Improvement of the Assignment Methodology of the Approach Embankment Design to Highway Structures in Difficult Conditions

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Abstract. Design issues of junction of bridges and overhead road with approach embankment are studied. The reasons for the formation of deformations in the road structure are indicated. Activities to ensure sustainability and acceleration of the shrinkage of a weak subgrade approach embankment are listed. The necessity of taking into account the man-made impact of the approach embankment on the subgrade behavior is proved. Modern stabilizing agents to improve the properties of used soils in the embankment and the subgrade are suggested. Clarified methodology for determining an active zone of compression in the subgrade under load from the weight of the embankment is described. As an additional condition to the existing methodology for establishing the lower bound of the active zone of compression it is offered to accept the accuracy of evaluation of soil compressibility and determine shrinkage.

1. Introduction
In all developed countries, including in the Russian Federation, transport is one of the basic branches of the economy, as well as an important part of the industrial and social infrastructure. Opportuneness, safety and environmental friendliness of transport services in freight and passenger traffic have a great economic importance.

Traffic conditions on the roads are improved due to complex of actions, which includes: improvement of methods for calculating the design of road elements; planning activities; increase of transport-operational qualities of road surfaces; equipment of roads by means of the organization of movement, arrangement of roads.

It is not difficult to see that only if the first event is properly executed all the others are effective. The authors focus on the development of the improvement of the existing assignment methodology of the approach embankment design to highway structures. A special document describing the procedure for the construction design of approach embankment, has not yet been developed. Moreover, the design procedure should include: compilation of a design model, a sustainability prognosis and weak subgrade shrinkage, calculation methods of actions to ensure stability and accelerate subgrade shrinkage. There are only a few methodological documents that solve particular issues of individual design of the approach embankment to the highway structures. The main paper for the standard design
is the document [1]. In addition there are a number of works, among them [2]. The main on individual design of approach embankments is ODM [3].

To increase the stability of the approach embankment on a weak subgrade, vertical reinforcing piles are used to ensure a smooth reduction in the embankment shrinkage towards the highway structure. To accelerate the settlement (consolidation) of the approach embankment on a weak subgrade, additional technological measures (temporary loading of the embankment) or constructive (vertical drains or drainage slots, substitution of foundation soil, etc.) are applied.

Despite this, the smoothness of the transition from the deformed embankment to the more rigid structure of the span structure is not ensured, especially in the case of the use of weak subgrade.

2. Methods

It is obvious that, in general, it is possible to provide the required reliability of the above-mentioned actions to ensure stability, accelerate the settlement and exclude inadmissible deformations of the approach embankment only with a systematic approach to solving this and related problems. The system approach includes:

1. improvement of the legal framework;
2. improvement of the regulatory and technical base;
3. scientific and technical support of all stages of the construction of the facility and its reconstruction.

We will consider in more detail the improvement of the regulatory and technical base. At the same time, it is necessary to take into account new scientific research, innovative developments in new building materials, equipment and technologies. Furthermore, it should be considered with the expansion of the geography of the construction of transport facilities in difficult conditions, including specific soils.

To understand the essence of improving the regulatory and technical basis, taking into account all of the above, it is advisable to consider the stages of development of the theory of designing structures. Conceptually, it can be distinguished the following stages in the development of this theory: the first is a separate calculation of the structure and grounds (typical design, 40-50 years of the previous century); the second is a joint calculation of the structure and the criteria (individual design, 80-90 years of the previous century); the third is the joint calculation of the structure and the grounds, taking into account the man-made impact of the subgrade structure (individual design, the beginning of the 2000s). Meanwhile, as a calculation system was used "structure-ground". As a result, a pleiad of scientists gave suggestions on calculations for the design of objects features of physical and mechanical properties of various types of soils [4, 5].

3. Results

In recent years, the man-made impact of construction projects on soils at their ground has significantly increased. This is due to increased load from the structure and transport, with increasing intensity and speed of movement of vehicles. In this regard, by Kuzakhmetova E. K. it is proposed to switch from the system "structure-ground" to the system "structure - man-made ground". The latter provides for an assessment of the change in the natural working conditions of soil to man-made using new criteria [6, 7]. According to this system, to implement the design of the structure as a whole system, it is necessary to compile a geotechnical model. Such model of the system “structure-man-made ground” includes:

1. structure with designed parameters and a soil profile of the subgrade soil;
2. assessment of the zone of influence of the structure on the subgrade, i.e. active zone of compression;
3. indicators of the composition, condition and properties of soils of different layers of the subgrade, the groundwater level in the natural state, and after the construction of structures (in the active zone of compression);
4. drainage conditions, both in the natural state and after compaction of grounds under load from the weight of the structure (in the active zone of compression).
In the process of individual design of the linear transport facility geotechnical model should be prepared for both the linear sections, and for concentrated structures of a facility.

Consider the features of designing and compiling a geotechnical model in the case of a combination of a non-rigid and rigid system on the example of the approach embankment to the bridge.

Let’s remind, that in the traditional approach for smooth entrance of the car on the bridge while junction construction of it with embankment it is proposed to follow the requirements:

1. to ensure the proper density of soils of the subgrade throughout its height;
2. to provide reliable drainage of surface water from the top and the mass of the embankment using drainage backfill behind the bridge bearing and in abutment, drainage course under the surface with side trays and impervious protection coating and roadside within junction;
3. to weather the subgrade until the pavement surfacing for at least a year during which the main subgrade and ground settlement occurs;
4. to lay approach slab of a length sufficient to cover zones of formation of local subsidence and to ensure a smooth junction between the roadway of the bridge and the road surface. Such a construction is shown in figure 1.

![Figure 1. Approach embankment design.](image)

In the opinion of the authors, it is necessary to add to the above listed requirements: the application of new innovative suggestions for ensuring the stability of the structure. This additional requirement includes, at least, the implementation of:

1. introduction of new building materials, including organic and inorganic additives for improving the properties of soils;
2. clarifying zone in the subgrade, which should be taken into account when calculating the design of the approach embankment.

In accordance with the studies of O.A. Tsukanova technology of ground stabilization with chemical or polymer-mineral stabilizers is useful layer-by-layer embankment filling behind bridge backwall and pavement surfacing on the approach embankment.

Replacement the traditional approach slab design based on macadam to the ground mixed with the chemical stabilizer will increase the strength properties of the layer and shorten the time of work execution. A high level of water resistance of stabilized grounds makes it possible to increase the stability of the structure due to the restriction of water ingress into the mass of the embankment.

Nowadays, there are a lot of agents for ground stabilization, each of which has advantages and disadvantages. Application area of stabilizing agents is predetermined by the type of soil, the road-climatic zone and the specific-conditions-of-use of the structure. It should be noted that all stabilizing agents are introduced into the soil together with organic and inorganic binders or are complex materials based on them. So, experience suggests that more effective is chemical («Kompozit STM» and SoilGrip, manufacturer – Lam-Torg ltd, Moscow) and polymer-mineral stabilizing agents («Nicoflok», manufacturer – Nikel ltd, Saint Petersburg) work with clay soils, and with sandy – mineral («Mobet Dortsem», manufacturer Biiskkhimstroymaterialy ltd, Biysk). Polymer stabilizing agents («TechniSoil», manufacturer - Dorogi Budushchego ltd, Moscow) it is advisable to stabilize dry soils [8]. For ground maturing, stabilized with mineral and chemical agents, it is necessary to
achieve optimum soil dampness with layer-by-layer compaction. Thus, the availability of modern road construction equipment and the right approach to the selection of the new generation of stabilizing agents are currently making a method of improving the properties of grounds (or their stabilizing) with various additives that are most expedient, economic and technological.

As for the definition of active zone of compression, it is a very important stage of individual design. To assign correctly the design of the approach embankment is possible only with an accurate assessment of the impact zone of the zone of its influence on the ground base. The existing approach of defining active zone of compression is that its lower bound corresponds to the level on which $\sigma_z = 0.2 \sigma_{gr}$, where $\sigma_z$ - stress from the weight of the embankment, $\sigma_{gr}$ - stress of own weigh if the ground. These criteria were proposed in the 60-80 years of last century, and focused mainly on tough and plastic clay consistency. They are also transferred to the updated documents [9, 10].

4. Discussion

Therefore, the competency of this approach for weak organic and organomineral soils was assessed by Kuzakhmetova E. K. Studies have shown that it is necessary to impose additional conditions for the assessment of the lower bound of the active zone of compression.

As a criterion for the additional condition, it is proposed to take the accuracy of estimating the soil compressibility and determining shrinkage. For this purpose, the permissible error in the settlement is assigned, for example 5% of its final number, that is, $S_t = 0.05 S_{end}$. Rate of strain $\lambda$ (weak mass) is calculated, corresponding $S_t$. Further on the consolidation-test curve of the form $\lambda = f(P)$ there is such a section on which, with a slight load increment $\Delta P$ rate of strain increment $\lambda$ does not exceed $\lambda_t$. On the consolidation-test curve this area has an inclination angle equal to $\tan \alpha = \frac{\lambda}{\Delta P}$. Load, at which the rate of strain is obtained $\lambda_t$, will correspond to the load on the desired level. Knowing its result, it is possible to set a refined the lower bound of the active zone of compression, after which the settlement is less than the accepted accuracy of its determination.

The above methodology will be considered using the example of an automobile road III technical grade. The height of the approach embankment is 4 meters, width on top is 12 meters, slope embedment is 1:2. At the subgrade embankment there is a muddy ground with medium dampness, its density is 1.7 t/m$^3$ and thickness is H=6 meters. Consolidation-test curve of the soil is shown on the figure 2.

![Consolidation-test curve of mud ground with density 1.7t/m$^3$](image)
Settlement of the weak subgrade under the load of the weight of the embankment and its own weight of soil is calculated by the formula \( S_{end}=\lambda \times H=2.16 \) m. The accuracy of the settlement estimate is 0.1 m. Hence \( \lambda = 0.016 \).

As an example, we determined the active zone of compression using the existing technique for the above conditions and for two different densities of mud ground (1.7 t/m\(^3\) и 1.0 t/m\(^3\)). The results are shown in figure 3.

The graph shows that with decreasing soil density active zone of compression increases. For density of soil 1.7 t/m\(^3\) the active zone of compression number is 12.7 m, for density of soil 1.0 t/m\(^3\) – 20 m. We specify the lower bound of the active zone of compression (12.7m), on which the load acts 0.21 MPa. For this purpose, we find the section on the consolidation-test curve with increment \( \Delta \lambda \) equal to 0.016. This site is close to the load 0.21 MPa. As a result, it was found that \( \Delta_\lambda \) corresponds to a load \( P=0.15 \) MPa. Knowing this load, it is calculated the refined lower bound of the active zone of compression, which turned out to be 9 m.

**Figure 3.** Definition active zone of compression according to the existing methodology.

Such methodology for determining lower bound of the active zone of compression in the subgrade under the load from the weight of the approach embankment, based on the including of the additional condition (accuracy of settlement estimation) increases the accuracy of finding the active zone of compression with all the ensuing consequences.

Thereby, the proposed approach to refine the active zone of compression, that is man-made impact zone of the embankment on its subgrade, is very important for increasing the reliability of assigning additional measures to accelerate the settlement of the embankment, as well as to ensure its stability. Consequently, this approach makes it possible to ensure operation capacity of pavement surfacing, and therefore traffic safety.
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