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NOTE: All of the above references unless otherwise noted are in the Russian language.

Basic Principles of Flexible Pavement Design and Construction in the USSR

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In the USSR, which comprises a vast territory between 35° to 78° North latitude and from 169° West longitude to 19° East longitude, there are widely varying physical conditions. There are regions now being economically developed, for which rational types of road pavements and bases have not as yet been worked out practically. Therefore, the elaboration of methods for estimating the quality of bases for the design and construction of road pavements is of very great importance in the USSR.

To take into account the climatic factors while projecting roads, the territory of the USSR is divided into road climatic zones coinciding approximately with typical landscape and soil zones; namely, the tundra and forest zones, the wet zones, the forest-steppe, transitional zones, the steppe zones, insufficiently wet zones, the semi-desert, dry steppe arid zone, except for mountain regions.

Moreover, within the limits of each road climatic zone there are various types of terrain distinguished by the influence of local moisture sources, character of surface drainage, and peculiarities of the hydrological conditions.

About 15 years ago the method worked out in the Central Highway Scientific-Research Institute (SOJUZDORNII) under the guidance of Prof. N. N. Ivanov began to be used in the Soviet Union for designing roads. This method for determining the thickness of flexible road pavements was based on the following thesis:

1. The stress conditions in the road structure at the beginning of failure are characterized by a definite ultimate value of accumulated vertical displacement, deflection, of the pavement. This increases in the wet period of the year under the repeated action of automobile wheel loads. For roads with high-duty and high-type pavements with high-speed traffic, the ultimate value of accumulated vertical displacement is limited by the allowable degree of smoothness of the riding surface.

It is necessary, however, to consider the possibility of failure of the road pavement before the accumulated deflections allowable for the given pavement are exceeded, with less strict requirements as regards permitted surfacing irregularity and the ease with which it can be restored. In such cases the allowable deflection is limited by the need to insure the required strength of the road structure.

2. The modulus of deformation of the structure (E) depending on the ratio between the unit load (p) acting on the surface of the structure and the total relative deflection (λ) caused by it, is the criterion for determining the resistance to deformation of flexible road pavements in the USSR.

$$E = f\left(\frac{D}{\lambda}\right) \qquad (1)$$

Relative deflection (λ) is a non-dimensional value equal to the ratio between the absolute deflection (ρ) and the diameter of a circle (B) equivalent to the contact area of dual-tire wheels of the design automobile with the road surface and for the subgrade, with the area of load transfer $\left(\lambda = \frac{\rho}{B}\right)$.

The value of the ultimate relative deflection is set by the requirements for the operating qualities of the pavement. On the basis of numerous investigations, this is accepted in the range from $\lambda = 0.03$ for high-duty road pavements with a very smooth riding surface, to $\lambda = 0.05$ for pavements operating at the safe-ultimate resistance limit, depending on the type of pavement, thickness of the pavement structure, and the relative rigidity of structural layers.

Since the relation between the relative deflection and the load for flexible road pavements is not usually a linear one, the value of the modulus of deformation depends on the relative deflection (λ). When determining the modulus of deformation, its value is calculated at the design figure for relative deflection of the given pavement layer or soil.

In addition to the factors of the area of load contact, thickness and composition of structural layers, the moisture content of the subgrade is regarded as of great importance in assessing the value of the modulus of deformation of the road pavement. This is also characterized by its own modulus of deformation, sharply changing during the year with variations of soil moisture content.

Shown *(Fig. 1)* are the variations of the modulus of deformation of silty-loam soil

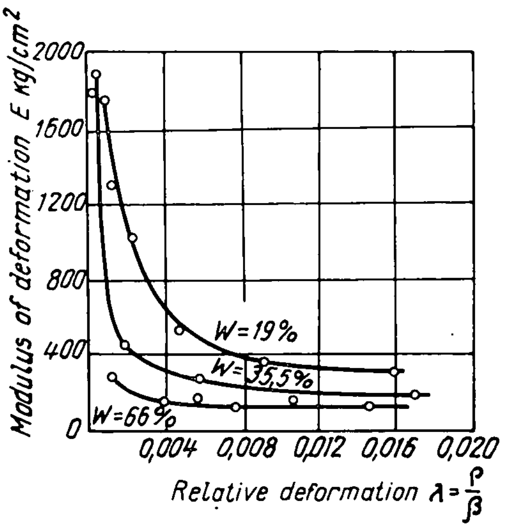

FIGURE 1

at different moisture contents calculated for several relative deflections.

3. The road pavement should be designed in such a manner that the absolute deflection (ρ) of the designed structure under the action of design load (p, B) does not exceed the allowable deflection taking into account the nature and intensity of road traffic.

The dual-tire wheel load of a design truck ($p = 5$ kg per sq cm and $B = 34$ cm) multiplied by the coefficient

$$K = 0.5 + 0.65 \lg N \qquad (2)$$

is taken as the design load in the USSR. The coefficient has been derived from laboratory and site observations. In formula (2) N is the number of design trucks passing along a two-lane road in 24 hours (traffic intensity) in the season of maximum, and simultaneously most frequent, weakening of the road pavement. This coefficient takes account of the influence both of repeated loads and the disturbance of the structure of the material and soil caused by the dynamic action of traveling vehicles.

The conversion of traveling automobiles of various types to the design automobile is performed by substituting a number of design automobiles of equivalent action on the road pavement for the actual number of traveling automobiles. As investigations have shown, the effect produced on the pavement by automobiles of various types may be determined with sufficient accuracy by the ratio between the products of unit pressure and the diameter of contact area.

The required modulus of deformation is to be determined by the following equation:

$$E_{req} = \frac{\pi}{2}\frac{p}{\lambda}(0.5 + 0.65 \lg N) \qquad (3)$$

where N, traffic intensity, is converted to the design automobile.

Usually for pavements with surfacing treated with organic binding materials, E_{req}, varies in the range of 400 to 700 kg per sq cm depending on the nature and intensity of traffic and also on the class of construction.

The method of design of flexible pavements employed in the USSR permits:

(a) The design of new road pavements with required operating properties (various values of λ and E_{req}) for various climatic conditions (E_o) with available data on traffic nature and intensity (N, p, B), and also data on the quality of material to be used (E_1, E_2 . . .).

(b) Varying designs of pavements of equal strength using various material in separate layers and creating, on the basis of comparison of these varying designs, the most expedient and economical structures.

(c) Estimates of the strength of existing pavements on existing roads, and on this basis the requirements for their improvement or restriction of traffic both as regards nature and intensity in the rainy period of the year.

The numerical values of deformability indices for pavements and subgrades (modulus of deformation) are obtained in the USSR as follows:

(a) By the analysis of data on the operation of existing road pavements.

(b) By testing of existing road pavements and subgrades using special mobile loading frames, applying the statistical analysis of conditions of entry of water to subgrades.

(c) By laboratory tests of soils and road-building materials.

The investigation of the behavior under repeated loads of subgrades is of primary importance as ultimately the behavior of road structures is determined by the condition of operation of the subgrade soil.

The results of tests by repeated loads applied through the bearing plate, and also by the traveling wheel on the experimental circular track, have shown that the regularity of accumulation of deformations and final condition of the soil, material or road structure after repeated loading, depends primarily on the relative value (in relation to the critical load, which causes failure at one application), of the acting repeated load.

In all cases the progressive accumulation of plastic deformations leading finally to failure was experienced at values of repeated loads lower than that of the destructive static loads. The degree of influence of repeated loads, however, was different for soils, materials and structures of different composition and moisture content. Thus, on moderately moistened clay and silt soil, road pavements with subgrades consisting of clay and silt soil, and also wet gravel-soil and crushed rock-soil mixtures progressively accumulate plastic deformations at repeated loads equal to 0.4-0.5 of the destructive static loads *(Fig. 2)*.

Wet clay and silt soil, as well as road pavements based on wet soil showed intensive accumulation of plastic deformations and final disintegration even under the action of considerably lower repeated loads (0.1-0.2 of the destructive static load) *(Fig. 3)*.

On the basis of the results of experiments performed in the USSR it is found that the design of high-duty and high-type road pavements with existing requirements as regards surface irregularities may be carried out by not allowing plastic displacement in the structural layers, i.e., considering that they must work in the elastic-viscous deformation stage.

The most widespread types of bases for flexible road pavements in the USSR are layers of rolled crushed rock, gravel or blast furnace slag placed on a stable subgrade. The stability of the subgrade is artificially increased by choice of high-quality soil, compaction of this soil, and elimination of the harmful influence of ground water.

Road structures sometimes contain layers of soil stabilized with mineral, cement or lime, and organic binding agents, bitumen and tar.

Sand and other similar porous layers, which are included in the road structure for drainage of the road pavement foundation are widely employed in regions with adverse moisture conditions of the road bed such as high ground water-level, sharp changes of temperature or deep and durable freezing, as a measure preventing frost heave. In these cases the porous layers are included in the calculations for finding the thickness of the road pavement and taking account of their modulus of deformation, together with the other structural layers.

The final choice of the base structure is made on the basis of technical and economical comparison of alternatives the equal strength of which is checked by compara-

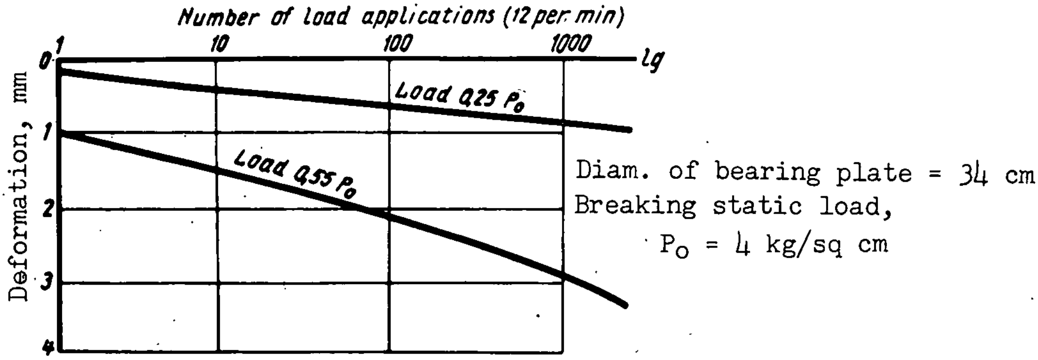

FIGURE 2

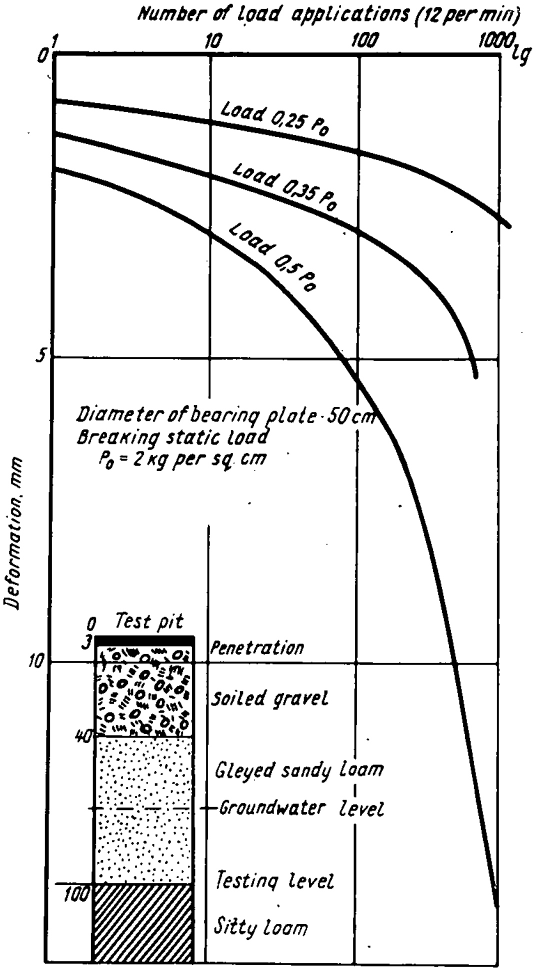

FIGURE 3

tive calculations according to the above mentioned method of maximum allowable deformations.

The initial data for designing flexible road pavement structures is the modulus of deformation of the subgrade, taking into account its stability during the year.

In the USSR it is considered that when new pavements are being designed the increase of their total strength should not be provided only by placing stronger layers in the upper part of the structure, because these layers are very expensive. It is more economical to develop the pavement in depth, taking measures to attain a stable value of the modulus of deformation of the subgrade until the depth is attained where the stresses of automobile loads, as well as the deformations caused by seasonal soil freezing, are not excessive.

The modulus of deformation of the subgrade should be related to the "design soil condition," characterizing the degree of its compaction and moisture content in the most unfavorable period of operation of the subgrade, taking into account the probability of development of this condition during the life of the road pavement. In the USSR the "design conditions," as the combination of weather conditions, moisture content and degree of soil compaction, are based partly on long-term observations of moisture condition of the road-bed and of the performance of road pavements at permanent experimental stations.

For maximum utilization of the bearing capacity of the soils and to reduce the thickness of the pavement structure, the degree of moisture of the road-bed soil by surface and ground water is limited by various structural measures. The principal measures are the provision of adequate drainage, ensuring a minimum elevation of the bottom of base layer above the ground water level and ground level, by building the road-bed on embankments with proper soil compaction, and by lowering the ground water level in cuttings by means of drains.

The choice of fill height, the thickness of frost-resistant layers and the specifying of the requirements for materials in the frost-resistant layers are dependent on climatic and hydrological conditions of the region and soil type.

On the basis of the reduction of stresses and the climatic effects by depth, it is best to arrange the structural layers of the base in such a manner that the degree of rigidity of successive layers decreases by depth in step with the reduction of compressive stresses while the frost-resistance decreases in step with the reduced temperature gradients.

This construction is considered the most economical, as not only high quality materials may be used, which are sometimes difficult to find at building sites, but also comparatively weak local materials, the use of which is not allowed as a rule, for layers at or near the surface. It is also considered advisable that the ratio of the moduli of deformation associated with the most unfavorable conditions of operation of adjacent layers of road structures be equal to at least 1.5 and not over 2.5-3.5, subject to the condition that the thickness of these layers will not be larger than the radius of wheel contact area B(2).

The criterion of the degree of soil compaction in the USSR is "standard compaction," which is similar to the well-known Proctor method. The "standard compaction" method differs from the Proctor method in that impact compaction of the soil sample is performed with a number of load impacts, determined for each soil when plotting the curve of relationship between the dry density of the soil and the number of compaction impacts. For "standard compaction" that number of impacts is chosen at which the dry density of the soil begins to approach asymptotically some constant value.

Properly performed soil compaction may substantially increase the subgrade resistance to loading and consequently create the conditions which admit of reduction of thickness of road pavements. Data is available showing that with thorough soil compaction the modulus of deformation of the soil may be increased by 40 to 50 per cent.

It is considered in the USSR that taking into account this restriction for the upper fill layers in the freezing-thawing zone, the degree of compaction should be not less than 95 per cent of the maximum value by the "standard compaction" method for non-cohesive silty soils and not less than 98 per cent for cohesive soils. The degree of compaction of those fill layers which are located below the freezing level, should be specified, taking into account the actual load and possible future moisture content of the soil.

In the USSR chemically stabilized soils are considered as high quality materials for building road foundations at places with poor resources of natural rock materials. Soil bases may be stabilized both by inorganic (cement and lime) and organic (bitumen, tar and synthetic resin) binding materials. Surface-active substances are also used, to widen the range of soils that may be stabilized and to lower the dependency of construction methods on seasonal conditions.

The principal soils stabilized in the USSR are clayey and silty soils. When considering stabilization these soils are regarded as complex colloidal-dispersion, polymineral and aggregated systems possessing sharp sorption capacity in relation to water, exchange ions and binding agents.

Special attention is being paid to the creation of optimal conditions for the formation of new, strong structural bonds by ensuring a high degree of soil pulverization and uniform mixing with the stabilizing reagent and thorough compaction during the operations for stabilization.

The investigation of the methods for efficient stabilization of soils with cement and lime and practical experience of the application of these methods for road bases constructed in the Soviet Union under the most variable soil conditions has shown that soils may be classified by the degree of their suitability for this type of stabilization into three groups.

Soils which do not meet the necessary requirements are not fit for stabilization with cement and lime in their natural condition, and the possibility of their utilization is determined by special laboratory tests.

It is not advisable to stabilize with cement soils having an acid reaction, pH below 5, as the acid media of the mortar filling the soil pores retards hydration and hydrolysis of the cement grains, due to which, even at cement contents up to 15-20 per cent, the soil does not become sufficiently stable and water resistant.

When carbonate soils conforming to the requirements (for example, loess, loess-like loam or grey desert soil) are stabilized with portland cement, the processes of hydrolysis and hydration proceed, on the contrary, in the most intensive way and the attained strength of the soil-cement is reached, other conditions being equal.

An important factor in determining the strength and water resistance of soil-cement is the quantity and activity of the cement. The best results in soil stabilization are obtained when adding portland cement with an activity of not less than 400 kg per sq cm.

If frost and water do not act together over a long period it is also possible to use lime for subgrade soil stabilization. In the latter case highly active lime, containing not less than 70 per cent of CaO, both slaked and unslaked, in ground form may be used. The use of lime more than 30 days old is prohibited.

Medium and quick setting cut-back bitumen and coal tar are mostly used in the USSR for soil stabilization. These materials in favorable climatic, geological and hydrological conditions, make sufficiently strong and stable mixtures. The compressive strength of soil stabilized with an optimum (7-11 per cent) amount of bitumen or tar in dry and warm climatic conditions varied in the range of 10 to 15 kg per sq cm; the modulus of deformation being 600 to 700 kg per sq cm.

Saline and salinous soils may be stabilized with bitumen and tars only when first heated with a solution of calcium chloride;

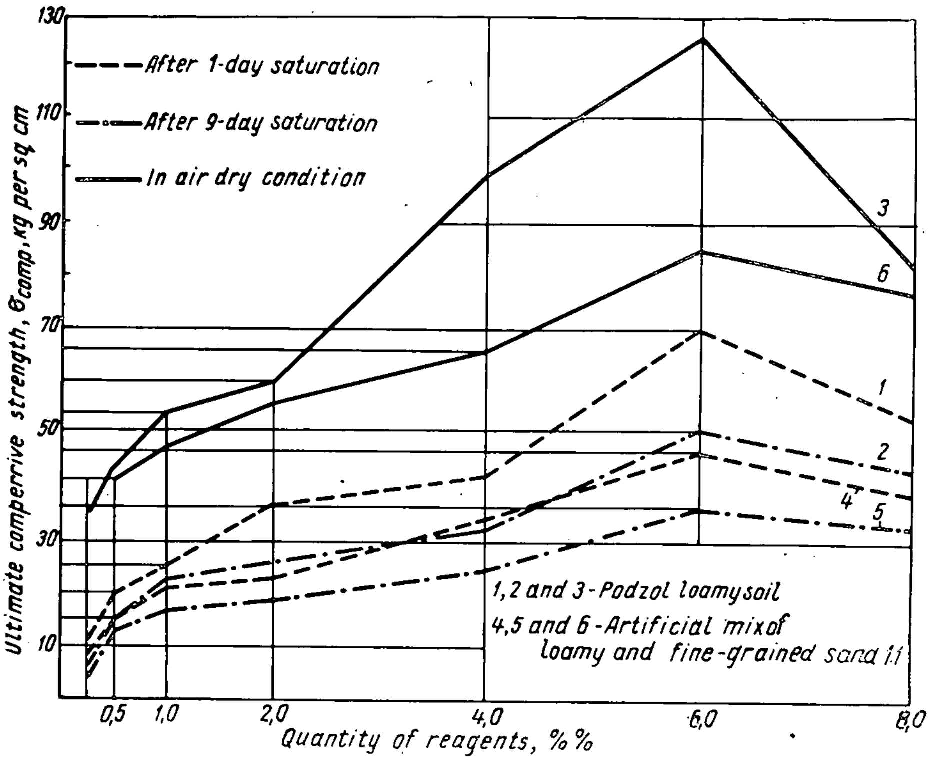

FIGURE 4

this changes salt conditions of the soil and ensures a water content near to the optimum moisture content. To increase adhesion as well, sodium salts of organic acids may be added to the bitumen.

Available experience shows that for stabilization with cut-back bitumen and tar various types of sandy loam, silty and clayey loam soils with a plasticity index below 17, may successfully be used in the central zone of the European part of the USSR. Carbonate varieties of soils and humus soils are used with a plasticity index up to 25. Soils of excessive plasticity are improved with bitumen or tar only after adding leaning additives of sand or sand-gravel material.

Soil stabilization with cut-back bitumen and coal tar in regions with excessive precipitation and comparatively cold climatic conditions is not as efficient and besides there are also technological difficulties, caused by excessive soil moisture content. In these conditions only sandy loam and light loamy soils with a plasticity index not over 12 are efficiently stabilized with bitumen.

Furforal aniline, naphtha soap and other surface-active reagents are also used for soil stabilization. When these materials are being considered, it is necessary to take into account the mineralogical constitution of the clayey part of the soil to ensure maximum ionic sorption, which lowers the surface energy of the soil and develops forces of ionic bond. An example may be the hydrophobic strengthening of non-carbonate acid loamy soil by its treatment with small quantities of furfurol aniline (1-2 per cent). Soils stabilized with synthetic furfurol aniline resins may be used successfully as bases of road pavements, as water-insulation, and as stronger layers.

When the amount of the reagent is increased, the rise of strength is regular up to a certain optimum value after which the soil strength drops, this being connected with the cohesion of the reagent, which is frequently less than its adhesion. In saturated condition the variation of strength of hydrophobized soil is of the same character, but with somewhat lower ultimate strength values *(Fig. 4)*.

Stabilization of Settling and Weak Clayey Soils by Thermal Treatment

I. M. Litvinov

Settling loess soils are very abundant in many countries and especially in the Soviet Union where they cover vast areas. Numerous cases of excessive differential settlement occur on these soils, often followed by collapse of various buildings and other structures owing to the high compressibility of such soils when wetted under applied load. This has already brought about great damage and will do so in the future, for an immense number of large buildings and structures have already been erected on settling soils and the rate of important construction on such soils is steadily increasing.

Different methods of loess soil stabilization have been suggested by a number of investigators. These methods, however, do not ensure the degree of consolidation required, or otherwise involve too much cost and labor.

The Southern Research Institute for Industrial Construction (Academy of Construction and Architecture, Ukrainian SSR) has developed different methods for the thermal consolidation of loess soils *(Fig. 2)*.

Thermal treatment of loess and other soils can be accomplished by two methods.

The first method, attributed to N. A. Ostashev, consists in blowing hot air under pressure into the soil through heat-proof pipes and bore holes, the air having been heated to a temperature of 600-800° C in special stationary or movable furnaces. This method has been found not to be sufficiently effective, hence it is not used in construction work.