Activities and technical solutions for ecological management of the city Vladikavkaz

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Abstract. The article is devoted to the activities ensuring city of Vladikavkaz ecohumanisation by engineering protection and development of recreational areas. The analysis of natural and climatic conditions and social aspects of the city development. Technical solutions and their justification on the example of the right-bank territory of Vladikavkaz, as well as the development of Park areas are proposed.

1. Introduction

The development of the city of Vladikavkaz in the Republic of North Ossetia (Alania) is an example of a rapid and successful transition from the status of a fortress to the status of a Capital. Vladikavkaz was built on the site of a swamped territory of the Terek river catchment area and transformed into a historical center, which became the cultural heritage of the Republic. It has an important political, social and industrial purpose. The intensive development of modern buildings makes significant changes in the appearance of the city and makes it necessary to control the processes associated with changes in the urban situation, prevention of degradation of the natural landscape and distortion of the pristine appearance of historical and cultural monuments within the boundaries of the historical center of Vladikavkaz [1]. Since the history of each individual landscape is unique, the dynamics of its development require planning to change it. Successful planning requires analysis of both rapid changes and gradual evolution, which contributes to a better description, prediction and appointment of activities in landscape planning [2].

Landscape transformation is one of the conceptual elements of ecohumanistic strategy in modern city [3]. Vladikavkaz has already passed the technogenic stage of development and now it is necessary to pay attention to environmental safety and humanizing development of recreational areas, not forgetting the engineering protection of the landscape. Vladikavkaz according to modern research is one of the largest cities with accumulated seismic activity [4]. Therefore, when designing recreational areas, it is especially important to give preference to earthquake-resistant structures of shore protection construction. According to the zoning plans of the city of Vladikavkaz (industrial, residential and recreational areas (fig. 1)) the most problematic is the landscape of the residential zone from the right bank of the Terek river, as well as the currently empty landslide site from the left bank, which has a significant slope. These areas are subject to erosion and landslide processes, which leads to negative environmental and humanizing consequences [5]. It requires planning of landscaping in two stages. At the first stage, it is important to implement measures for engineering protection of the river bank, ensuring the least impact on the historical landscape and ecology of the territory. The use of new soil-
reinforced structures of shore protection structures, including those built on weak biogenic soils, allow to restore and improve the landscape, creating conditions for its further transformation and use. The second stage includes eco-humanizing measures for the improvement of the territory by expanding the park areas, which gives a lot of information and recreational areas, combined with the device of shore protection structures (fig. 1).

**Figure 1.** Map of Vladikavkaz with the designation of the territory for planning a recreational zone: a) the planned area of reconstruction; b) the increased fragment of the territory recommended for planning of a recreational zone; c) 1 – erosion and landslide site, a zone of reconstruction of a landslide site

2. **Measures for engineering protection of residential area of Vladikavkaz from erosion and landslide processes on the right Bank of the Terek river**

2.1. **Prospects of application of new technical solutions**

One of the priority measures is to carry out works on building of shore protection construction that ensure the stability of the coastal zone together with the national economic objects located on its territory. Also, during these activities, the preservation and expansion of existing beaches, parks and other recreational areas is ensured. Existing rigid structures of shore protection structures do not provide sufficient reliability and their destruction occurs when the base subsidence [6]. In the absence of high-quality local building material and subsidence soils, the most effective is the use of soil-reinforced structures.

Theoretical and experimental studies conducted by foreign and domestic scientists: Schlosser, Long, Hausman, Mogilkov, Hristo, L. N. Timofeeva, G. M. Kaganov, I. M. EVDOKIMova, etc., show the prospects and feasibility of soil reinforcement with the use of local building materials [6-8]. To justify the use of structures of soil-reinforced structures, we consider the design provisions for their stability.

The deformation of the reinforcement equal to the lateral deformation of the soil is determined by the following relationship [5, 9]:

$$\varepsilon_a = \Delta_a = \frac{\sigma_0 A_{tp}}{E_a A_a},$$

(1)

where $E_a$ – is the modulus of elasticity of the reinforcement material, MPa.

The tensile stress in reinforcing strip, in accordance with the theory of Rankine, at depth $z$ can be represented as follows (Fig. 2):

$$F_{a,z} = K_s \gamma z S_y S_z.$$

(2)

That is, the maximum tensile force perceived by the lower reinforcing layer, according to formula 2, is defined as:

$$F_{a,\text{max}} = K_s \gamma HS_y S_z.$$

(3)

The safety factor of the reinforcing strip at break is determined taking into account the formula (3) and is equal to:

$$K_s^N = R_p b_a \delta / K_s \gamma HS_y S_z.$$

(4)
We accept coefficients that take into account the reinforcement area, as well as the decrease in the strength of the reinforcing material during the operation of $Kc$ for composite polymer materials. Then formula 9, taking into account formula 5, is reduced to the form:

$$K_S^N = \mu R_p K_c / K_a \gamma H = \mu R_p K_c / \left( \tan \left( \frac{\pi}{4} - \frac{\theta}{2} \right) \right) \gamma H. \quad (5)$$

The friction force holding the reinforcement in the soil mass is determined by the Rekin’s formula:

$$F_f = 2 f \gamma b_a \cdot l_a,$$

where $f$ – the coefficient of friction between the ground and the material reinforcing strip in the area of the compacted backfill; – the length of reinforcing strip taken not less than 1,5 m.

The factor of safety of the reinforcing strip on pulling out, according to formulas 2 and 6, is defined on the following dependence:

$$K_S^C = F_f / F_{a,c} = 2 f b_a l_a / K_a A_{rp}. \quad (7)$$

Primed and reinforced structures from polymer composite materials include four main structural elements: coffers the front surface (front wall) with the use of rubber-córdoba, geotextile and other materials; anchor elements of the same material, including fued of soil shell; reinforcing strip of composite materials (straight, double, oblique); soil, interacting with the anchoring devices, flexible connections, anchoring and drainage systems. The proposed new technical solutions of soil-reinforced structures provide the lowest weight of the structure due to the use of a flexible front wall of geosynthetic material (fig. 2 a, b) [10-12]. When calculating the strength and stability of these structures, two types of limit state are considered: internal strength and overall stability of the entire structure.

![Figure 2.](image)

Figure 2. Engineering solutions of ground-reinforced shore protection structures: a – method of creating a ground reinforced supporting structure and a device for its implementation (Pat. RF 2352713): 1 – front wall; 2 – bulk soil; 3 – flexible connections; 4 tape shells; 5 – corrugated and flat armor; 6 – drain shell; 7 – special holes; 8 – drainage system; 9 – anker blocks; b – ground-reinforced shore protection structure on the foothill section of the river Gizeldon; c – Engineering solutions of ground-reinforced shore protection structure with a front wall made from a multi-layer composite material: 1 – a front wall; 2 face elements made from composite materials resistant to wearing; 3, 4 – horizontal and vertical sections of the front elements 2; 5, 6 – inclined lower and upper reinforced tapes respectively; 7 – ground massif (for example, technogenic soil); 8, 9 – ground-filled multi-shell lower and upper anchors; 10 – drainage; 11 – textile material with seeds

The latter is determined taking into account the total tensile force in the valve at the design level, determined by the following formula [6, 8]:

$$N_0 = N_1 + N_2 = \int_{l_1} 2b_1 \cdot m_1 \cdot f_1 \cdot \gamma \cdot z \cdot dl + \int_{l_2} 2b_2 \cdot m_2 \cdot f_2 \cdot \gamma \cdot z \cdot dl =$$

$$= 2 \gamma \cdot h \cdot (bm_1 \cdot f_1 \cdot l_{a1} + bm_2 \cdot f_2 \cdot l_{a2}), \quad (8)$$

Where $N_0$ is the total tensile force in all layers of reinforcement, corresponding to the surface of collapse, kN/m; $N_1$, $N_2$ – the tensile stress in reinforcing strip with a different tilt kN/m; $b_1$, $b_2$ – width straight and sloping reinforcing strip with a different tilt, m; $m_1$ and $m_2$ – are the coefficients of
the slope of reinforcing strip $z$ – height of the considered layer of soil over reinforcing strip, m; $f_1$, $f_2$ – a coefficient of friction of the soil on the valves; $l_{z1}$, $l_{z2}$ - the length of armament, m; $\gamma$ – weight of unit volume of the mound, kN/m$^3$.

To assess the overall stability of reinforced soil, we will use one of the most common methods, which is based on the round-cylindrical method.

To assess the overall stability the safety factor is determined as the ratio of the moments of resistance forces and shear moments:

$$K_{san} = \frac{M_R}{M_F}.$$  \hspace{1cm} (9)

For structures made of reinforced soil, the moment of resistance is determined by the following formula (Fig. 4) [4, 5]:

$$M_R = \sum_{i=1}^{k} F_{T,i} \cdot r + \sum_{i=1}^{k} F_{C,i} \cdot r = \sum_{j=1}^{n} \left( F_{a,j} \cdot \cos \beta_j + F_{a,j} \cdot \sin \beta_j \cdot \tan \varphi_j \right) \cdot r_{1j} ,$$  \hspace{1cm} (10)

where $F_{T,i}$, $F_{C,i}$ – respectively, the conditional forces of friction and resistance in the I-section compartment is directed along the tangent to the slip surface, kH; $F_{a,j}$ – is the resistance of the reinforcing element defined equal to the calculated stress of reinforcement at break kH; $R_{a,j}$ - the strength of the j-reinforcement layer in the gap; $r$ – the radius of the curve slip, m; $\beta_j$ – angle between the radius of the curve of the slide and the vertical; $\varphi_j$ – the angle of internal friction of the i-section; $r_{1j}$ - the distance from the center of moments; $r_{1j} = d_j / \cos \beta_j$ ; $d_j$ - the shoulder lines of action $F_{a,j}$ about the center of moments (fig. 4).

The moment of shear forces will be equal to:

$$M_F = r \sum_{i=1}^{k} G_i \sin \beta_i ,$$  \hspace{1cm} (11)

where $G_i$ -the weight of the i-section into which the potentially unstable array is divided; $\alpha_i$ - the angle of inclination of the sliding platform within the i-section.

The assurance factor can be represented taking into account the dependencies (14-16) in the following form:

$$K_{san} = r \sum_{i=1}^{k} \left( \sigma_n \cdot \tan \varphi_i + c_i \right) \frac{l_i \cdot S_y}{\cos \alpha_i} + R_a \cdot \alpha_i \cdot \sum_{j=1}^{n} d_j \left( 1 + \tan \beta_j \cdot \tan \alpha_j \right) \frac{1}{r} \sum_{i=1}^{k} G_i \sin \beta_i ,$$  \hspace{1cm} (12)

where $\sigma_n$ – is the effective normal stress at the elementary shear site, which can be defined as; $\sigma_n = G_i \cdot \cos \alpha_i / l_i$ ; $c_i$ – the specific clutch of the i-section [4].

The value of the calculated value of the allowable tensile stress for the layer $\sigma_d$ appointed by the results of special tests to assess the long-term strength. For the preliminary calculations, the value of $\sigma_d$ allowed to take a proportion of short-term strength of reinforcing strip under uniaxial tension $R_a$ : for woven materials, rigid meshes of polyamide, polyester raw materials $\sigma_a = 0.6 R_a / \delta$ , polypropylene raw materials $\sigma_a = 0.3 R_a / \delta$ – non-heat-treated or heat-treated needle-punched reinforcing strip of polyamide, polyester raw materials сырья $\sigma_a = 0.25 R_a / \delta$ , polypropylene $\sigma_a = 0.1 R_a / \delta$ .

Selection of the number of layers of reinforcement is performed according to the formula:

$$n = 0.53 K_{san, np} \sum G_i \left( \cos \alpha_i - \sqrt{\cos^2 \alpha_i + 4 \sin^2 \alpha_i} \right) - \sum \sigma_{pi} l_j S_y / \sigma_A,$$  \hspace{1cm} (13)

где – требуемый коэффициент запаса устойчивости откоса.
In the case of preliminary tests of the reinforcing strip material, its length is determined by the following formula:

\[ l_{ij} = 0.5R_i \sum \rho_i \cdot h_i \cdot \tan \varphi' + c', \]  

where \( \rho_i, h_i \) – the density and thickness of the soil layers located above the top of the layers.

It was found that in the range of the smallest reinforcing strip length for sand minimum is 3 m, sand and clay – 3.5 m, and for loess and loam soils – the maximum length of not more than 4.2 m [9-12].

The safety factor of the formulas must be greater than or equal to the stability factor:

\[ K_{\text{san}} \geq \gamma_n \gamma_{kc} / \gamma_c, \]  

where, \( \gamma_n, \gamma_{kc} \) – respectively, the reliability coefficients of the responsibility of the structure and the combination of loads; \( \gamma_c \) – coefficient of working conditions.

The calculated values of the stability coefficient with the appropriate combination of loads should not exceed the value of \( \gamma_n \gamma_{kc} / \gamma_c \) more than 10 %, unless this is due to the characteristics of the structure.

Since the considered structures belong to class IV, take the coefficients of resistance to SP 58.13330.2012: \( \gamma_n = 1.10 \); \( \gamma_{kc} = 1.0 \); \( \gamma_c = 0.95 \). Then \( \gamma_n \gamma_{kc} / \gamma_c = 1.16 \) and the condition of the General stability of slopes of a ground construction will have the following form:

\[ 1.28 \geq K_{\text{san}} \geq 1.16. \]

However, for greater reliability (according to the results of research by prof. Kaganov G. M.), the condition of stability of the soil-reinforced slope is proposed based on the following condition [6]:

\[ K_{\text{san}} \geq 2.25. \]  

The calculation of the front wall of the shore protection structure is performed in accordance with the theory of instantaneous soft shells, taking into account the deformation of the material.

To determine the parameters soil-reinforce structures developed algorithm to create the program of calculation of parameters for soil-reinforce coast protection works on a computer, which can be used to ensure reliable operation of bank protection structures in the considered residential area [12].

The use of these structures, which have a minimal negative impact on the surrounding landscape and the ecological state of the environment, contributes to the implementation of the first stage of landscaping of the coastline of the Terek river, passing through the Central part of the residential zone of Vladikavkaz.

3. Humanizing measures for the improvement of the city

Due to technical measures (strengthening of the river banks) we have partially solved the problem of environmental impact. After that, we proceed to the second stage of planning – humanizing protection measures. In the process of urbanization and socio-economic development of society, along with the solution of environmental and functional problems, there were prerequisites for solving the problem of preserving cultural heritage and traditions [13-16]. A solution to the above task involves planning along the fortified banks of the river recreational areas, contributing to: 1) expand the use of bank protection structures; 2) the problem of inaccessibility of the territories; 3) humane impact these structures have on the person; 4) the restoration and preservation of the cultural heritage of the region.

When planning recreational areas, it is important to take into account both the seismic characteristics of the terrain and the features of the Terek river, which has heavy alluvial regimes that bring significant changes to the landscape during floods. Due to alluvial regimes, new sleeves are formed spontaneously and chaotically, which adversely affects the landscape and urban infrastructure [17-19]. To stabilize the negative impact on the landscape and create favorable environmental structures, it is proposed to use the properties of regulatory constructions (spurs) [20] and shore protection constructions, which delay
sediments of solid runoff and eventually form new landscape forms created by nature and controlled by man.

In these geographical conditions, it is appropriate to design Park recreational areas with a developed network of terraces, pedestrian bridges and recreation areas with different design schemes. Analogous to the creation of parkland on wetlands can serve as Park Yanweizhou in Jinhua city, Zhejiang province of China [14]. The Park is located at the mouth of three rivers in a swampy area, which was a prerequisite for the design of flooded bridges for pedestrians, which during the flood are closed for walking.

The creation of recreational areas with the additional use of local plants and the inclusion of regional artifacts in the landscape contributes to the protection and preservation of the ecosystem, as well as the preservation and development of architectural and cultural traditions of the region [17].

It is also necessary to use unfavorable areas of the left bank of the Terek river, including a long dangerous landslide along the sleeve, as a recreational zone, provided that retaining walls are created, on the terraces of which sections of different-level Park zones and a network of pedestrian and Bicycle paths can be organized. Modern designers do not note the aesthetics of concrete as a building material for the facial finishing of building structures and to improve the stability of the infrastructure, they offer technologies based on biological methods, combining the use of concrete and biomaterial for shifting surfaces [21]. An alternative to bicycle paths near the shore can serve as plants located on shore protection structures and retaining walls, strengthening the soil cover and creating an aesthetic landscape.

To achieve sustainable development of Vladikavkaz it is necessary to ensure the interaction of the entire spectrum of factors: recreational architecture, planning organization, economic, environmental, humanization and cultural indicators, supported by the support of government agencies and the population [22].

4. Conclusion

The vector of ecohumanistic approach in the development of the city is aimed at achieving sustainability of the city. Considered in our study, a separate indicator strategy ecohumanistic [18]– eco-friendly construction technologies, materials and activities in landscape planning, we have combined and established synergies between the technical and humanities areas. It helps to closer horizons for achieving the global objectives of sustainable urban development, recognized at the international summit of the UN in 2016 a guide for all mankind. Using new design of soil and reinforcing bank protection structures on low nutrient soils, the algorithm and the methodology of calculations for determining their parameters, while expanding the functionality of facilities and humane influence of structures on people, we reduce the negative impact on the landscape and contribute to its sustainable development taking into account the positive evolutionary patterns and ecological safety.

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