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Retaining walls made of infilled blocks in civil engineering

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ABSTRACT: The article deals with a calculation method and examples of application of a rapidly erected retaining wall design. The retaining wall has an increased resistance to dynamic loads, aesthetic appeal, and relatively low cost. The retaining structure is a stepped semi-gravitational structure made of blocks filled with soil. The joint work of the blocks is ensured by the forces of dry friction due to the dense placement of the filler soil inside each block, as well as due to the formation of a compacted wall base on the slope being strengthened. The task of constructing a simulation method of retaining structures consisting of blocks having no rigid structural connection and filled with a granular body is set. The given technique can be applied to any retaining walls of a similar design solution. Examples of constructing such walls in the climatic conditions of the Russian Far East are given.

1 INTRODUCTION

The specificities of solving the problem of protecting a soil massive from collapse (the main functional purpose of retaining structures) determine the range of application for a particular constructive solution. At present there exists a wide array of constructive solutions for retaining structures, such as solid (gravity), semi-solid (semi-gravity), piling, and reinforced soil structures (Anderson, 2012, Tsimbelman, 2009), among which are beneficially standing out retaining walls comprised of separate blocks with granular infill which can be classified as semi-gravity retaining walls. The walls of this type have received rather widespread use in regions with increased seismic activity, including Japan (Civil Engineering Research Centre, Japan, 2016).

The known positive aspects of prefabricated structure technology compared to monolithic structures, such as rapid installation and dismantlement, the lack of «wet» processes during construction, superior aesthetics, structural flexibility and comparatively high dynamic load resistance, can be attributed to advantages of such structures. The use of rubble (or other drainage material) as infill allows, in the majority of cases, to omit the installation of wall-adjacent drainage. The described conceptual constructive solution of retaining walls comprised of separate blocks with soil infill can be used in industrial, civil and road construction practices (Figure 1a).

Despite the mentioned advantages, the use of retaining structures of such constructive solution in Russian construction practice (Tsimbelman, Estrin, 2009) has yet to become widespread due to historically established dominance of traditional constructive solutions as well as certain issues of theoretical nature, which the work examined in this article aims to solve.

The primary goal of this work lies in identifying the constructive specificities inherent to retaining structures of the described type which significantly affect their calculation method, suggesting a formula for determining active ground pressure on the pressure face of the

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retaining structure, as well as denoting tasks for future research of retaining walls comprised of soil-infilled blocks.

2 CALCULATION METHOD AND SPECIFICITIES

In essence, the calculation method for retaining walls comprised of separate soil-infilled blocks corresponds to the general calculation algorithm for similar structures regimented by existing Russian norms. The principal constructive specificity of the described structure lies in the fact that the levels of blocks making up the wall are not structurally tied to one another: soil-infilled blocks are held in the designated position due to the friction forces formed by the weight of the structure itself (Figure 1a).

a)

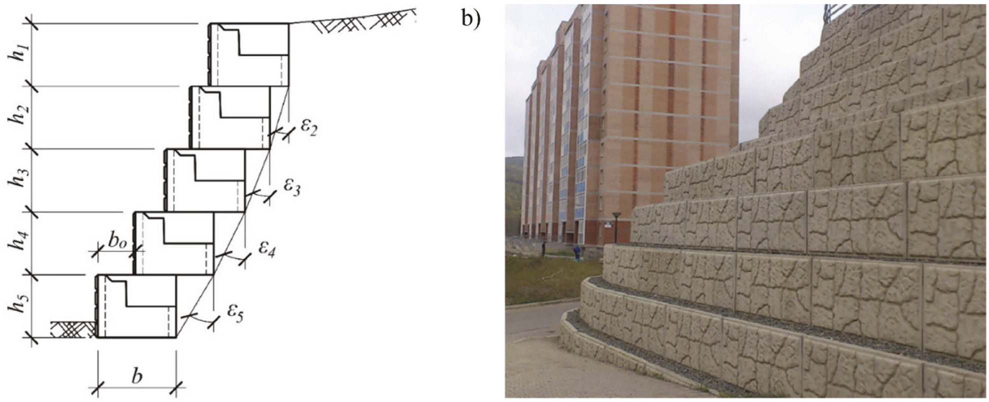

Figure 1. Retaining wall: a – infilled block layout scheme; b – retaining wall comprised of infilled blocks with height of up to 9 m (Vladivostok, Russia).

As a result, the first and foremost specificity of the calculation procedure consists of sequential (from top to bottom) determination of lateral earth pressure with simultaneous monitoring of the possibility of block-on-block displacement. During this process, the pressure face inclination angle will be changing from level to level, and the force of the overlaying block level and the earth load it receives will be transferred to the underlaying level with a cumulative total.

When determining active earth pressure on retaining walls with complex shape pressure face, generally employed methods are either approximate methods which do not consider the pressure face change with the height of the structure (Klein, 1964, Snitko, 1963) or the method of enumerating possible slide angles of the soil collapse prism (Civil Engineering Research Centre, Japan, 2016). Employing methods based on considerable tolerances does not consistently provide results with the required level of accuracy while the consequent enumeration method is exceedingly difficult to implement without the use of specialized computer software due to the bulkiness of the method.

The prerequisites to the method of determining earth pressure on retaining walls of the described design generally match classic solutions for which the balance of forces applied to the prism of soil collapse arising behind the pressure face of the wall is considered. The sliding prism is at an equilibrium by the forces of its own weight, the reaction of the retaining wall and the reaction of the rest of the granular body (Klein, 1964, Snitko, 1963, Brooks, 2018, Braja M. Das, 2007). Next, by expressing the reaction of the retaining wall from the equation and differentiating this expression by the soil collapse angle, a condition is found where earth pressure takes the maximum value. At the same time, determination of active earth pressure on each level of the wall must include taking into account the shape of the pressure face of the overlaying wall level, since ignoring this parameter can lead to significant discrepancies in calculations.

In the case of flat backfill surface under evenly distributed load and «polygonal» surface of the pressure face of the retaining wall, the value of active earth pressure E_a (kN/m) should be calculated using the formula proposed by the author (1).

$$Ea_i=\frac{\gamma}{2}\left(\sum_{j=1}^{i-1}\frac{h_j}{\cos(\varepsilon_j)}\frac{\cos(\varepsilon_j+\rho)}{\cos(\varepsilon_i+\rho)}+\frac{h_i}{\cos(\varepsilon_i)}\right)^2\frac{1}{\cos(\varepsilon_i-\varphi_s)}\lambda_i^2\left(1+\frac{2p\cos\rho}{\gamma\left(\sum_{j=1}^{i}\frac{h_j}{\cos(\varepsilon_j)}\cos(\varepsilon_j+\rho)\right)}\right)-\sum_{j=1}^{i-1}\frac{Ea_j\cos(\varepsilon_j-\varphi_s)}{\cos(\varepsilon_i-\varphi_s)} \quad (1)$$

where γ = specific gravity of soil (kN/m^3); ε = pressure face inclination angle (°); ρ = backfill surface inclination angle (°); φ_s = angle of internal soil friction on pressure face (°); h = retaining block height (m); λ_i = lateral earth pressure coefficient; p = load on original ground surface (kN/m^2); φ = internal soil friction angle (°); E_a = active earth pressure value (kN/m); i = number of the block for which active pressure is being calculated; j = sequence number of the block.

The lateral earth pressure coefficient in this case is calculated using the formula (2).

$$\lambda_i=\frac{\cos(\varepsilon_i+\rho)\cos(\varepsilon_i+\varphi-\alpha_i)}{\cos(\varepsilon_i+\rho-\alpha_i)\left(1+\sqrt{\frac{\sin(\varphi+\varphi_s-\alpha_i)\sin(\varphi-\rho)}{\cos(\varepsilon_i-\varphi_s)\cos(\varepsilon_i+\rho-\alpha_i)}}\right)} \quad (2)$$

where α_i = angle providing the transition from factual prism of collapse (with polygonal base) to arbitrary (with triangular base) (°).

This problem is directly connected to the question of determining the self-weight of the wall, since the volume of soil involved in the work of the wall (block infill and wall-adjacent prisms – Figure 1a) is separated from external surrounding soil by an arbitrary pressure face, for which active earth pressure is calculated and which is polygonal since for each row of blocks it has its own angle of deviation.

As an example, a retaining structure simple in configuration and small in height will be considered with height h = 3 m and flat horizontal infill surface (ρ = 0) upon which a load with an intensity of p = 10 kN/m^2 is evenly distributed. Specific gravity of soil γ = 19 kN/m^3, internal soil friction angle φ = 30°, angle of internal soil friction on pressure face φ_s = 20°, pressure face inclination angle of the first two blocks $\varepsilon_{1,2}$ = 11.31°, pressure face inclination angle of the third block ε_3 = 21.8° (Figure 2).

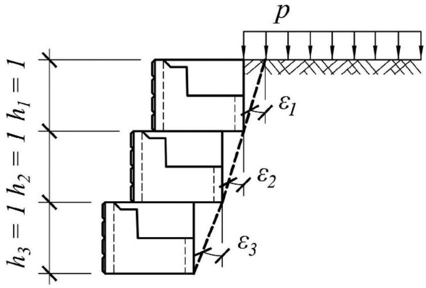

Figure 2. Retaining wall calculation scheme.

The calculation results using the formulae (1) and (2) are as follows: value of active earth pressure on the first block of the retaining structure E_{a1} = 4.36 kN/m; value of active earth pressure on the second block of the retaining structure E_{a2} = 8.62 kN/m; value of active earth pressure on the third block of the retaining structure E_{a3} = 9.32 kN/m.

A comparison of the received results and the solution obtained via the in-progress enumeration method (Civil Engineering Research Centre, Japan, 2016) proves the validity of the derived analytical expression for calculating active earth pressure value on each of the blocks of the retaining structure. The discrepancy between the received results and the results described in (Civil Engineering Research Centre, Japan, 2016) amounts to less than 1%, which allows the use of the proposed formulae in calculating tall retaining structures of more complex configuration when the enumeration method calculation becomes irrational.

Due to the cyclicity of the procedure of determining earth pressure on the wall and the accompanying calculations it would be reasonable to form a software package allowing to automate the procedure of by-level load gathering and sequential calculations via a certain algorithm. The software must offer the selection of optimal form of the cross section of the retaining wall (number of rows, wall inclination, the presence and magnitude of recesses from row to row) depending on calculation conditions. The calculation procedure is implemented for a limited set of initial conditions in a pilot computer program (Kotik et al., 2019) for which interfacing modules are currently being developed.

3 APPLICATION PRACTICE

During the 2010-2022 period twenty-five retaining facilities implementing the described structure have been erected in the Russian Far East with the total area of 40 000 m^2 in six cities of federal and district significance, as well as a range of minor structures in the landscaping sector. The largest retaining structure built to date in Russia within city limits and comprised of infilled blocks using the proposed technology is situated in Vladivostok (Figure 1b).

The retaining wall was erected in December of the year 2010 with a maximum height of 9 m and a total area of 7668 m^2. During the more than nine-year lifetime the structure has not generated any criticism from maintenance services and supervising entities, no maintenance work on the structure is required. High operational reliability and aesthetic appeal of the structure, including greening potential and great integration into the surrounding landscape, allow the facilities of described structure to be used in low-rise and private real estate areas (Figures 3).

4 RESEARCH OBJECTIVES

Numerical modeling of retaining walls of similar constructive solutions was previously done predominantly in the plane formulation (Civil Engineering Research Centre, Japan, 2014). Taking into consideration the contemporary recommendations to calculation modeling of structures (cl. 6.1.9 SP 381.1325800.2018, cl. 5.1.10 SP 22.13330.2016, cl. 8.1.7 SP 248.1325800.2016), the task of creating a method of numerical modeling of retaining walls comprised of soil-infilled blocks in the spatial formulation with experimental verification according to the results of natural and semi-natural testing, or small-scale model testing in a laboratory environment on condition of following the provisions of similarity theory, is established. At the same time, special attention must be paid to the relevant question of delineating the conditions of medium interaction on the contact surface between the infill (representing a fundamental constructive material of the structure) and the block walls. This problem can be solved following the example of thin-walled soil-

Figure 3. Retaining structures comprised of infilled blocks with greening (Vladivostok, Russia).

infilled shell research (Bekker et al., 2015) since the hollow box represents a shell holding the infill (compacted rubble) in its designated position.

A justified numerical model will allow, first of all, to solve the problem of assessing the stress-strain state of the components of a retaining structure comprised of blocks with granular infill, and second, to create the algorithm of selecting the optimal form of the diameter (and form a set of standard solutions) depending on the purpose of the structure (technological and other loads) as well as the properties of infill, backfill and foundation soils.

5 CONCLUSIONS

The retaining structure comprised of separate thin-walled blocks with soil infill represents a promising constructive solution for civil, industrial and road construction purposes. The structure possesses an array of significant advantages which allow to shorten the construction period, avoid labor-intensive technological operations during installation, and, as a result, provide economic efficiency of the structure. It should be individually noted that the structure is well predisposed to withstanding dynamic loads (transportation vibration, impacts, seismic influences).

Despite the affirmative usage experience of erected retaining structures comprised of soil-infilled blocks (during the period from the year 2000 and onwards approximately 10 000 meters of retaining structures of this type have been erected in the Russian Far East), the scope of application is restricted by the difficulties of calculational and theoretical justification.

This article proposes a calculation formula for determining the value of active earth pressure on a retaining structure possessing a complex pressure face shape in the form of a polyline. Preliminary results of calculating active earth pressure on each of the blocks of the retaining structure have shown high convergence with results received via the enumeration method (the discrepancy value amounts to approximately 1%). Thus, the formulae suggested in this work can be used in determining active pressure on comparatively tall retaining walls with complex outline of the pressure face when employing approximate methods and methods based on value enumeration proves irrational due to their increased laboriousness.

Among the primary questions the need for forming an algorithm and an adaptation of the calculation method for Russian criteria is denoted. The research task of creating a method of numerical modeling of structures comprised of soil-infilled blocks in the spatial formulation is also established. Research must include calibration and verification of numerical models based on experimental data. The task of developing automatization means for the cyclical calculation procedure typical for this type of structure, as well as the task of forming an algorithm of selecting the optimal form of the cross section of the structure, are also established.

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