Creating a Zone in the Body of the Embrace of the Road for Optimal Position of Retaining Walls in it

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Abstract. In all cases of designing retaining walls (RS) on roads, their main purpose is to ensure the stability of the roadway. At the same time, special attention is paid to ensuring the stability of the retaining walls themselves, on which the stability of the structure as a whole depends. Therefore, it seems advisable to first determine the area of the roadway within which the roadside walls are guaranteed to be stable against overturning in accordance with the applicable regulations on the road where the retaining walls are to be designed. The article deals with the problem of forming the mentioned zone in the body of the embankment of the road for the optimal placement of reinforced concrete thin-walled retaining walls in it.

Introduction

The existing technique for designing retaining walls of roads is not sufficiently perfect, since it does not properly reflect the geometric features of design factors that affect the position of retaining walls and its optimal dimensions.

The lack of a clear concept of the existing method of designing retaining walls, as well as the presence in some cases of design solutions of retaining walls of a random character, is obviously explained by the small amount of work on the construction of retaining walls in comparison with the total volume of structures in the complex of which they are included. However, the total annual costs for the construction of retaining walls are so significant that the construction of them according to projects that do not sufficiently meet modern requirements leads to a large overrun of material and a significant increase in the cost of construction. The process of retaining walls design can be considered as the process of solving the geometric optimization problem, where the design parameters are the geometric parameters of retaining walls with the specified restrictions [1].

Retaining walls are usually rigid walls designed to support the soil mass laterally. Lateral soil pressure is the main factor in analysis and design of retaining walls [2].

Studies were carried out on the optimal design of retaining walls from masonry of unarmored or reinforced concrete. At the same time, the cost of material is one of the main factors in the construction of gravitational retaining walls. Therefore, minimizing the weight or volume of these systems can reduce the cost [3].

There are studies on the use of metaavristic optimization, where attempts are made to expand the concept of design based on characteristics on the design of retaining walls [4].

The methodology for obtaining the optimal design of reinforced cantilever retaining walls from the point of view of the lowest costs, using various backfilling options that meet the stability criteria [5, 6].

Assessment of characteristics of the retaining wall of gravitational type during earthquake is performed, where the simplest case of retaining wall is considered, in which backfilling is considered dry and less durable [7-8].

When designing a cantilever reinforced concrete retaining wall, there are modern achievements in the field of computerized design, in particular, there are special computer programs for cantilever

reinforced concrete retaining walls, where the optimal design is also investigated in terms of the minimum cost of cantilever retaining walls made of reinforced concrete and other materials [9-13].
It is possible to obtain a design for a suitable retaining wall that can be used on a vertical slope. Construction of retaining wall with inclined wall in front part of retaining wall gives higher safety margin than design of retaining wall with a thin shape [14].

Methods

The proposed design methodology is considered in relation to precast concrete corner retaining walls, since such retaining walls include the largest number of geometric problems encountered in the design of other types of retaining walls.
The enlarged scheme of the proposed design methodology for retaining walls of roads passing through poorly crossed terrain can be presented in the following sequence:
1. Based on the results of the analysis of the initial data for the design of retaining walls on the section of the road where its location is assumed, the first (approximate) position of retaining walls is established.
2. Within the boundaries of the subgrade slope, a zone is allocated within which retaining walls can be located in accordance with a given system of restrictions (conditions of stability against capsizing; soil and geological conditions; conditions for minimizing the area of the right of way, etc.), i.e. the so-called optimal placementzone (OPZ) of retaining walls is formed.
3. An optimal placement function is formulated, which establishes positional and metric relations between the optimal placement zone and the retaining walls placed in it. Taking into account the existing restrictions, the optimal placement of retaining walls is carried out and its geometric parameters are determined.
4. The obtained optimal position of retaining walls is checked against the first and second limit states:
-the first group (for bearing capacity) provides for calculations: on the stability of the wall position against shear and the strength of the soil base; strength of structural elements and joint units;
- the second group (in terms of serviceability) provides for checking: the basis for permissible deformations and structural elements for permissible values of crack opening.
5. If the test results are positive, the design process stops and the results are taken as design parameters of the retaining walls, otherwise, the shape and position parameters of the retaining walls are adjusted, or the parameters of the optimal placement zone are adjusted at the discretion of the designer.
The zone of optimal placement of retaining walls (Fig.1) serves as the basis for solving the main problem of optimal geometric design of retaining walls - placement of retaining walls and their elements in the zone of optimal placement taking into account the preset conditions.
The optimal placement zone is a three-dimensional body bounded by surfaces of various dimensions (0÷3-dimensional), which reflect various factors that affect the position of the retaining walls. Changing the dimension of these surfaces is related to the specific design conditions of the retaining walls. In particular, the area of optimum top placement may be defined by the slope surface (plane). In this case, it is sometimes necessary to increase the zone of optimal placement from the side of the slope surface to a certain level (see Fig. 1), which may be associated with the possibility of the top line of the retaining walls beyond its limits. At the bottom, the optimal location zone can be limited (depending on local soil and geological conditions) by the design surface (plane) of the foundation or by some parallelepiped limiting the depth of the foundation of the retaining walls.
In general, the lower boundary of the optimal placement zone may have a more complex structure. Depending on the curvature outline of the road section where the retaining walls are designed. The optimal rear and front placement zone may be defined by vertical planes or cylindrical surfaces,

and on the sides by either vertical planes or parallelepipeds that take into account the boundary conditions of the start and end of the retaining walls.
When retaining walls are placed in the optimal placement zone, the upper, lower, and side boundaries define one of the above boundaries. Therefore, when forming the optimal placement zone, special attention is paid to the definition of these boundaries, which are conventionally calledOPZ regions (see Fig. 1): Ω_B - upper, Ω_H - lower, Ω_1 -

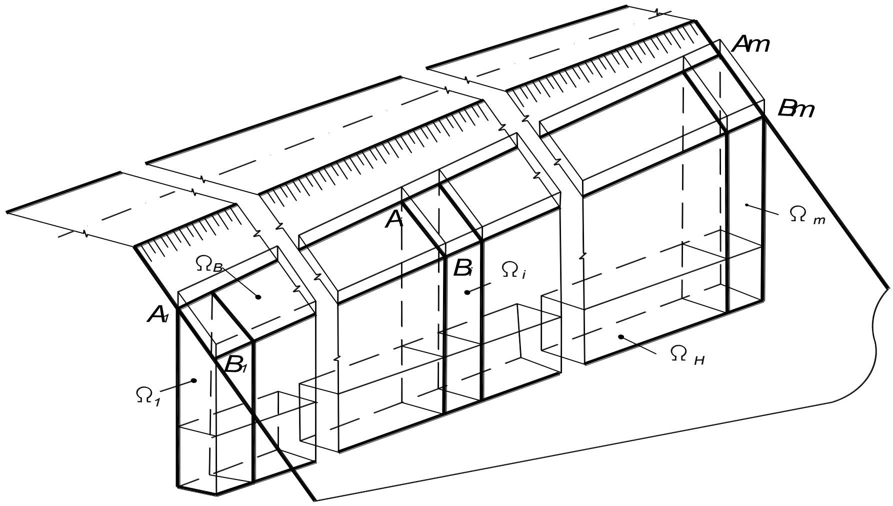

FIGURE 1. Location zone of optimal placement in the body of the slope embankment

initial and Ω_m - final regions. In addition, in some cases it is necessary to introduce intermediate areas - $\Omega_i$that limit the location of the joints of neighboring sections of retaining walls, which differ in the degree of deepening into the ground or include type of elements of different classes.Thus, in general, the optimal location zone can be considered as a collection of a number of constituent areas:

$$\Omega = \Omega_B+\Omega_H + \Omega_1 +\Omega_m+ \sum_{i=2}^{m-1} \Omega_i \tag{1}$$

within the limits, which the required arrangement of the corresponding elements of retaining walls should be provided, and its formation is reduced to some generalization of these areas.
The value of each of these areas in the optimal placement zone, in terms of placing retaining walls in it, is different. Thus, the upper Ω_B and the lower Ω_H of the area are designed to accommodate the defining elements of the retaining walls - the top and bottom (sole). They therefore have the greatest impact on the nature of the changes in the shape and position of the retaining walls. The presence and dimensions of the start $\Omega 1$, end Ω_m and intermediate areas Ω_i, as noted above, depend on the specific design conditions. For example, if there is a significant slope of the top line of the retaining walls (with a small curvature of it), as well as when the nature of the bedding of soils abruptly changes, the number of intermediate areas can increase. Or, conversely, in some cases these regions may be absent altogether, i.e.

$$\sum_{i=2}^{m-1} \Omega_i = 0. \tag{2}$$

The upper Ω_B and lower Ω_H areas are determined based on stability calculations, while minimizing the area of fertile land and the amount of excavation can act as additional factors influencing the definitions of these areas.
It should be noted that when determining the lower region of the Ω_H along with others, soil and geological conditions of the terrain are also taken into account, such as the depth of the foundation, the depth of freezing, the thickness of the layer of weathered rock, etc.
You can consider in more detail the definition of the upper area Ω_B the optimal placement zone, the design diagram of which is shown in Fig. 2.
The required calculation values are the boundary values of lengths l_A and l_B distances l of the inner face of retaining walls from the edge of the roadway, corresponding to the maximum permissible values of the coefficient of working conditions - [m], adopted depending on the type of structure of retaining walls of its base.
By design values of coefficient of working conditions m are foundconditions of RW stability against tipping, expressed byformula [15]

$$M_{over} \Big/ M_{\lim} = E\ y \Big/ \sum_{i=1}^{n} P_i\, a_i < [m], \tag{3}$$

where M_{over} –calculated overturning moment relative to the plane of the foundation sole:
$M_{\lim}$–limit overturning moment relative to point 0; *E*– active (horizontal) soil pressure; *y*–shoulder of force E relative to the plane of the foundation sole;P_i–forces corresponding to the weight of soil and elements of RW; a_i–shoulders of forces$P_i$relative to vertical line passing through point 0; *[m]*–maximum permissible values of the coefficient m, taken, for example, for the section of reinforced concrete structures with a foundation on a non-rock base– [0.7 ÷ 0,75].
The calculation begins with determining the active soil pressure E on the retaining walls and constructing the corresponding pressure diagram. To determine the effect of active soil pressure on retaining walls, it is necessary to know the characteristics of the backfill soil, its own weight, the coefficient of internal friction of the soil $tg\varphi$ and other physical and mechanical parameters[16,17].
When calculating, a section of retaining walls with a length of 1 m is considered, for which the active soil pressure E and other loads are determined.The active soil pressure E is determined for the entire height of the retaining walls, including the depth of foundation (see Fig. 2).
The general formula for determining this pressure is:

$$E=(\gamma h^2 \lambda) / 2$$

whereγ–specific gravity of backfilling soil; *h*–height of retaining walls; λ–coefficient of active soil pressure on retaining walls, the value of which depends on many factors, including soil characteristics.
As is known [18], when determining the own weight of retaining walls, as well as the weight of soil above elements of retaining walls, its cross section is divided into simple geometric figures.
Forces P_i corresponding to weight of soil and elements of retaining walls are applied in center of gravity of each of these geometrical figures.
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$$P_i \ = F_i \gamma,$$

whereF_i–cross-sectional area of the geometric figure.
When designing retaining walls, it is often necessary to determine the soil pressure taking into account the time load located on the collapse prism. The uniformly distributed load located on the collapse prism, with intensity *q* (see Fig 2), is replaced by a layer of soil equivalent in intensity to this load having height

$$h_0 = \frac{q}{\gamma}$$

The intensity of soil pressure on retaining walls is determined by the formulas

$$q_0 = \gamma\, h_0\, \lambda \text{ и} \qquad q_H = \gamma\left(H + h_0\right)\, \lambda .$$

In various design situations, the design M_{over} and limit $M_{\lim}$ moments in (1) can be modified depending on the inclination angle of the βsurface of the soil backfill beyond the retaining walls relative to the horizontal plane at the level of the top of the retaining walls. For example, for the design case shown in Fig. 3, a, when $\beta \neq 0$.

$$M_{пред} = (P_1 a_1 + P_2 a_2 + P_3 a_3 + P_4 a_4 + P_5 a_5) \ , \qquad (3)$$

where$tg\,\vartheta$ – tangent of angle of sliding plane of collapse prism, i.e.

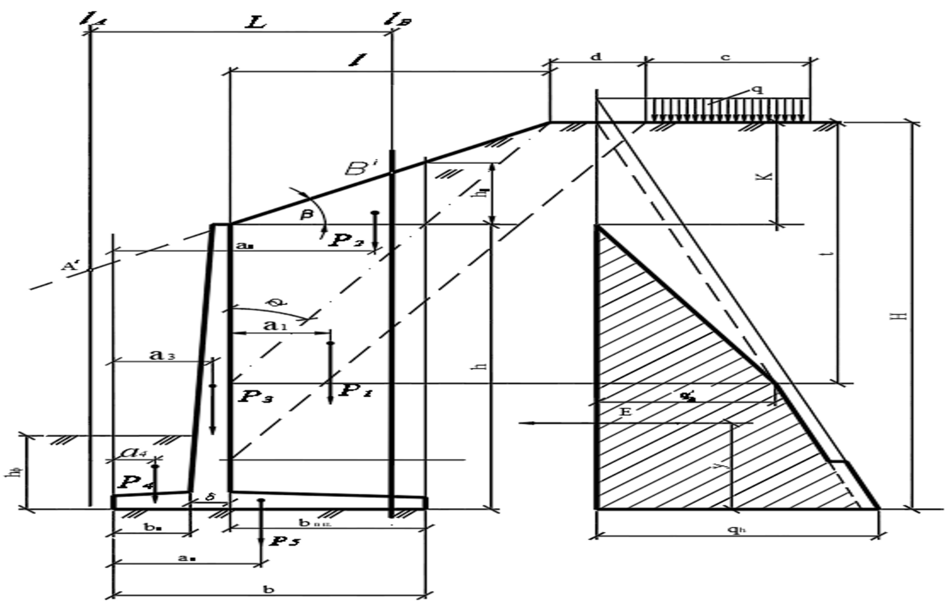

FIGURE 2. Calculation scheme for determining the upper region Ω_B zone of optimal placement

$$tg\,\vartheta = -tg\varphi + \sqrt{(1 + tg^2\varphi) + \frac{4ch_0 + 2\iota k + 2dh_0}{(H^2 + 2h_0 H)\sin 2\varphi}} \qquad (4)$$

$$M_{опр} = Eyn = \frac{\left((H^2 + 2h_0)tg\,\vartheta - (2h_0 + \iota k + 2dh_0)\gamma\right)}{2tg(\vartheta + \varphi)} Yn \qquad (2)$$

whereφ–angle of internal friction of the soil; n–coefficient of soil or reinforced concrete overload. And in the case when $\beta = 0$ (Fig.3, b), expressions (2) and (3) take the form:

$$M^{опр} = Eyn = \frac{\left(\gamma h^2 (tg\,\vartheta h^2 + 2h_0 c)\right)\gamma n}{4\,tg(\vartheta + \varphi)} \qquad 5$$

(5)

$$M_{пред}=(P_1a_1+P_3a_3+P_4a_4+P_5a_5)\ n. \quad (6)$$

However, for the case $\beta=0$, the problem of determining the boundaries of the optimal location zone does not make sense, since in this case $\iota_i = 0$, i.e.the retaining wall is located at the edge of the subgrade of the road, which should be economically justified.

Thus, to calculate M_{over} and $M_{\lim}$, it is sufficient to use only expressions (2) and (3).

The boundary values ι_A and ι_B of the distance ι can be determined both numerically and analytically. The analytical method, which involves the derivation and solution of a general equation, may be acceptable in some particular design cases. In complex design situations, it is more expedient to use the numerical method, which is distinguished by its simplicity.

In a numerical method, several arbitrary values of distance ι are specified in each particular calculation case. When solving (1), calculated values of coefficient m corresponding to specified values of ι_i are determined. Then, based on the obtained results, a graph is plotted between the specified distance values of ι and the calculated values of coefficient m, from which the desired boundary values of the interval $[\iota_A\text{-}\iota_B]$corresponding to the maximum permissible values of coefficient m are determined, which can be traced by a specific example.

a) b)

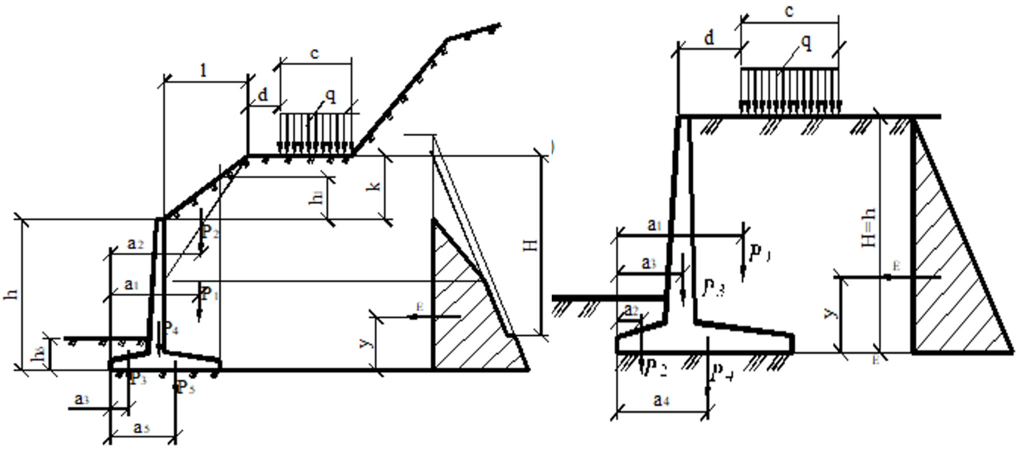

FIGURE 3. Diagram of modification of tilting moments depending on slope angle β.

Results and discussion

Let us consider the case of determining ι_A and ι_B for the section of the roadbed shown in Fig. 3.

Set the height of the embankmentH = 10 м, embankment slope$i$ - 1:1.5, i.e.β=33^{0}40', as well as γ=1.7 т/м^2(medium sand), γ_c=2.5 т/м^2(for reinforced concrete), φ=35^0, n = 1.2, q = 25 kPa.

Let's start with ι= 2 м. Find corresponding values of RW parameters by formulas:

$K = tg\beta\iota;\ \ h_1 = b_{вн.}\ tg\beta;$

$h = H - k$ - the height of the retaining wall;
$h_\phi = h/4$ - depth of foundation of retaining wall;
$b = 0.45\ h$ -width of the foundation slab of the retaining wall;
$b_k = 0,1\ h$ - width of the cantilever part of the foundation slab;
$b_{BH} = 0.33\ h$ - width of the inside of the foundation slab;
$\delta = 0,02\ h$ - wall and base plate thickness.

As in this case $\beta \neq 0$, M_{over} and $M_{\lim}$ are defined from expressions (2) and (3) for calculating tgϑ from (4), we find value of active pressure of soil $E$to (2).

To construct a pressure diagram, first determine the value of the active pressure coefficient

$$\lambda = \frac{tg\ \vartheta}{tg(\vartheta + \varphi)},$$

as well as other necessary data (see Figure 2)

$$t = \iota / tg\vartheta,\ q'_h = \frac{q_h}{H} t.$$

The arm of the resultant E is defined as the distance from the base of the wall to the center of gravity of the pressure diagram

$$y = (\sum_{i=1}^{m} S_i y_i) / \sum_{i=1}^{m} S_i,$$

whereS_i –areas of individual geometric figures, which are divided pressure diagram;y_i– respectively, the applicates of the centers of gravity of these geometric figures.

We find the forces of P_i according to the formulas:

$$P_1 = b_{BH}(h - \delta)\gamma = 0.33h^2\gamma;$$
$$P_2 = (b_{BH} h_1 \gamma)/2 = 0.072h^2\gamma;$$
$$P_3 = b_K(h_\phi - \delta)\gamma = 0.031h^2\gamma;$$
$$P_4 = \delta(h - \delta)\gamma_c = 0.019h^2\gamma;$$
$$P_5 = \delta b = 0.006h^2\gamma_c.$$

The shoulders of these forces are determined by the formulas

$$\alpha_1 = (b_{BH}/2) + \delta + 0.1h = 0.258h\ ;$$
$$\alpha_2 = (2b_{BH}/3) + \delta + 0.1h = 0.34\,h\ ;$$
$$\alpha_3 = (b_K/2) = 0.05\,h\ ;$$
$$\alpha_4 = b_K + \delta/2 = 0.11\,h\ ;$$
$$\alpha_5 = b/2 = 0.22\,h.$$

Finally, according to formulas (3) and (4), the calculated M_{over} and limit $M_{\lim}$ overturning moments are determined

M_{over} =76.19 т, M_{lim} = 148.2 t,

In this case, the stability condition against overturning is equal to

$m = M_{over}/ M_{lim}$=0.52.

Having set a few more arbitrary values ι=(4.0, 5.5, 7.0,…), we perform a similar calculation. The calculation results are summarized in the table.

Based on the results obtained, a graph was constructed (Fig. 4), from which the desired values of ι_A and ι_B are determined, i.e. at [m] = [0.70 - 0.75] they will be equal to ι_A = 5.1 м, ι_B=6.25 м. Table 1 shows the results of calculating three more examples, similar to those discussed above, which differ by setting H and ι_i. Figure 4 shows their graphs accordingly.

One can consider an analytical way of calculating ι_A and ι_B. In this case, we have a formula that follows from (2) and (3)

$$\sqrt{(1+tg\varphi)^2+\frac{2F}{G\sin 2\phi}}\ \left((G+tg\varphi\ F)\gamma\ yn-2n[m](H-l\ tg\varphi)^3\left(0.1\gamma+0.001\gamma_c\right)\right)-$$

$$-\left(G\gamma(tg\beta+1)-\frac{2F\gamma}{\sin 2\phi}+F\gamma(tg\beta+tg\varphi)\right)yn=0\,, \qquad (6)$$

where $F=2ch_0+\iota^2\ tg\beta+2dh_0,\ G=H^2+2Hh_0$.

After transformations, formula (7) will take the form of an 8th order equation with even degrees, i.e. at $\iota = x$

$$Ax^8+Bx^7+Cx^6+Dx^5+Ex^4+Gx^3+Hx^2+Kx\pm L=0,$$

the roots of which can be found approximately with some accuracy. However, taking into account the cumbersomeness of this equation, which obviously requires large calculations, it seems appropriate to determine the desired ι_A and ι_B in the above numerical method.

After determining the values of ι_A and ι_B, the position of points A_i and B_i on the slope surface (see Fig. 2) is found, which determine the boundaries of the area Ω_B, the zone of optimal placement in the considered section of the subgrade.

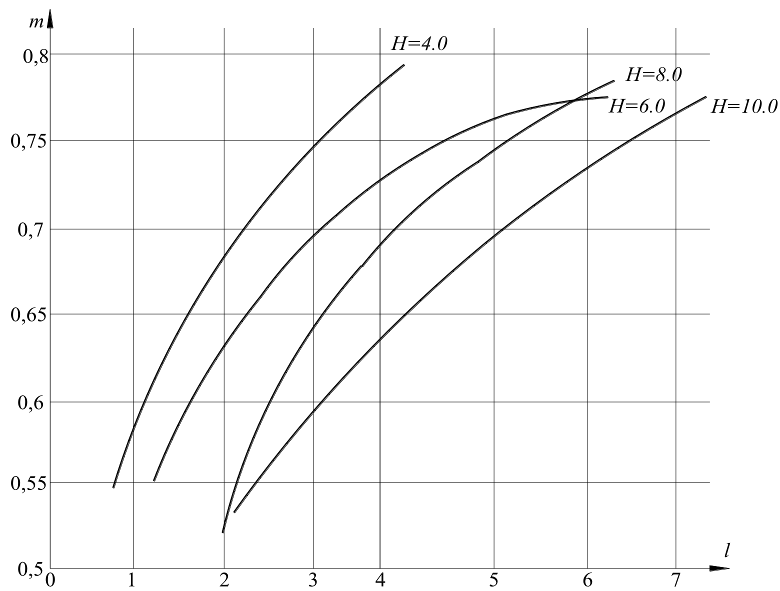

FIGURE 4. Schedule based on the results obtained, where the desired values of ι_A and ι_B are determined

For the case where the retaining wall is placed on a straight section of road of constant height, the above calculation is performed for only two sections at the ends of the section. When the road section is curved, the calculation must be made for a large number of sections, which is determined on a case-by-case basis. By connecting the corresponding points A_i and B_i in series, the boundaries of Ω_B are defined (see Fig. 4).

Thus, when forming the optimal placement zone, separate areas are first defined, which are then combined into one whole. The obtained zone of optimal arrangement represents the first approximation, which can be further refined and corrected taking into account other geometric factors. Thus, given the decrease in the fertile land diversion band, the resulting optimal placement zone can be narrowed to a certain limit (Fig. 5). The same adjustment can be made for curvature of the curvilinear zone of optimal placement, since for it there is some restriction associated with the tolerance for the amount of clearance $\Delta\tau$ between the foundation slabs of the blocks of retaining walls in the plan Therefore, if the value of the $\Delta\tau$ exceeds the maximum permissible value, then the radius r of curvature of the resulting optimal placement zone should be increased.

Conclusions

Thus, from all of the above, it can be concluded that the problem of forming the optimal placement zone is itself an optimization problem, the result of which is important as a basis for solving the problem of optimally placing retaining walls in the optimal placement zone.

At the same time, the concept of optimal placement implies such a position of retaining walls in the optimal placement zone, which provides a comprehensive account of various geometric factors. In other words, it is required to place the retaining walls in the zone of optimal placement in such a way that all elements of the retaining walls, including the top, bottom, end faces, junctions of individual sections, are located in the respective areas without going beyond them (exit of the top of the retaining walls beyond the upper region is an exception). And at the same time, the predetermined requirements for their placement would be met in the best possible way.

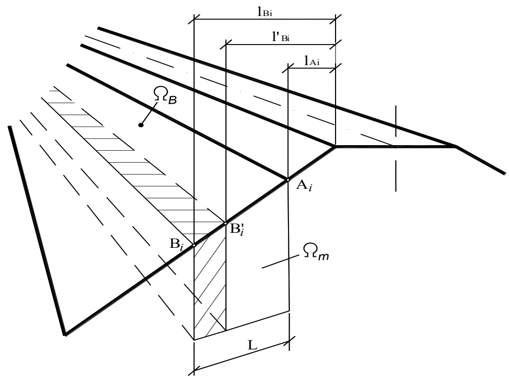

FIGURE 5. Correction of the resulting zone of optimal placement

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