압밀기반에서 안전한 상태의 제방건축 산출

Calculation of the safe mode of embankment erection on the consolidated basis.

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ABSTRACT

본 연구에서는 K.Terzaghi의 유효응력이론을 인용하여 압밀기반의 안전하중 산출 과정과 결과를 제시하였다. 일반적인 강도를 평가하기 위하여 이용된 J.I.Solovyov의 순간강도 이론에 기초를 두어, 제시한 방법은 포화된 연약점토지반에서 도로의 유지보수 뿐 아니라 축조 과정에 안전하중의 계산 적용이 가능하다. 실제로 편리한 표준 압밀 drain test에서 정의된 점착력, 내부 마찰각과 같은 강도정수를 가진 유효응력은 실제적 적용을 고려하기 위하여 산출된다.

key word : effective stress, safe loading, consolidated basis, instant durability

1. Introduction

The paper presents derived equations and calculation results for safe loading on the consolidated basis with principle of effective stress developed by K.Terzaghi. Based on the theory of instant durability of J.I.Solovyov which has been used to estimate general durability, the proposed method can be applicable to the calculations of safe loading at construction process as well as further maintenance operation of the road on weak water sated clay soil. Effective stress with the parameters of durability such as coefficient of intercept cohesion and angle of internal friction defined in the standard consolidated and drained test that is convenient in practice, is calculated to consider practical application.

2. Calculations for embankment

The problem of an estimation of durability and stability of the consolidated bases of embankments arises at erection and the further operation of roadbed railways and highways on weak water sated clay soil. Exact definition of concept of durability and stability we will consider proceeding from the calculation scheme of an embankment on the weak basis.

It is supposed that the material of an embankment is much stronger, than a basis ground. Occurrence and development of areas of limit equilibrium will take place, first of all in the weak basis. For realization of the theoretical analysis of this process the influence of embankment on the basis is represented in the form of strip loading with the form of normal component diagram, similar to contour of a cross-section

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profile of roadbed. We will consider the most typical design of the roadbed having trapezoid form of cross-section. You can see on fig. 1 calculation scheme of an embankment on the weak basis.

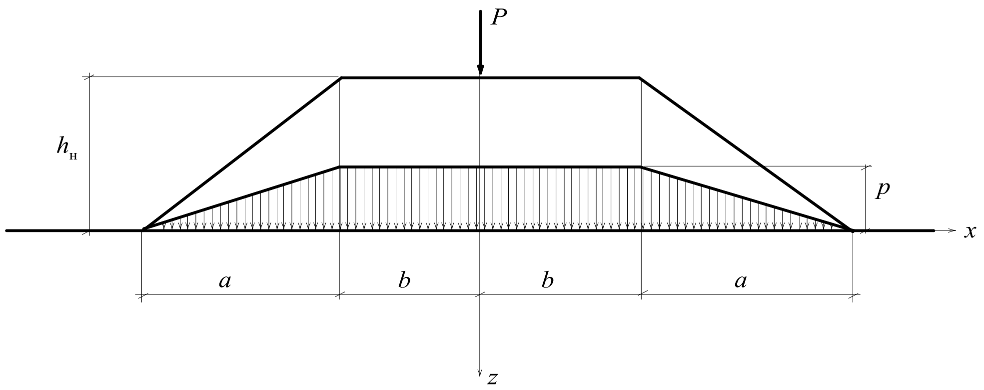

Fig. 1. The calculation scheme of an embankment on the weak basis.

The maximum ordinate of trapezoid diagram of normal pressure p will be equal:

$$p = \gamma_{\text{H}} h_{\text{H}} + \frac{P}{a+b} \tag{1}$$

Where γ_{H} - is relative density of a material of an embankment; $h_{н}$ - embankment height; $2b, a$ - Width of the basic platform and steepness of slope; P - Equally effective running force from time loading and weight of the top structure of a way (for railways) or a road covering (for highways).

The resulted settlement scheme is widely used at designing of roadbed on weak soil [1].

Durability of the weak basis is characterised by size of safe loading $p = p_{\text{без}}$ to which ground destruction in one point answers. From point of soil mechanics, safe loading can be qualified, as the first critical pressure with trapezoid diagram of normal components. We will notice that at definition of safe loading pressure tangents on an embankment sole are not considered. Stability of the weak basis is characterised by size of trapezoid maximum pressure at which the areas of limit equilibrium defining lateral blow are completely formed.

The technique of definition of safe loading has been developed by V.D.Kazarnovskiy [2]. Application of a technique of V.D.Kazarnovskiy for an estimation of durability of the consolidated bases is now based on the theory density ?and humidity N.N.Maslov [3]. According to this theory, safe loading is calculated depending on durability parameters – intercept cohesion c_w and angle of internal friction φ_w, corresponding to the reached density (ρ) and humidity (w)a ground in each point. For calculation realization it is necessary to establish change of humidity conditions in the basis and to have special experimental functions $c_w(w)$ and $\varphi_w(w)$.

The other way for decision of the given problem consists in use of a principle of effective stress of K. Terzaghi [4]. From these positions the given decision was not considered till now. Though in the practical relation it can appear more preferable. For its realization it is necessary to establish an effective stress and to have parameters of durability c and φ, defined in the standard it is consolidated water supply tests.

The given work is devoted calculation of safe loading on the consolidated basis from positions of a principle of effective stress. Here, for an estimation of durability of a consolidated ground it is expedient to use the theory of instant durability of J.I.Solovev [5] according to which the condition of limit equilibrium in a point registers in full pressure:

$$s = \sigma \sin\rho + k\cos\rho \tag{2}$$

Where $s = \dfrac{\sigma_1 - \sigma_3}{2}$ $\sigma = \dfrac{\sigma_1 + \sigma_3}{2}$ k and ρ - parameters of instant durability of a consolidated ground (intercept cohesion and a angle of internal friction).

Characteristics k and ρ calculate by formulas:

$$\sin\rho = (1-\beta)\sin\varphi \;; \qquad k = \frac{\sin\varphi}{\cos\rho}\left(\beta\sigma_э^* + c\,\mathrm{ctg}\,\varphi\right) \tag{3}$$

Where $\sigma_э^*$ - the average effective stress operating during the considered moment of time to the appendix of pressure σ β - coefficient pore pressure.

The coefficient pore pressure is defined by the ratio:

$$\beta = \frac{\Delta u}{\Delta\sigma} \tag{4}$$

Where Δu - Instant increment pore pressure at the instant appendix of an increment of average full pressure $\Delta\sigma$.

Let's define the safe loading to the consolidated basis. We will execute the decision of problem in relative variables: unit of mass force relative density of a ground of the bases γ unit of length – steepness of slope a a time unit - the ratio $\dfrac{a^2}{c_v}$, (c_v - coefficient of consolidation). We will not use special designations for relative pressure and coordinates.

According to decision of the theory of linearly elastic medium, value s and q from trapezoid loadings and taking into account a tension it is possible to define by formulas:

$$\sigma = \bar{p}A + z \;; \quad s = \bar{p}\sqrt{B^2 + T^2} \tag{5}$$

$$A = \frac{1}{\pi}\left[\alpha_1 + \alpha_2 + \alpha_3 + b(\alpha_1 + \alpha_3) + x(\alpha_1 - \alpha_3) - z\ln\frac{\cos\beta_2\cos\beta_3}{\cos\beta_1\cos\beta_4}\right]$$

$$B = \frac{z}{\pi}\ln\frac{\cos\beta_2\cos\beta_3}{\cos\beta_1\cos\beta_4} \quad T = \frac{z}{\pi}(\alpha_1 - \alpha_3)$$

$$\beta_1 = \mathrm{arctg}\frac{x + \bar{b} + 1}{z} \; \beta_2 = \mathrm{arctg}\frac{x + \bar{b}}{z} \; \beta_3 = \mathrm{arctg}\frac{x - \bar{b}}{z} \; \beta_4 = \mathrm{arctg}\frac{x - \bar{b} - 1}{z}$$

$$\alpha_1 = \beta_1 - \beta_2 \; \alpha_2 = \beta_2 - \beta_3 \; \alpha_3 = \beta_3 - \beta_4$$

Let's imagine that in the considered moment of time the compacting trapezoid loading $\overline{p}^*$ affects on the basis and process of consolidation has come to the end because of this loading. Then in any point of the basis the reached level of effective average stress will make:

$$\sigma_э = \overline{p}^* A + z \tag{6}$$

Defining durability parameters by formulas (3) taking into account expression (6), from a condition of limit equilibrium (2) we will receive expression for size $\overline{p}$:

$$\overline{p} = \frac{z + \beta \overline{p}^* A + \eta \operatorname{ctg} \varphi}{\sqrt{B^2 + T^2} - A \sin \rho} \sin \varphi \tag{7}$$

Where $\eta = \dfrac{c}{\gamma a}$.

The size of safe loading is at least expressions (7) on coordinates z, x from a positive range of definition $\overline{p}$. Thus, for absolute size $p_{без}$ it is possible to write down like:

$$p_{без} = \gamma a \overline{p}_{без}, \; \overline{p}_{без} = \min \overline{p}(z, x) = f(\overline{b}, \beta, \eta, \varphi) \tag{8}$$

The resulted expressions allow counting the safe loading of an embankment on the consolidated basis taking into account its preliminary consolidation. The minimum of expression (7) is defined by a numerical method.

At $\overline{p}^*$ = 0 we will have the natural not-compacting basis and, accordingly, it is possible to find initial value of safe loading by means of expression (8). To this size the basis can be loaded almost instantly. The further increase in loading should correspond to degree of compaction of the consolidated basis and the reached level of its durability. The calculation procedure of speed of increase loading provides that during each moment of time, the reached level of loading will be equal to its safe size.

Let's consider a case of uniform increase in loading from 0 to size $\overline{p}$ in time $\overline{T}$. We will find size of safe loading for time $\overline{T}$. Definition of an effective stress we will define with use of decisions of the theory of filtration consolidation of the Terzaghi , Gersevanov and Florin for uniform strip compacting loading [6]. During some moment of time $0 \le t \le \overline{T}$ uniform strip loading is put to the basis $d\overline{p} = \dfrac{\overline{p}}{\overline{T}} dt$ in width $a_t = \overline{b} + 1 - \dfrac{t}{\overline{T}}$ (fig. 2) is put to the basis.

The infinitesimal increment of effective stress by the time of time $\overline{T}$ from loading $d\overline{p}$, enclosed at the moment of time t will be defined by integral:

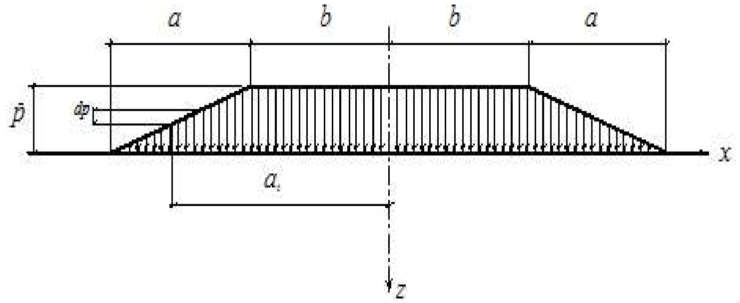

Fig. 2. The calculation scheme to definition of a mode of an embankment erection.

$$d\sigma_э = \frac{\bar{p}z}{\pi\bar{T}} \cdot \int_{-a_t}^{a_t} \frac{1}{(x-\xi)^2 + z^2} \cdot e^{\frac{(x-\xi)^2+z^2}{4(t-\bar{T})}} d\xi dt \qquad (9)$$

Level of the reached effective stress by the time of time $\bar{T}$ taking into account household pressure will make:

$$\sigma_э^* = \frac{\bar{p}z}{\pi\bar{T}} \cdot \int_0^{\bar{T}} \int_{-a_t}^{a_t} \frac{1}{(x-\xi)^2 + z^2} \cdot e^{\frac{(x-\xi)^2+z^2}{4(t-\bar{T})}} d\xi dt + z \qquad (10)$$

The formula (7) for definition value p in this case will become:

$$\bar{p} = \frac{z + \beta\sigma_э^* A + \eta \operatorname{ctg} \varphi}{\sqrt{B^2 + T^2} - A \sin\rho} \sin\varphi \qquad (11)$$

Further, the value of safe loading is defined by means of expression (8). However, in this case, the received value $\bar{p}_{без}$ should be equal to selected value $\bar{p}$. Equality $\bar{p}_{без} = \bar{p}$ is reached by a method of successive approximations. Search parameter in this case is time $\bar{T}$. Thus, time of erection of an embankment is define under the condition that loading on the consolidated basis will be equal to safe value in the end of heaping.

Let's consider a case of non-uniform speed heaping of embankments. For this we will digitize the increment of load process. We will accept n stages, on each of which loading increases by size

$\bar{p}_i =$ const in time $\bar{T}_i$. The trapezoid form for that stage will be characterised by geometrical parameters $\bar{b}_i = \bar{b} + 1 - \frac{i}{n}$ and $\bar{a}_i = \frac{i}{n}$.

So for some intermediate stage $1 \le l \le n$ for time moment $\sum_{j=1}^{j=l} \bar{T}_j$ the reached level of an effective tension will be defined by expression:

$$\sigma_э^* = \frac{z}{\pi} \sum_{i=1}^{i=l} \frac{\bar{p}_i}{\bar{T}_i} \int_0^{\bar{T}_i} \int_{-a_{ti}}^{a_{ti}} \frac{1}{(x-\xi)^2 + z^2} e^{\frac{(x-\xi)^2+z^2}{4\left(t - \sum_{j=i}^{j=l} \bar{T}_i\right)}} d\xi dt \qquad (12)$$

$$a_{ti} = \bar{b}_i + \bar{a}_i \left(1 - \frac{t}{\bar{T}_i}\right)$$

Further, the size of safe loading is established by the formula (12).

Thus, the time $\bar{T}_i$, at which the reached level of loading is equal to safe size, is define at each stage by method of successive approximations.

3. Example of calculated embankment

Let's consider results of an example of calculation. The embankment in height h_H=6 m with width of the basic platform $2b$=6 m, steepness of slope $a =$ 6 m is projected.

The embankment will be heap from fragment material with relative density $\gamma_H = 20 \frac{kN}{м^3}$.

The basis ground is combined by the water sated loam with characteristics: $\gamma = \gamma_{sb} = 10 \frac{kN}{м^3}$, $c = 10$ kPa, $\varphi = 20^\circ$, the coefficient of consolidation makes $c_v = 20 \frac{м^2}{day}$, $\beta = 0{,}9$. It is required to calculate a safe mode heaping of roadbed.

We establish relative values of the initial data:

$$\eta = \frac{10}{10 \cdot 6} = 0{,}17 \quad \bar{b} = \frac{3}{6} = 0{,}5 \quad \bar{p} = \frac{20 \cdot 6}{10 \cdot 6} = 2{,}0$$

We break process of increase loading into 7 stages in which size $\bar{p}_i$ it will be equal 1,4 at the first stage and 0,1 on the subsequent.

Relative time of erection of an embankment calculated by an offered technique is presented in table 1.

Table 1. Relative time of a safe mode

Intensity Relative loading	1,4	1,5	1,6	1,7	1,8	1,9	2,0
Relative time of a safe mode	0,27	0,47	0,79	1,3	2,8	3,7	6,9

Taking into account time unit of measure $\frac{a^2}{c_v} = \frac{36}{20} = 1{,}8$ on fig. 3 the schedule of a safe mode of erection of an embankment in time is resulted.

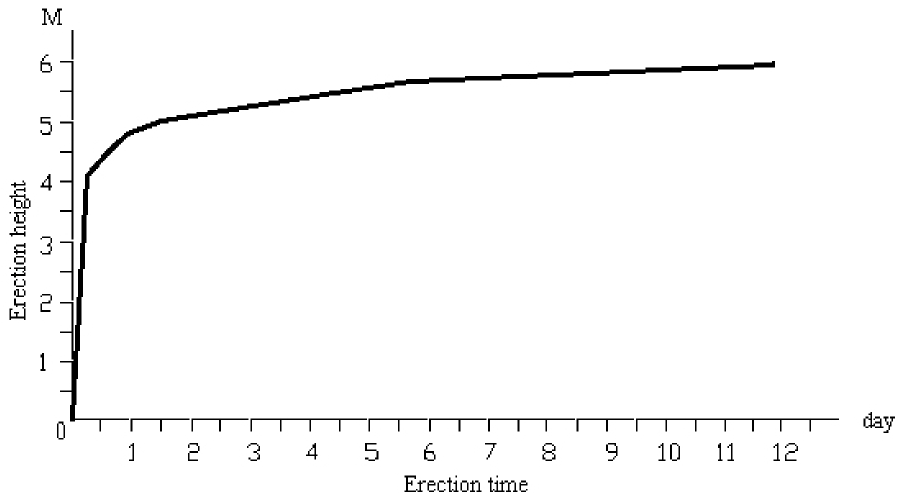

Fig. 3. An example of the schedule of a safe mode of embankment erection.

4. Conclusion

The calculation procedure of safe loading of an embankment stated on the consolidated basis and calculation of a safe mode of roadbed erection in given article are offered for practical use at designing of embankments railways and highways on weak consolidated soil.

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