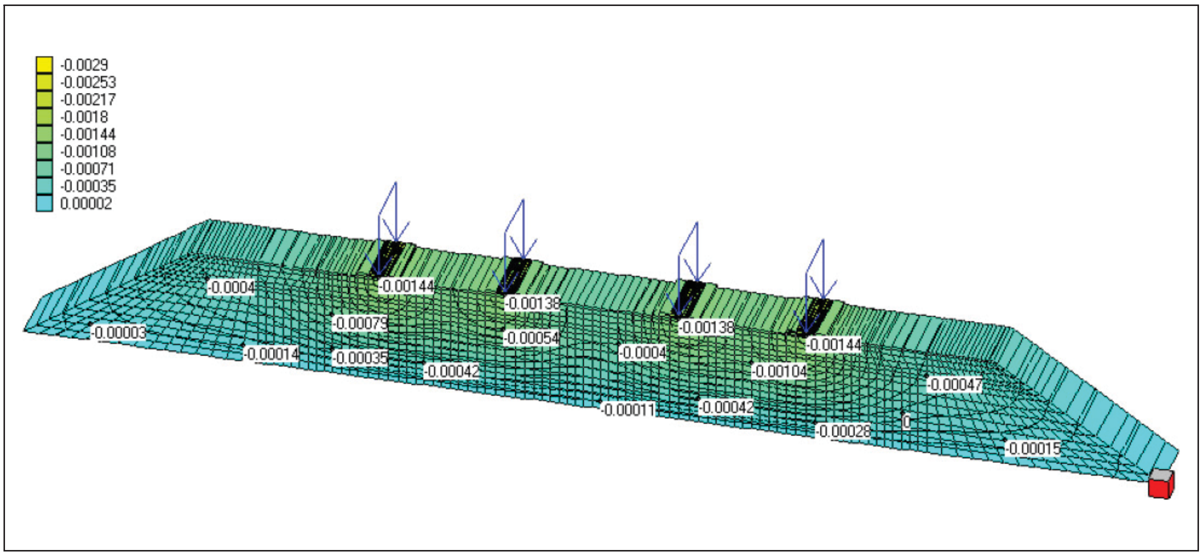

Figure 3 Distribution of vertical deformations in rational structure, m

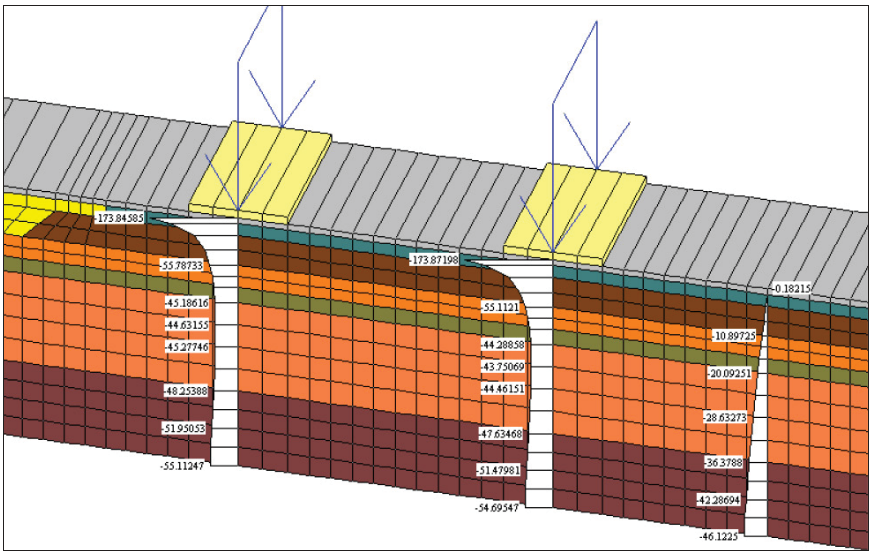

Figure 4 Diagram of vertical stresses in depth, kPa

When solving thermodynamic problems on receiving a rational structure in the given operational conditions, the “Termoground” mathematical model was used to model numerically the freeze-thaw and freeze heaving processes in an annual cycle. The model is an integral part of “FEM-models” program complex. Modeling allows to take into consideration the phase transformation of water in the range of negative temperatures as well as presence of moisture as a result of its migration, Figure 5. The calculated values of heaving in a structure reinforced with an integral geogrid and the crushed stone layers being lessened do not exceed 27mm per year, Figure 6.

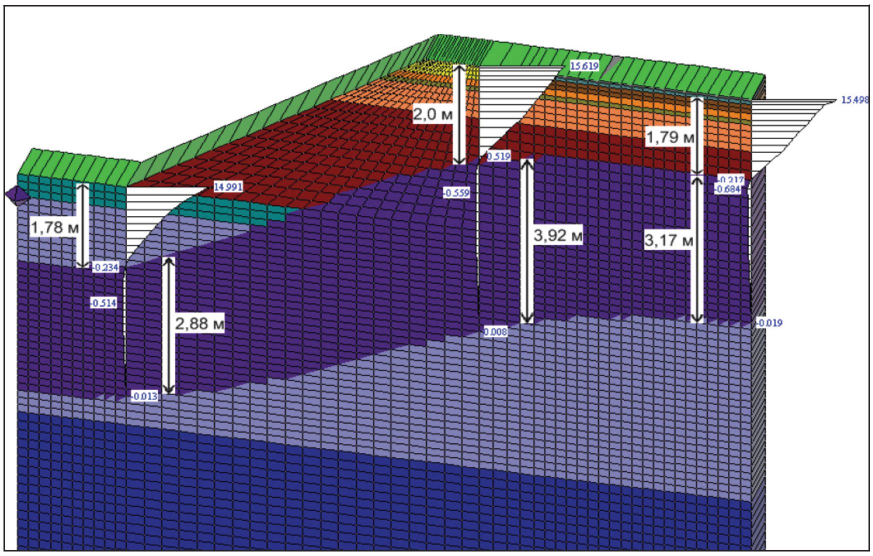

Figure 5 Diagram of temperatures (ºC) and values of freeze and thaw (m) in the structure under research (the second decade of July)

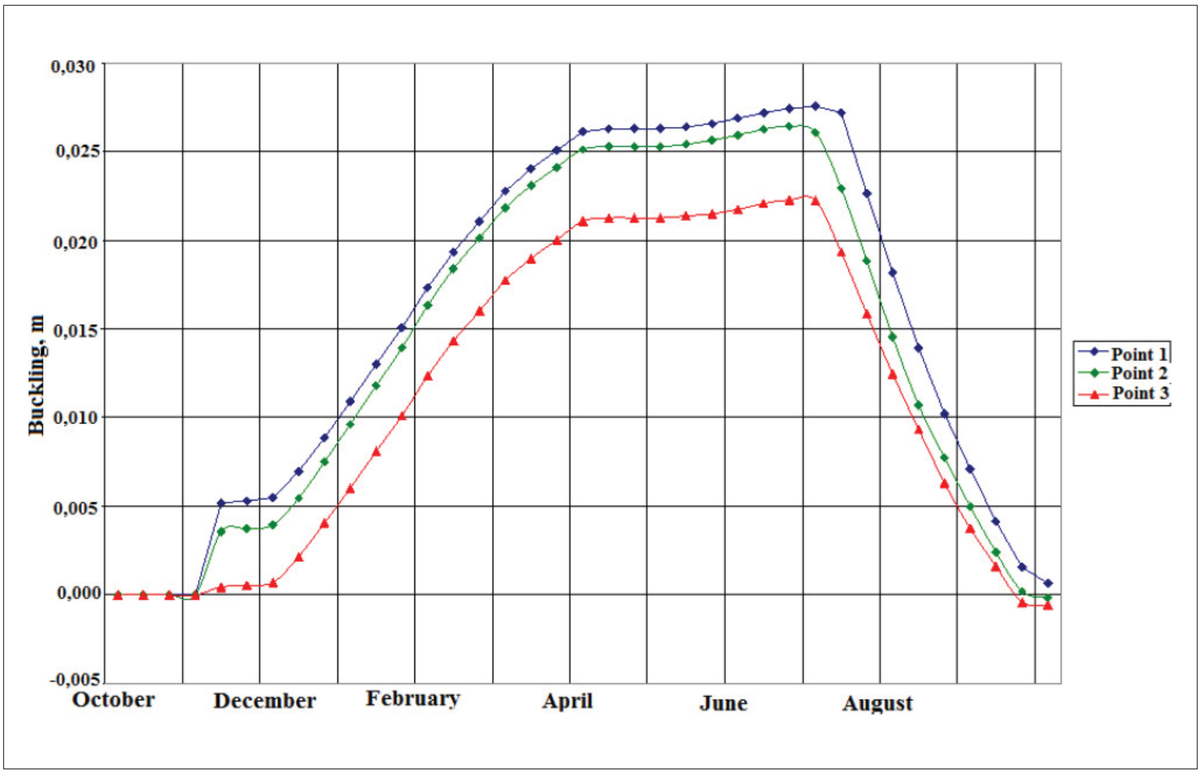

Figure 6 Heave values with increasing totals in an annual cycle according to month decades in the reinforced structure

4 The studies of structures on testing sections of the operating highway

This section of the highway is on the approaches to the bridge. The construction of the lightweight embankment of this section consists of expanded polystyrene and a geogrid, Figure 7. To measure the effects of traffic in the layers of structures some pick-ups were installed in loading zones.

Figure 7 The construction of the lightweight embankment which consists of expanded polystyrene

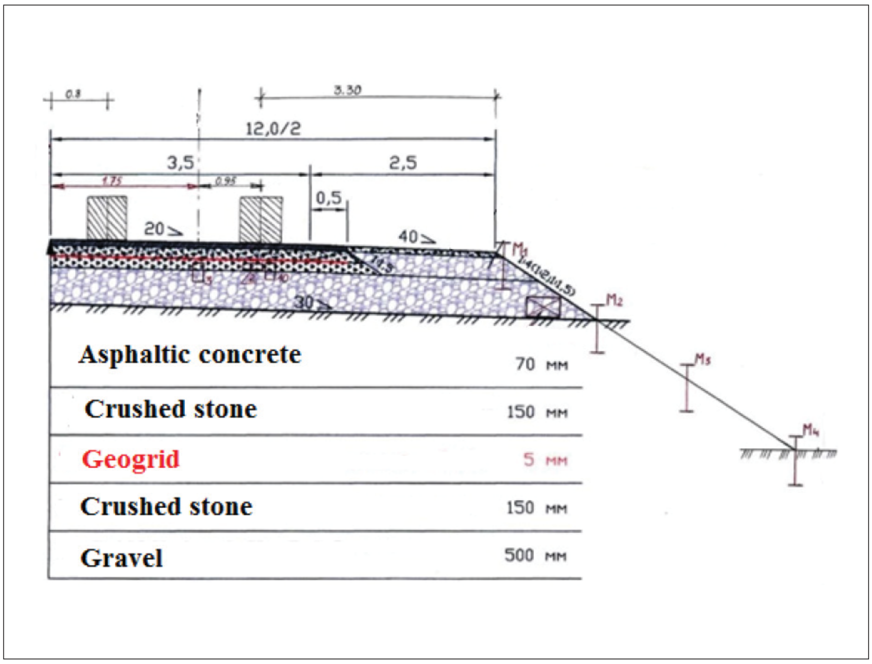

Figure 8 Testing cross section, devices and equipment

The received results followed their statistical processing were used for the comparative analysis with the numerical modeling data. The results of the analysis showed good convergence. At present the measurements of stresses and the survey of deformations are going on at key points Mj (Figure 8). The direct estimation of supporting power of highway structures reinforced with integrated geogrids (with a non-complete layer of crushed stone) and non-reinforced ones (with a complete layer of crushed stone) was carried out to confirm the results of the studies. A standard device for loading the foundations, "Testing", was used, Figure 9.

Figure 9 “Testing”, the device for standard die loading

The studies showed that the original and rational structures provide the required durability of road pavement. The geotechnical modeling proved the values of elastic deformations and stresses in the designed rational structure do not exceed the required values for materials and structures in general. The calculated deformation values of frost heaving in the designed structure constitute no more than 70 % of the norm values during an annual cycle. The stress and deformation values measured in the field section in the designed rational structure and the calculated ones received in the numerical modeling converge well. That proves the theoretical prerequisites being reasonable for the studies. The results of testing the supporting power of the highway rational structure showed its required durability. The complex studies carried out during designing the highway structure with a geogrid proved the operational reliability of its elements in cold regions of the Russian Far East.

References

[1] Berestyanyy, Y., Valtseva, T., Kudryavtcev, S., Fedorenko, E.: Using geomaterials when reconstructing Yakutsk-Magadan road. Roads. Innovations in construction, 29, pp. 96-100, 2013.

[2] Berestyanyy, Y., Valtseva, T., Kudryavtcev, S., Mikhailin, R.: Using geotechnical materials in structures when constructing roads in snow region of Russia, 2st International Symposium “Physics, chemistry and snow mechanics”, pp. 96-100, Yuzhno-Sakhalinsk, Russia, 2013.

[3] Berestyanyy, Y., Goncharova, E., Kudryavtcev, S., Mikhailin, R, Valtseva, T.: Motorway Structures Reinforced with Geosynthetic Materials in Polar Regions of Russia, 24th International Off-shore (Ocean) and Polar Engineering Conference, pp. 502-506, Korea, 2014.

[4] Valtseva, T., Goncharova, E., Kudryavtcev, S., Mikhailin, R.: Using designs of variable rigidity on weak soils roads in the Russian Far East, 6th International geotechnical symposium on Disasters Mitigation in Special Geoenvironmental Conditions, Indian Institute of Technology, pp. 409-412, Madras, India, 2015.

[5] Berestyanyy, Y., Valtseva, T., Mikhailin, R.: Geotechnical cartridges for embankment strengthening. Track and its facilities, 6, pp. 34-35, 2011.

[6] Berestyanyy, Y., Kudryavtcev, S., Fedorenko, E., Valtseva, T., Goncharova, E., Mikhailin, R.: Use of geosyntetic materials on weak basses in highways of the Far East Russia, International Symposium on Geosynthetics Technology, pp. 117-125, Seoul, South Korea, 2011.

[7] Kudryavtcev, S., Kazharsky, A., Goncharova, E., Valtseva, T., Kotenko, Z.: Thermophysical feasibility of railway embankment design on permafrost when projecting side tracks, 15th International scientific conference "Under-ground Urbanisation as a Prerequisite for Sustainable Development", pp. 1080–1086, St. Petersburg, Russia, 2016.

[8] Kudryavtcev, S., Valtseva, T., Goncharova, E., Kazharsky, A.: Strengthening design for weak base using geomaterials on "Amur" automobile road section. Internationa Scentific Conference Energy Manegement of Municipal Transportational Facicties Transport EMMFT 2017, pp. 145-153, Khabarivsk, Russia, 2017.