Designing new sustainable anti-landslide systems under constrained city conditions

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Abstract. This article discusses the development of technical solutions for anti-erosion and landslide impact designs in the design and construction of buildings and structures in cramped urban conditions. They are created from composite nanomaterials. Many foreign and domestic scientists are engaged in such structures from soil-reinforced and soil-filled elements. We also examined the methods of calculating their justification and the results of experimental studies.

1. Measures to eliminate landslide phenomena

Currently, a number of environmental and social problems arise during construction in cramped urban conditions associated with natural and technological impacts, including erosion-landslide phenomena. To address this issue, the authors propose technical solutions and measures to preserve the sustainable development of urban construction. Table 1 below presents measures for the elimination of erosion-landslide phenomena in urban development [1-3].

| Types of changes     | The causes of the formation of erosion-landslide phenomena | Suggested activities and solutions                  |
|----------------------|-----------------------------------------------------------|---------------------------------------------------|
| Natural              | Change in stress state of the soil                        | Creation of underground structures at the base, loading at the site of the expected bulging of earth masses, horizontal and vertical drainage; inclined slot, microplaning, trays, tracks, etc. |
|                      | Ground and surface water, weathering                      | Mechanical resistance to movement of earth masses: soil reinforced, soil filled, gabion retaining walls, pile rows, dowels |
|                      | The combination of a number of active reasons             | Special regime in the erosion-landslide zone: fencing of construction works, operation mode |
| Man-made             | Human activity                                            |                                                   |

Table 1. Measures to eliminate erosion-landslide phenomena
2. Technical solutions of shell structures made of composite nanomaterials

The Department of PSGiF developed technical solutions using soil-reinforced and soil-filled shell structures made of composite nanomaterials, which can be created in cramped conditions by new methods of their construction and an application for inventions has been filed to eliminate such natural and technogenic phenomena (Figure 1).

Figure 1. Technical solutions of retaining structures. 1 – soil massif; 2 – gabion element; 3 – arm tape; 4 – placeholder; 5 – drainage; 6 – moving soil massif; 7 – geotextile; 8 – fender; 9 – the front shell; 10 – internal soil-filled shell; 11 – perforation for removal of the filtration stream; 12 – front wall; 13 – front element; 14 – rectilinear arm tape; 15 – inclined arm tape; 16 – soil-filled shell

2.1. Calculation justifications

When designing retaining structures from soil-reinforced elements (Figure 1), the maximum horizontal force $T$, which keeps the slope in equilibrium for given soil characteristics (approximately for a triangular distribution of soil pressure), should be determined by the following relationship:

$$ T = \frac{1}{2} \cdot K_a \cdot \gamma \cdot H^2, $$
where $K_a = t g^2 \left( \frac{\pi}{4} - \frac{\varphi}{2} \right)$ is the coefficient of active soil pressure;

$\gamma$ is the specific gravity of soil, kN/m³; $H$ is the height of reinforced layer, m; $\varphi$ is the angle of internal friction of the embankment.

When using straight and inclined arm tape, the calculation of the forces in them can be carried out according to the following relationship:

$$T_0 = T_1 + T_2 = \int_0^{l_1} 2 \cdot b_1 \cdot m_1 \cdot f_1 \cdot \gamma \cdot h \cdot dl_1 + \int_0^{l_2} 2 \cdot b_2 \cdot m_2 \cdot f_2 \cdot \gamma \cdot h \cdot dl_2$$

where $T_0$ is the total tensile force in all layers of reinforcement corresponding to the collapse surface, kN/m; $T_1, T_2$ is the tensile forces in rectilinear and obliquely located arm tape, kN/m; $b_1, b_2$ is the width of a straight and inclined arm tape, m; $m_1, m_2$ is the number of reinforcement strips per 1 m soil reinforced wall; $H$ is the height of the considered layer of soil over armor tape; $f_1, f_2$ is the rebar coefficient of soil, where $f = t g(\varphi)$ ($\varphi$ of the soil internal friction); $l_1, l_2$ is the straight and inclined arm tape length, m; $\gamma$ is the bulk density of the embankment t/m³; $k$ is the coefficient taking into account the slope of the arm tape.

Based on Experimental studies of soil-reinforced structures, taking into account patent No.2444589, were conducted under the supervision of the doctor of technical science Kasharina T.P. by graduate students Prikhodko A.P. and Kundupyan K.S. in a flat deformation tray made of organic glass with a working space of 0.8 * 0.1 * 0.6 m, while dry sand was used as a backfill and ground-reinforced foundation [5-11].

The sizes of the front wall (150, 100, 50 mm) and the front element (50, 30, 10 mm), the length of reinforcing tapes $l = 0.7H$, where $H$ is the total height of the moving wall, were changed.

Figure 2. The diagram of fixed deflections of horizontal and inclined reinforcing tapes, obtained using the method of photometry

Figure 2 clearly shows that inclined reinforcing tapes experience the greatest deformation and they appear at 2/3 H. This allows the most efficient use and adjustment of the parameters of the ground-reinforced mass.

The ground-filled elements with sorbents, purifying groundwater and surface water, are used as drain anchors. They are calculated according to the empirical dependencies with a load of up to 120 kPa. The deformation of the ground-filled shell was $\varepsilon = 0.3$ mm, and its tension is determined by the dependencies [12-18]:

\[ e = \frac{3}{4} \left( \frac{K}{H} - 1 \right) \]
\[ T = (h + y)(1-a) + (1-am)y^2 \] + 
\[ + (1-am)\left( hy + \frac{y^2}{2} \right) \], \quad (3) \]

where: \( T \) is the tension force in the shell,
\[ T = \frac{T_0}{\gamma_0}, \text{kN/m}. \]

The equation describing the shape of the shell is the elastic equation of the second kind:
\[ y = \left( 1 - \sqrt{1 - \frac{\sin^2 \varnothing}{k^2}} \right) h, \quad (4) \]

where: \( \varnothing \) is the angle of internal friction of the backfill soil, degrees; \( k \) is the modulus of elliptic integrals.

The first and second derivatives of equation (3) take the following form:
\[ y' = \frac{h \sin \varnothing \cos \varnothing}{k^2 \sqrt{1 - \frac{\sin^2 \varnothing}{k^2}}} \]
\[ y'' = \frac{h (k^2 \cos 2\varnothing + \sin^2 \varnothing)}{k^4 \sqrt{1 - \frac{\sin^2 \varnothing}{k^2}}} \]. \quad (5) \]

On the basis of the obtained dependencies, a program was compiled for calculating a closed ground-filled shell under load [1].

3. Conclusion

The study results are currently used in the design of the retaining structures to protect the urban area. The above calculation justifications are necessary to create simulation models.

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