The use of geotextile in road building on soft soils

L'utilization des géotextiles dans les constructions routières sur sols mous

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SYNOPSIS: The report deals with the use of geotextile interlayers as reinforcing elements in the embankment foundation as well as for regulating the water-and-temperature regime and bearing capacity at the top of the subgrade built on soft soils. Data are given on investigating the durability of polycaproamide geotextile, field data included. Consideration is also given to proposals on refining methods for testing the geotextile strength, to experience of the application of geotextile and similar interlayers in timber haul road structures on soft soils as well as to the use of geotextile in drainage course structures and for frost heave deformation control.

1 MAIN TRENDS IN THE USE OF GEOTEXTILE IN CONSTRUCTION OF ROADS OVER SOFT SOILS

With implementation of geotextile into the practice of road building new possibilities have arisen for decision of a number of problems connected with construction of engineering structures over soft soils. In application to the road construction these problems can be divided into two types: those connected with bearing capacity and deformation of the embankment foundation and those connected with an improvment of the water-and-temperature regime of the subgrade (in the case of soft soils there are always conditions for subgrade overwetting and frost heaving, etc.).

In the USSR appropriate methods of structural design with the use of geotextile interlayers are developed, regular observations on the performance of these structures are carried out and some preliminary conclusions on their efficiency under various conditions are obtained. The results obtained show that the geotextile interlayers allow:

- to reduce the non-uniformity of settlements of the embankment foundations (this permits to shorten the terms of construction of road pavements on sections where the embankments are built on deformable foundations);
- to lower the non-uniformity of frost heaving;
- to improve the bearing capacity of structures for temporary and access roads in the form of thin-layered fills on weak foundation;
- to provide drainage of the subgrade using the geotextile interlayers as draining and capillary-intercepting layers;
- to increase the service life of road pavements, etc. /1/.

However some problems remained insufficiently studied and their solution required long-term observations on real projects.

2 DURABILITY OF GEOTEXTILE

One of tendencies in the production of geotextile is towards its obtaining from polymer melt.

In the USSR initially development of the technology and equipment for geotextile production was oriented at polycaproamide (PCA), the most widely available polymer in this country. In connection with deficit in the original PCA and a high cost of the latter a technological process and equipment have been developed for production of the geotextile from a secondary polymer (regranulate) obtained from fiber waste.

Since a basic amount of the geotextile was designated for road construction in West Siberia, characteristics of the materials produced were predetermined by structural solutions and conditions of construction and operation of oil field roads: conventional strength 70-120 N/cm, rupture elongation 150-170%, water permeability 80 m/day, conventional modulus of deformation 100 N/cm, and conventional modulus of elasticity 150 N/cm.

For experimental sections trial lots of geotextiles of other characteristics were also produced.

In the USSR, first road sections with the use of polycaproamide geotextile materials were built in cooperation with Giprodornii in 1975 on Moscow-Gorky motorway. The polycaproamide nonwoven materials were also used on a number of road sections built in the European part of the USSR under the supervision of Giprodornii.

In 1978-1979 experimental sections of earth timber haul roads including structural layers of the polycaproamide geotextile were built in the Kalinin and Novgorod regions. At the same time temporary roads with the use of polycaproamide geotextile were constructed on swampy areas and areas with a high underground water level in the Leningrad region.

Since 1980 in the BAM (Baikal-Amur Magistral) region tests are carried out of an embankment structure laid over subsideous permafrost soils with application of polycaproamide geotextile in the subgrade foundation. However, a main proving ground where nonwoven fabrics of various types are tested and implemented is the oil fields in West Siberia where about 6 million sq.m. of the polycaproamide geotextile have been used. The first road section with polycaproamide geotextile in this region was built near Samotlor in 1978 /1/.

To date the polycaproamide geotextile has been tested in various structures and under various conditions: the embankment foundation over swamp and mineral soft soils, ground sill, the embankment body, and road pavement base courses /2/. Trial lot of the polycaproamide geotextile of surface density 700-800 g/m^2 was produced. However there is no common opinion between specialists, especially in relation to durability of geotextile coming into contact with peat and water in swamps. Laboratory studies allow to obtain only a rough evaluation of the durability but do not allow properly to take into account complicated real conditions.

Particularly when investigating in laboratory the stability of polycaproamide geotextile in the acid or alkali media at pH values approaching the field ones, preference is usually given to strong mineral acids rather than organic ones. However in the soil, low-active humic acids are prevailing. As investigations with the use of organic acids carried out by VNIINTM (All-Union Research Institute of Non-Woven Geotextile Materials) in 1976 shown, physical-and-mechanical properties of the polycaproamide geotextile subjected to the action of hydrocloric acid and alkaline media with pH from 2 to 5 and from 8 to 12.5 during 5 months remained at the level of those for original samples. Similar investigations in VNIINTM and MTI have shown that exposure of the material to buffer hydrocloric-acid media (pH values of 4-6, temperature 13 to 23°C) during a year didn't impair its strength but with an increase in the acidity of the medium up to pH value of 2-3, all other things being equal, a 1.6 to 3.7-fold reduction in strength was observed as compared with the strength of original sample during the same period.

To evaluate an actual durability of geotextile it is also necessary to consider that under conditions of West Siberia, temperature in road pavement sections with the geotextile interlayer, as a rule, ranges from -10° to +5°C. Temperature at which low microbiological activity is still possible takes place during 3 months. During the rest of the time microflora is in the latent state and exchange processes are halted. As investigations (in cooperation with the Ukrainian Research Institute of Agricultural Microbiology) have shown, polycaproamide geotextile is to retain a sufficient strength and microbiological stability under conditions studied during at least 30 years.

It is taken into consideration that swamp waters in West Siberia do not contain agressive cations and anions, but contain little amouts of calcium, magnesium and ferrous cations as well as of CO_3^{-2}, HCO_3, SO_4^{-2} anions; low-active humic acids are prevailing in the peat soils and swamp waters. The acidity of soils is characterized by pH values of 3.5-6.0. Data of model tests have indicated that under the above conditions indices of the physical-and-mechanical properties of the geotextile are to be retained during at least a 30 year period.

Along with the durability studies on models, the geotextile specimens were regularly taken from the road pavement structures under operation.

As tests shown, after 9 years of service the strength of geotextile was higher than a minimum specified one (by 1.1-1.4 times) and the rupture elongation reduced by 1.5-2.0 times.

Similar observations were carried out by Giprodornii on road sections in the central part of the RSFSR, where the geotextile specimens were taken periodically (every 1-3 years). A total period of observations on separate sections (7 sections in a whole) is 6-12 years. Each section consisted of a number of runs differing in the type of geotextile and location of the latter in a road structure. The use was made of usually nonwoven, needle-punched geotextils produced from polyamide (PA), polyester (PE) and polypropylene (PP) raw materials.

It is found that there is a sharp decrease in the initial strength and further gradual stabilization of a rate of this decrease, and this pattern of the change in strength is most clearly seen in the case of polyamide materials. Strength R_t at time T may be determined by formula

$$R_T = \frac{R_o}{a \times T^b + 1}$$

where R_o - initial strength;

a, b - parameters depending on the type of polymer ($a = 0.09$ and $b = 0.5$ for geotextile of PE and PP and $a = 0.4$ and $b = 1.0$ for geotextile of PA).

Similar relationships for deformation characteristics haven't been established due to a considerable spread in data. However there is, as a rule, a decrease in deformability.

3 ON EVALUATION OF THE GEOTEXTILE STRENGTH

In the textile industry strength characteristics are usually determined by the uniaxial tension of specimens with working area 100 x 50 mm in size. However the use of this method for testing nonwoven geotextiles from the staple fibers may introduce large errors in the determination of design characteristics.

When testing standard specimens a considerable contraction in the transverse direction takes place before their rupture. Uniform distribution of stresses and strains along the length and width of a specimen is not provided, and this results, as a rule, in the rupture of the latter near the clamps rather than in the middle. In the process of tension along the length of such specimens three zones are formed, which are characterized by different orientation of the fibers. While in the central zone the process of fiber orientation along the axis of tension is not disturbed, in the edge zones this process is disturbed by the clamps and the fiber orientation takes place at a certain angle to the axis of tension. This explains why during the tests of standard strips most ruptures occur near the clamps in the edge zones. In the zone of specimen rupture both weak and strong sections of the fabric may occur, and this results in a large scatter in data.

More reliable characteristics of the materials made of the staple fibers may be obtained by increasing the width to length ratio. Using available machines for the rupture tests it is possible to test specimens 10 cm wide. As the test results for specimens of the above width and working length (i.e. the length between the clamps) of 5–15 cm shown, the least scatter in data takes place at the working length of 5 cm. At tension of wider specimens more uniform stress distribution is achieved through the specimen width and their rupture, as a rule, takes place in the middle between the clamps.

Data obtained at the uniaxial tension of specimens were compared with the results of testing the same materials by means of a circular tension device similar to that used in FRG. A test method corresponded to DIN 54307-82.

As an index of geotextile tensility, an absolute magnitude of specimen deflection (but not a relative change in the specimen area) was taken, which seemed to be a more objective index. This allows to establish a close correlation between the results of uniaxial tension tests of wide geotextile strips and those of circular tension of specimens: correlation coefficients are 0.995 and 0.970 for rupture loading and deformation indices, respectively, which confirms that these test methods are mutually substitutive. However for the uniaxial tensile tests of standard narrow specimens similar relation has not been found.

4 THE USE OF GEOTEXTILE IN CONSTRUCTION OF TEMPORARY AND SPECIAL ROADS OVER SOFT SOILS

An expediency of the use of interlayers in the form of woven and nonwoven synthetic materials, grids and mats, waste synthetic broadcloth and mesh as well as glass-reinforced bituminous paper /3/ was considered from two points of view:

- increasing the quality and lowering the operation cost of permanent roads;
- lowering the cost of temporary road building.

Due to local deformations of geotextile and similar interlayers, which accompanied by the stress redistribution, there occurs lowering in an unfavourable effect of the non-uniformity in strength of the subgrade soil, the non-uniformity of materials, and variation in thickness of road pavement layers. This enables to reduce expenditures on construction of the timber haul roads through a decrease in the road pavement thickness, lowering the height of an embankment, and using local soils instead of imported materials. In the second case, besides the above possibilities, the use is made of the geotextile ability to take up loads and transfer them to the adjacent soil areas, which results in lowering the rut depth.

On the basis of the Laplacian law, general equations of the elasticity theory and some assumptions a mathematical model has been developed, which permits to evaluate an influence of geotextile on the strength of the road pavement structure taking into account thickness of road pavement, modulus of deformation of the road pavement material, modulus of soil deformation, stamp diameter, load on the stamp, geotextile characteristics, diameter and depth of a deformation basin of the subsoil.

Stand tests by a stamp 34 cm in diameter were carried out to check experimentally structures including a 25 cm layer of preliminary compacted sand-gravels and an interlayer of glass-reinforced bituminous paper laid over the subsoil. Tests were also conducted on similar structures without interlayers. The tests were performed according to a generally used method but the stamp settlement was brought up to 10–12 cm.

A relationship between an increase in strength of a structure including glass-reinforced bituminous paper and a magnitude of deformation (based on the results from five stand tests) shows a satisfactory coincidence of theoretical and experimental data at a rut depth up to 6 cm and later on an essential discrepancy which is explained by the fact that partial ruptures of the mesh of glass-reinforced bituminous paper begin at a strain of 5-6 cm with a sharp increase with a further growth of deformations.

To verify the reliability of the above design relationship, data were analysed on the change in rut depth with a number of passes of timber carriers for the road pavement structures 30, 40 and 50 cm in thickness, with and without geotextile /3/. The analysis has shown that theoretical values of increase in strength are lower than corresponding experimental ones. However it is clearly enough seen an agreement in general regularities of the change in coefficients, especially in the case of the road pavement 30 cm thick.

On the basis of these investigations specifications on the use of geotextiles for various categories of timber haul roads as well as those on the design and construction of timber haul roads with geotextiles have been worked out.

The application of geotextile in the timber haul road structures provides a 2-2.5 fold increase in their quality indices, strength and service life. Even though the cost of road-building materials is not reduced, the construction cost increases only by 2-6% at additional expenses 2.0-2.5 thousand roubles for glass-reinforced bituminous paper and waste synthetic broadcloth and mesh at 40-120 thousand roubles per 1 km of timber haul road.

5 THE USE OF GEOTEXTILE FOR REGULATING THE WATER-AND-TEMPERATURE REGIME IN ROAD SUBGRADES OVER SOFT SOILS

To solve the problems of improving the water-and-temperature regime in the upper part of road subgrade under circumstances when soft overwetted soils are utilized and there are sources of overwetting from below the geotextile is used for draining and frost-protective courses and some types of geotextile may function as a capillary-intercepting interlayer /1/.

Similar successful experience on the use of geotextile in frost-protective courses lapping the clay soils of increased moisture content is gained in the railway construction.

The protective course laid on the clay soil surface may consist either of sand or of its combination with nonwoven synthetic material or nonwoven material placed directly on the surface of basic area under the ballast prism. The thickness of the draining soil course laid over the geotextile surface is taken according to special specifications on the design of railway subgrades of clay soils with application of the geotextile. The sand pad laid on the surface of nonwoven material is specified taking into account the moisture content of clay soil at the liquid limit W_L , the flow index I_L and the depth of freezing. At W_L 0.23 and I_L 0.25 the sand pad is not placed. At 0.23 W_L 0.55, I_L 0.5 and a depth of freezing up to 2.5 the pad thickness is in the range of 0.3 to 1.0 depending on values of the above indices. In the case of either W_L 0.55 or I_L 0.5 the subgrade structure is designed individually.

The thickness of the protective layer of draining soil above the geotextile is calculated on the basis of a hypothesis proven experimentally on the change in moisture regime of the clay soil underlying the nonwoven material towards a reduction of both a range of variation in soil moisture content and an absolute humidity. The latter results in an increase in subgrade strength and in a lowered frost heaving.

When calculating the protective layer, the moisture content of clay soil is predicted taking into account the change in its porosity during swelling-shrinkage and freeze-thaw processes for the most unfavourable combination. On the basis of the change in the moisture content of clay soil its strength characteristics and frost heaving indices are predicted as well as bearing capacity of the subgrade and magnitude of frost heaving are determined.

Another important practical result of the geotextile application is the possibility of substantially wider utilisation of local soils, undrained ones included, for building the subgrade structures. For instance, under conditions of the North of West Siberia the application of subgrade structures including the geotextile interlayers and envelopes has allowed to provide a required reliability of a route at subgrade construction on a round-the year-basis utilizing local silty sand and sandy loam and maintaing the rapid pace of construction. An efficiency of the geotextile application in these regions, as compared with other engineering solutions requiring the use of imported draining soils, is assessed as follows: 10-20% reduction in the construction cost, 18-36% of labour saving and 30% of energy saving.

In the field of railway construction design schemes are under development which are based on analytic and numeric methods applied in mechanics of continua.

The analytic methods are reduced to setting up the equilibrium equations for interacting structural elements - probable blocks of soil displacement and geotextile interlayers or envelopes supporting these blocks. Thereby it is taken into account the fact that either during construction process a soil is subjected to relative deformations of 2-4% in magnitude causing the reinforcing elements to work or special engineering measures are provided to create a preliminary elongation up to 4-6%.

Numeric methods are implemented in a package of applied programs which is based on the method of finite elements with the use of models of the "flow" type of non-linear soil mechanics.

The application of the above programs makes it possible to establish specifications on the properties of geotextiles utilized for soil mass reinforcement as well as to determine rational schemes for the placement of reinforcing elements of specified characteristics in the earth structure.

Practical application of the above method for substantiating the schemes of embankment reinforcement for Surgut-Urengoy and Yagelnaya-Yamburg railway lines and subsequent observation the project behaviour proved the efficiency of placing the geotextile in the form of reinforcing sheets, closed and semi-closed envelopes.

Investigations have shown that the geotextile interlayers can have a distinct effect on the magnitude of frost heaving, with lowering the nonuniformity of the latter /1/. This allows, if required, to reduce the thickness of frost-protective layers as well as to utilize more widely local soils of increased frost heaving for subgrade construction. To take into account the effect of the geotextile interlayer on the magnitude of frost heaving of the subgrade foundation , appropriate design schemes and methods are proposed. A methodics suggested by the Perm Polytechnical Institute allows to determine both deflection caused by the settlement and buckling resulting from the frost heaving and thrust occuring in the process of geotextile deformation. In the design scheme Vinkler model is applied.

One of available measures of regulation of the water-and temperature regime is dewatering of the upper part of the subgrade by the use of drainage sand courses. Their thickness h_g is found by calculations. Local sands mostly have a coefficient of filtration not more than 2.0-2.5 m/day at density equal to 1 according to the standard method taken in the USSR. With such sand quality, for instance for silty soils on excessively moist road sections in the central regions of the European part of the USSR, thickness h_g is usually at least 0.5 m.

Due to difficulties of the ground right-of-way for pit working out, during recent years the cost of sand increased at least 2.0-2.5 times, and the haul distance now exceeds 20-25km.

In order to reduce a required truck fleet the Moscow Highway Institute (MADI) has proposed to increase a drainage capacity of drainage layers by laying down the geotextile on the subgrade surface. The coefficient of longitudinal filtration of the geotextile (in uncompressed state) produced in this country is about 60 m/sec. The thickness of geotextile underlying the sand layer is reduced from 4 mm to 3mm while the coefficient of filtration is, in average, decreased by 35%, i.e. it is about 38.5 m/day.

On the basis of numeric computer-aided solution of a two-dimensional problem using a finite-element method appropriate nomograms have been worked out for various conditions to determine the thickness of a drainage course including the sand laid over the geotextile (V.V.Borovikov, MADI).

Under most unfavourable conditions which, according to the USSR current standard, are characterized by unit excessive water $q = 10\ l/m^2/day$, a total thickness of a drainage sand course laid over the geotextile is reduced by at least 25-40% as compared with that for a drainage layer without the geotextile.

In Moscow on many streets and thoroughfares drainage courses with geotextile are placed with a 20 cm average reduction in thickness, the total area being about 160,000 m^2. This also allows to reduce an earthwork volume as well as to decrease the need in construction transport by 30%.

Geotextile is also used instead of filtration filling around both drain pipes and low drainage, which results in a 2.0-2.5 -fold increase in productivity as compared with application of multi-layered filtration filling of high-strength frost-resistant crushed stone. Six-year observations carried out by MADI have shown that frost heaving on sections with geotextile is less than that on sections without geotextile and does not exceed an admissible level. The coefficient of filtration of geotextile is many times higher than that of sand and therefore a velocity of water runoff from the drainage course increases and more efficient draining of the subgrade top is achieved.

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