Experimental road structures for permafrost regions

S.E. Grechishchev, V.D. Kazarnovsky, Y.S. Pshenichnikova & Y.B. Sheshin
The State Road Research Institute, Soyuzdornii, Moscow region, Russia

ABSTRACT: Road construction in the North of West Siberia is connected with a number of problems, some of which can be solved by the use of geosynthetic materials. In the area of a sub-arctic gas field, a geocell Geoweb has been successfully applied both for slope stabilization and as a layer of the road pavement. However, for a wider use of geocells in the road pavement structure, it was necessary to determine the appropriate design parameters. With this objective in mind, the modulus of elasticity of the geocell infill has been defined. Cellular (foam) polystyrene plates have been also used successfully on experimental sections. Appropriate design methods are developed for their application to road construction.

1 INTRODUCTION

In road building under permafrost conditions in the North of West Siberia, there are three main problems. Freezing and related phenomena may cause deformations in the road pavement structures, there is a lack of soil suitable for embankment construction and it is often necessary to build the road over subgrades that are not entirely stable in order to provide traffic passage when either the settlement of the embankment or the compaction of the embankment has not yet been completed.

Engineering-geology investigations of roads in the North of West Siberia have shown that the main processes that influence the strength of the subgrade are erosion, crack formation, thawing of ground ice, and thermokarst. Erosion processes cause specific forms of relief, gullies and rain rills. Gullies appear on the valley slopes and in cuts along the embankments. Rain rills occur in cut and fill slopes.

On many sections of roads, both under construction and in service, longitudinal cracks form on the edges of embankments. Their length can reach 50 m or more, and the width of opening at the top can be 10–15 cm. This crack formation is connected with thawing and subsidence of icy soils in the foundation. During winter, at air temperatures of about −20°C, transverse frost cracks have been observed in embankments. Generally speaking, the crack opening and width increases with decreasing temperatures.

In the spring, transverse and longitudinal cracks serve as pathways for filtration of surface water. These are precisely the places where erosion rain rills are formed in the embankment slopes during the spring and summer.

In the zone of disturbance to the soil-vegetative cover as well as in the fill foundation, thermokarst processes actively progress on the sections where the route crosses ice-saturated peatland. Water accumulates in thermokarst depressions, which contributes to the thermo-erosion process and the development of erosional forms of relief.

2 DATA AND RESULTS

Soyuzdornii (The State Road Research Institute) has made an effort to solve some of these problems by the use of geosynthetic materials in the road pavement structures. In 2000–2002, studies were carried out, which included in-situ investigations of existing roads in the permafrost zone as well as the structural design and application of experimental structures with two types of geosynthetic materials: three-dimensional “Geoweb” and cellular polystyrene plates “Penoplex”. The geocell was used according to the manufacturer’s recommendations (Geoweb 1998) on trial road sections in the territory of a sub-arctic gas field near the town of Yamburg.

The geocell was applied as a structural layer of the road pavement (as a temporary surfacing) and as a structure for stabilization of fill and cut slopes. The
geocell was perforated, 10 cm high, with a 20 × 20 cm cell, similar to the type usually applied in road construction (Fig. 3).

In the first case, this solved a problem of the traffic passage over the embankment before the subgrade was completely stabilized, whereas in the second case, the geocell prevented or stabilized cryogenic processes on the slopes.

The investigations performed one year later showed that the pavement, including the geocell filled with sand and crushed stone, was in good condition. No damage in the form of settlements or ruts were observed. In the cut slopes and trenches that were stabilized using the geocell filled with crushed stone and peat-sand mixture in autumn of 2000, complete stabilization of the erosion processes took place. The cut trenches were beginning to be overgrown, which is indicative of stability and absence of any geodynamic processes. For a wider use of this geocell in road pavements, it would be necessary to perform strength calculations for design.

In the Russian practice of road construction, the road pavement design is based on calculations of elastic deflections. The essence of the design is in the comparison between the required modulus of elasticity of the road pavement, determined based on traffic density, and the total (equivalent) modulus of elasticity of the road pavement. The equivalent modulus of elasticity is computed by successively reducing the two-layered system to the one-layered system according to a method worked out through solving a problem of the elasticity theory for the layered semi-space (Ivanov 1973, VSN 1985). For this purpose (at the soil test in Soyuzdornii), a series of loading tests of the geocell filled with sand was conducted for determining the modulus of elasticity. The tests comprised the transfer of load from a hydraulic jack by means of a rigid plate to the geocell with sand infill and a 3 cm protective course (placed according to the approved technology) and then measuring displacements by a standard lever deflectometer equipped with an indicator (Fig. 4).

Load was applied in steps through a rigid plate, 33 cm in diameter. After achieving each loading step, complete unloading was carried out, and the elastic component of the total deformation was determined from a difference between readings at each step of the loading. The computation of the modulus of elasticity for this geocell was then performed.

On the basis of the data obtained, an averaged curve of elastic deformation – load was plotted (Fig. 5). The total modulus of elasticity for the structure, including
the geocell with infill and a sand base, \( E_{total} \) was found from Equation 1, which was 132 MPa. The modulus of elasticity of sand in the base, \( E_n \), was equal to 100 MPa.

\[
E_{total} = 0.25\pi \Delta \sigma D(1 - \mu^2)/\Delta l
\]

(1)

where \( \Delta \sigma = \) stress acting on plate for a selected loading interval, \( D = \) diameter of the rigid plate, \( \mu = \) Poisson’s ratio, \( \Delta l = \) elastic deformation corresponding to the load for a selected loading interval.

The modulus of elasticity of the geocell with infill, \( E_c \), was found from Equation (2) to be 400 MPa, which was based on elasticity theory (Ivanov 1973, VSN 1985) and on relating the total modulus of elasticity of the base, \( E_n \), and the structural layer, \( E_c \), as well as a parameter \( h/D \) (the ratio of the thickness of geocell with a protective course to the plate diameter).

Thus, the modulus of elasticity of the composite geocell plus sand infill exceeds that of the infill material by a factor of four. Note that the influence of the protective layer on the geocell was not taken into consideration.

\[
E_{total} = \frac{1.05 - 0.1 \frac{h}{D} \left(1 - \sqrt{\frac{E_n}{E_c}}\right) E_c}{0.71 \sqrt{\frac{E_n}{E_c}} \cdot \arctg \left(\frac{1.35h}{D}\right) + \frac{E_c}{E_n} \cdot \frac{2}{\pi} \arctg \frac{D}{h_3}}
\]

(2)

where:

\[
h_3 = 2h \sqrt{\frac{E_c}{6E_n}}
\]

(3)

\( h = \) thickness of composite layer (geocell wall depth), \( E_c = \) design modulus of elasticity of the layer (sought), \( E_n = \) design modulus of elasticity of the half-space, \( E_{total} = \) value of total modulus of elasticity on the surface of the two-layered structure, which is determined from a value of deflection \( \Delta l \) under the application of load \( \Delta \sigma \).

Heat-insulating cellular polystyrene plates (Penoplex) can be used for road structures in the permafrost regions to prevent frost cracking of frozen soils in the subgrade during construction. Permafrost is retained in the embankment foundation and body by the use of structural layers of heat-insulating plates of the thickness that ensures a decrease in amplitude variation of winter (negative) temperatures of the soil under the plates, up to a pre-determined admissible value. Computations have indicated that this occurs, even under very severe conditions. For this purpose, it is sufficient to use plates of 0.06–0.08 m in thickness.

Prevention of new permafrost formation and multi-year frost heave induced by temperature variations in frost-susceptible soils of the embankment foundation and body may also be achieved for sections with unfrozen soils (to a depth at least 6 m) in zones of sporadic and discontinuous permafrost.

A further very complicated problem is avoiding multi-year (not seasonal!) freezing and heaving of unfrozen soils in the area of the southern boundary of permafrost by the use of the same heat-insulating plates. In this case, the thermo-engineering efficiency of the road structure sharply increases when polystyrene plates are applied in combination with peat layers.

3 CONCLUSIONS

The data mentioned above show the main problems, which could be solved by using the geosynthetic materials such as geocells and polystyrene plates, attending road construction in permafrost areas. The modern experience of application in the permafrost regions of Russia shows good results to date.

REFERENCES
