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Search for Rational Contour of Back Surface of Retaining Wall

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Abstract. The analysis of the simplified theory of soil pressure on steep retaining walls detected the absence of clear mathematical dependence between the curvature of the surface contacting with bulk material and the nature of the lateral pressure profile. The problem of the dependence between the equation describing the load-bearing surface of the retaining wall and the equation specifying the lateral pressure function of the bulk material on this surface is considered. The formulation of the problem is based on hypotheses and assumptions that correspond to the Coulomb theory according to which the pressure of the bulk material on the side surface is directly dependent on the lateral pressure coefficient, which in its turn, is in a trigonometric dependence on the angle of inclination to the vertical that takes this surface pressure. Exact dependence is obtained in the form of a fourth-degree equation between the function describing the lateral pressure profile on the bulk material and the tangent of the angle between the vertical plane and the tangent to the generatrix of the back face of the retaining wall. Account of the seismic effect in the design of retaining structures is analyzed. Strategy for searching the dependence between the configuration of the retaining wall contacting with the ground and the nature, magnitude of the effect of the seismic load on the structure taking this pressure was proposed by analogy with the static formulation of the task.

INTRODUCTION

Creation of structures with specified positive properties is one of the priorities of up-to-date building science [1,2]. This predetermines the development of methods and tools for designing and building effective systems that minimize their weight. In this regard, the traditional (reverse) approach adopted in the design can not ensure the integral positivity of solutions. An alternative to it is the search for strategies and methods aimed at search of geometric, physic-mechanical parameters of carrier systems with predefined positive properties. The aggregate "retaining wall - soil" is considered taking into account this direction as the main line of the research where two specified attributes are interdependent and are considered as a whole: the nature of distribution and the lateral pressure of the bulk material are completely dependent on the configuration of the back face of the retaining wall and vice versa.

STATIC FORMULATION OF THE TASK

The active horizontal pressure of the bulk material is determined according to [4] and is directly dependent on the lateral pressure coefficient of bulk material λ, which in its turn, is in a trigonometric dependence on the angle α of the inclination of the surface taking this pressure to the vertical. The information presented in [4] is based on the generally accepted theory of the lateral pressure distribution in bulk media. In the general case, the diagram of lateral pressure of bulk material has a trapezoidal outline. A similar pressure distribution is inherent in structures having a flat face of contact with the bulk material. However, if the surface contacting with the bulk material has a contour that is different from the plane, the nature and magnitude of the lateral pressure will change (Fig. 1) [6].

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Taking into account the foregoing, the rationalization of the system under consideration can be carried out, to a certain extent, by reducing the pressure of the bulk material on the structure taking a lateral pressure. The latter is possible due to ensuring certain outline to the back wall.

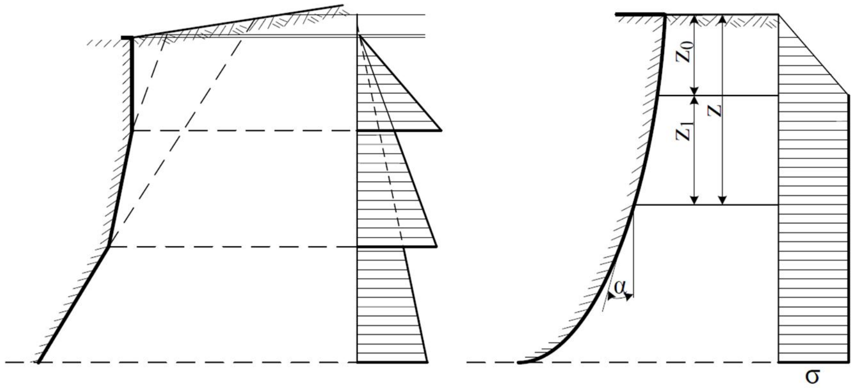

FIGURE 1. Search of retaining wall configuration.

The works [6,7] describes the analysis of mutual influence of the surface configuration and the lateral pressure profile of a bulk material influencing this surface. The angle α of the inclination of the surface contacting with the bulk material to the vertical (Fig. 1) is taken as n external control parameter.

Moreover, the proposed formulation of the task is based on hypotheses and assumptions corresponding to the Coulomb theory, according to which the pressure of the bulk material on the side surface is directly dependent on the lateral pressure coefficient λ, which in its turn, is in a trigonometric dependence on the angle α of the inclination to the vertical taking this surface pressure. The task is reduced to solving the equation:

$$\lambda = \left[tg\left(45 - \frac{\phi + \alpha}{2}\right) + tg\alpha\right]^2 \cos\alpha = \frac{\sigma(z)}{\gamma \cdot (z_0 + z)}, \tag{1}$$

where:

φ – angle of internal friction of soil;

γ – bulk soil weight;

σ(z) – function describing the pressure profile below the mark zo.

Due to a number of trigonometric transformations and changing the variables in (1), an exact dependence is obtained in the form of a fourth-degree equation between the function describing the lateral pressure profile from the bulk material and the tangent of the angle α between the vertical plane and the tangent to the shell generatrix:

$$k^4 + \delta_2 \cdot k^3 + \delta_3 \cdot k^2 + \delta_4 \cdot k + \delta_5 = 0; \tag{2}$$

$$\delta_2 = \frac{-2tg\psi - 2F^2(z) \cdot tg\psi}{1 + F^2(z) \cdot tg^2\psi}; \ \delta_3 = \frac{1 + tg^2\psi - F^2(z) \cdot tg^2\psi + F^2(z)}{1 + F^2(z) \cdot tg^2\psi};$$

$$\delta_4 = \frac{2 \cdot F^2(z) \cdot tg\psi - 2 \cdot tg\psi}{1 + F^2(z) \cdot tg^2\psi}; \ \delta_5 = \frac{tg^2\psi - F^2(z)}{1 + F^2(z) \cdot tg^2\psi}; \ F(z) = \sqrt{\frac{\sigma(z)}{z \cdot \gamma}}; \ \psi = 45^o - \frac{\phi}{2};$$

$$tg\alpha = \pm\frac{2k}{1 - k^2} = \frac{dy}{dz},$$

where:

y(z) – equation of the shell generatrix.

The obtained solution (2) opens the possibility of controlling the character of the distribution of the lateral pressure of the bulk material by giving a certain outline to the surface taking this pressure. Fig. 2 shows the different shapes of the lateral pressure profiles calculated according to (2) and surface configurations that ensure the corresponding pressure distribution.

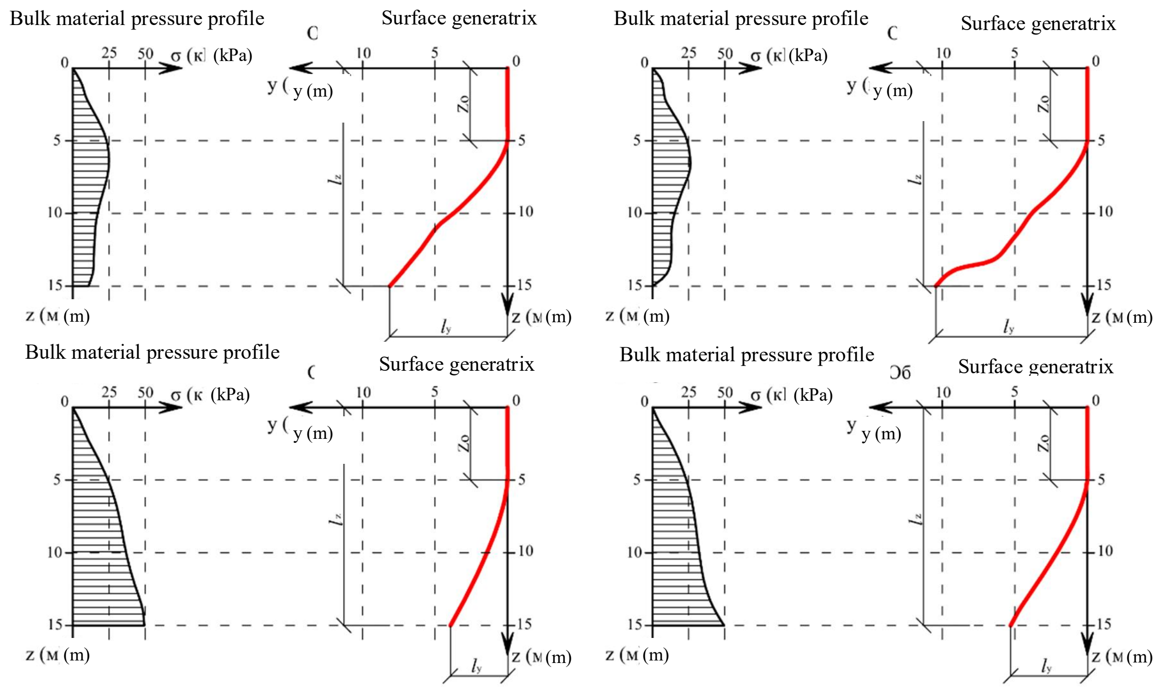

FIGURE 2. Various configurations of the retaining wall back face surfaces and the corresponding lateral pressure profiles of bulk material.

ACCOUNTING FOR THE EFFECT OF SEISMIC ACTION

The foregoing relates to the static action of the bulk material on the side surface. The works [3, 4] analyzes the approach to take into account the seismic action of the soil on the retaining walls according to which two changes are made in comparison with the static approach: the angle of internal friction of the soil is arbitrarily reduced to the so-called seismic angle (θ) and the volumetric weight of the soil is conventionally increased:

$$\varphi_d \approx \varphi - \theta\,; \qquad (3)$$
$$\gamma_d \approx \frac{\gamma}{cos\theta}\,,$$

where:

$\theta = arctg\,\frac{\tau_0}{g}$ – angle of seismicity,

τ_0 – seismic acceleration;

g – acceleration of gravity.

These assumptions lead to a certain transformation of the expression of the lateral pressure coefficient of bulk material, which, in its turn, is defined as the following in accordance with the current European standards [8]:

$$K = \frac{sin^2(\psi + \varphi_d^1 - \theta)}{cos\theta sin^2\psi sin(\psi - \theta - \delta_d)\left[1 + \sqrt{\frac{sin(\varphi_d^1 + \delta_d)sin(\varphi_d^1 - \beta - \theta)}{\sin(\psi - \theta - \delta_d)\sin(\psi + \beta)}}\right]^2}\,, \qquad (4)$$

where, ψ – angle of deflection of the retaining wall back surface;

β – backfilling material declination angle from horizontal;

$\varphi^1{}_d$ – design value of shear resistance angle;

δ_d – design value of the angle of friction between the soil and the wall;

θ – seismic angle.

Numerical analysis of expression (3) is carried out taking into account the experience gained in the seismic examination of the problem of transformation of the lateral soil by giving the specified outline to the back face of the retaining wall. To do this, we use the initial data: H = 10m - height of the retaining wall; $\varphi = 28$ °, $\gamma = 18$ kN/m^3; β, $\delta_d = 0$. We will look for the external geometry of the retaining wall that provides the transformation of the lateral soil pressure profile from proportionally increasing (triangular) to trapezoidal with a constant value of pressure starting from a depth of 3 meters. To do this, we divide the retaining wall into 10 equal sections in height. The task is to find the coefficient of lateral pressure of bulk material K for each section which will determine the equality of the lateral pressure in this section to the pressure at a level of three meters. The solution is made by selecting such a value of the inclination angle of each section which predetermines the required value of the lateral pressure coefficient. The results are given in Table 1.

TABLE 1. Geometric attributes of the transformed retaining wall.

z (m)	θ=0°			θ=5°		
	σ (kN/m2)	K	α (degrees)	σ (kN/m2)	K	α (degrees)
1	6.4986	0.36103	90	7.5249	0.41805	90
2	12.9972	0.36103	90	15.0498	0.41805	90
3	19.4958	0.36103	90	22.5748	0.41805	90
4	19.4958	0.32952	104.65	22.5748	0.27077	115.16
5	19.4958	0.27698	114.04	22.5748	0.21662	124.44
6	19.4958	0.24183	120.21	22.5748	0.18051	130.12
7	19.4958	0.21635	124.48	22.5748	0.15472	133.9
8	19.4958	0.19695	127.59	22.5748	0.13538	136.61
9	19.4958	0.18165	129.95	22.5748	0.12034	138.62
10	19.4958	0.16919	131.79	22.5748	0.10831	140.21

Figure 3 shows the geometry of the retaining wall obtained in accordance with the above methodology. In the first case, it is assumed that the angle of seismicity is θ = 0 ° which leads to a static formulation. It should be noted that the geometry of the retaining wall obtained in this case coincides with the solution (2) which confirms the representativeness of the approach. In the case of giving a non-zero value of the seismic angle (θ = 5°), the configuration of the retaining wall is significantly modified.

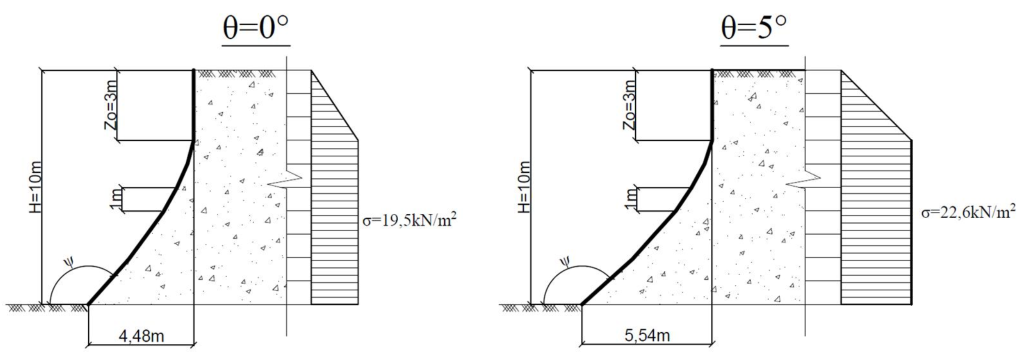

FIGURE 3. Transformed geometry of the retaining wall.

CONCLUSION

The analysis of expression (4) makes it possible to conclude that the obtained results of the consideration of the static aggregate "retaining wall - soil" take place when considering the seismic action of the bulk medium on the side surface. In further studies, it is of interest to search for a direct analytic dependence between the curvature of the surface taking the seismic action of the bulk material and the nature of the distribution of this pressure.

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