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GABION RETAINING WALLS: FEATURES OF CALCULATION AND DESIGN

ГАБІОННІ ПІДПІРНІ СТІНИ: ОСОБЛИВОСТІ РОЗРАХУНКУ ТА ПРОЕКТУВАННЯ

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The results of the master's research on calculation and construction of the gabion retaining wall are given. The results of the influence of various factors on its stability are analyzed

Наведено результати магістерського дослідження з розрахунку та конструювання габіонної підпірної стіни. Проаналізовано результати впливу різних факторів на її стійкість.

На початку дослідження було обрано тип і форму конструкції підпірної стінки, згідно з прив'язкою до місцевих умов, до конструкції підсилюваного насипу, призначено основні розміри. При розрахунку габіонної підпірної стіни враховували її зовнішню і внутрішню стійкість. Зовнішню стійкість стіни оцінювали на опір зсуву, перекидання і втрату несучої здатності основи. Внутрішню стійкість перевіряли шляхом розрахунку міцності в найбільш небезпечних перерізах (у місцях з'єднання габіонів між собою).

У роботі було виконано вісім віріантів розрахунків, перший – із заданими вихідними даними, решта – зі зміною певних параметрів, таких як кут нахилу стіни, пористість габіонів, висота та ширина габіонів, зміщення габіонних ящиків один відносно одного, наявність чи відсутність геотекстилю в основі конструкції.

Аналіз впливу змінюваних параметрів на стійкість конструкції габіонної підпірної стіни показав, що при збільшенні кута нахилу стіни до 6° (2-й варіант розрахунку) стійкість підпірної стіни проти ковзання і перекидання збільшувалась на 9,25% і 6%, відповідно. При збільшенні пористості габіонів з 30 до 40%, зменшенні ширини основи до 4 м і збільшенні висоти стіни на один ряд габіонів (до 8 м), а також при вкладанні геотекстилю в основу стійкість стіни знижувалась на 12,2% - 50,2% (варіанти розрахунків 3-6). При збільшенні величини зміщення габіонів кожного ряду з 0,5 м до 0,6 м стійкість стіни проти ковзання зростала на 29,7%, а проти перекидання – на 18,4%; додаткове збільшення кута нахилу стіни при цьому на 1° підвищувало ці показники до 44% і 28,4%, відповідно.

Keywords: gabions, retaining wall, calculation, stability
Ключові слова: габіони, підпірна стіна, розрахунок, стійкість

Formulation of the problem. Experienced architects and builders know how to turn the weak spots of the site with slopes in interesting and profitable decisions in various aspects, so most often in such situations the retaining walls are used to strengthen the slopes. Unlike concrete and reinforced concrete, such constructions from gabions are are advantageously distinguished by the simplicity and speed of installation, under any weather conditions, at any time of the year, sometimes with the use of a minimum of machines and special equipment, often involving both skilled and unskilled labor. The gabion retaining walls are the best in terms of complexity and cost of construction. Therefore, modeling of the correct approach to the design and calculation of gabion retaining walls, observance of technology of their arrangement and maintenance, understanding of possibilities of solution of ecological urban planning problems, which can be avoided, using gabion structures- is relevant.

Analysis of known researches and publications. Gabions are divided into different categories, depending on the material of manufacture, structural features, type of mesh, functional purpose and other aspects. Consequently, each of the gabions has its own specific name, form and purpose. According to structural features, the gabins are divided into: basket, mattress, cylindrical. Baskets gabions or "Jumbo" are the most common, the main areas of their use are construction of retaining walls; strengthening of roads and railways; strengthening of slopes and dams, banks, protection against erosion and landslides; construction of fences, foundations, terraces, parapets; manufacturing of decorative elements in landscape design.

Gabion structures have gained considerable popularity due to their advantages. They are strong and durable, flexible and permeable, attractive and economical [1]. But perhaps the most important advantage is their environmental friendliness. Among a number of ecological problems of our time one of the most influential and least controlled is the problem of carbon dioxide emissions [2]. Our future, the future of the planet and humanity in general depends on their control. Compared to, for example, a concrete retaining wall, a gabion wall of the same height will reduce these emissions by 80%. In addition, they can be reduced by absorption by vegetation that appears over time on gabion structures.

These structures do not require powerful foundations - due to the elasticity of the mesh, the structure tolerates small shifts and subsidence of the soil quite well. The structure of the gabion wall has good water permeability, so drainage is not necessary.

Gabion structures do not prevent the growth of vegetation and over time become part of the natural landscape [3]. They are well suited to any style of the site, almost completely merging with it, perfectly complementing the aesthetic

value of nature [4]. These are stable structures that do not require special care. If all rules and technologies were taken into account during construction, then gabion structures can last 50-100 years or more. Over the years, gabion structures do not lose their purpose [5]. They are ideal for all types of soil and climate conditions. The designed structures are also used as cooling systems in hot climates, providing passive cooling [6].

The objective is to study the calculation method and features of the design of gabion retaining walls, to analyze the impact of changes in wall parameters of the wall on the stability of the structure.

The main tasks of the research:

- to determine the modern tendencies of application of gabion constructions;
- determine the advantages and disadvantages of using gabions for the construction of retaining walls;
- to investigate the method of calculation of gabion retaining walls;
- to perform the calculation of the retaining wall under different initial conditions;
- to analyze the impact of various factors on the stability of the gabion retaining wall.

Description of article's main material

The construction of a gabion retaining wall can be different, depending on the angle of the slope and the load on the wall (Fig. 1).

As for the technology of construction of gabion retaining walls, at the first stage, a construction project is developed, which describes in detail the technology and basic rules of execution of works [3].

The storage gabion boxes are transported folded way to save space. The wire used for the manufacture of gabions has a strength boundary of 380-500 MPa and an elongation of up to 12%. The main requirements for the mesh are corrosion resistance and tensile strength.

Then directly on the place, the boxes are connected into parallelepipeds using lacing wire or fasteners made of stainless steel, galvanized rings, depending on the specifications.

Then prepared empty gabions are installed next to the ones already filled with stones in place according to the project and tied to them. In order to fix the lower gabions in the design position, metal rods are used, which are driven into the corners to pull out the gabions to give them a stable shape [3,7].

A solid stone material (granite, basalt, slate, rubble, pebbles, etc.) serves as an aggregate. When filling the gabion, tensioning wires are used, which in the future will protect the wall from bulging, providing a smooth front surface.

Fig. 1. Examples of gabion retaining walls [6]

General design principles. Gabion retaining wall is a flexible structure that holds the soil with its own weight. It is constructed according to the same principle as a gravity wall: a significant mass of stone in gabions must resist shear forces from the soil and external loads. At the same time, the gabion mesh should hold the stones inside with a slight deformation that will not affect aesthetics and internal stability [8].

Designing, it is necessary to make an accurate calculation of the height and thickness of the retaining wall, since the reliability and quality of the gabion structure will depend on this [9]. It is necessary to start with the specification of geometric dimensions and the number of gabions, then the dimensions are specified in further calculations according to limit states [7].

According to the first group of limit states, which involves the loss of bearing capacity or significant damage, the following calculations are performed:

- general stability (external stability):
  - resistance of the wall against displacement on the base;
  - resistance of the wall against overturning;
  - strength of the soil base;
- internal stability:
  - displacement of some gabions relative to others;
  - gabion strength as a structural element.

According to the second group of limit states (unsuitability for normal operation), the calculation includes a check for permissible deformations during operation of the structure. The calculation is carried out on the effect of normative loads, that is, the coefficients of the reserve in relation to the load and materials accept equal units [7].

The front faces of gabion retaining walls can be stepped and smooth (vertical or inclined). Depending on local conditions and initial data, the configuration of gabion walls can be different. In this study, a wall with a stepped face front is adopted.

The design of gabion retaining walls begins with the collection of initial data. They should cover the entire range of information necessary for the analysis of the state of the embankment, the determination of the forces acting on the supporting gabion structures, the calculations of the main parameters of the structures, their reinforcement, the development of technologies for the arrangement of retaining walls and their technical and economic assessment [3].

The basic for designing gabion structure are: physical and mechanical characteristics of soils, requirements to drainage, width of the base, depth of laying, angle of inclination, loading, density of gabions, volume of backfill, presence of seismic influences [8].

Traditionally, due to the porosity of gabions, drainage systems for gabion walls are not suitable, unlike concrete or reinforced concrete. If the construction site is dominated by clay or sandy soils, it makes sense to provide a geotextile filter between the wall and the gabion.

The width of the base of the gabion wall for a height of H from 1 m. to 6 m. is recommended from 0.6 to 0.75 H, and for a height of more than 6 m. to 10 m. - 0.55-0.65 H and to meet the requirements of the project [8].

The minimum depth of gabion retaining wall must be not less than 0.5 m. for flat surface at H 1 m. to 6 m. and 1 m. for H 6 m. to 10 m. (as per IS 14458 part 1).

The depth of freezing, shrinkage and erosion of the soil, the presence of seismic activity and water washing also affect the depth of laying. Usually, the minimum depth for any structure is taken 0.5 m. The exception is the structure that is erected on rocky soils. In this case, the depth of the wall can be less, due to the fact that the base is a priori strong and the earthwork is much more complicated. Here, respectively, the depth can be 0.3-0.5 m., and the foundation can be leveled by installing dowels and concreting the base [8].

The norms recommend placing a gabion wall at an angle of 3-6° to the vertical. The wall can also be vertical, and arrange for the gabions to be offsetted to the outside.

Methodology of construction and calculation of a gabion wall. The gabion gravity wall should be designed taking into account the possible schemes of its destruction, as shown in fig. 2 [3,8].

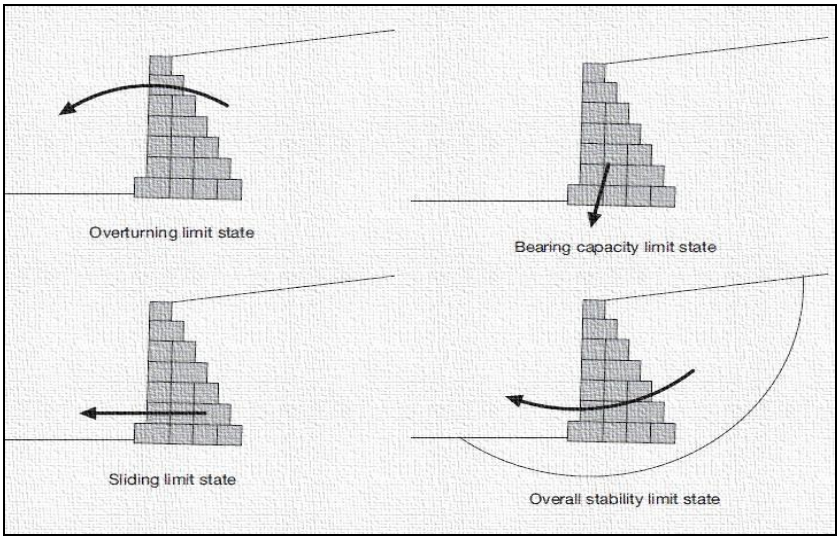

Fig. 2. Possible schemes of destruction of the gabion gravity wall [available online]

First, the type and shape of the structure of the retaining wall is chosen, according to the local conditions, the structure of the reinforced embankment, the main dimensions of the wall are assigned. The height of the wall should ensure the stability of the upper part of the slope (embankment). The width of the gabions that make up it and the shape of the wall are set under the condition of the wall's resistance against shifting and overturning, additionally checked by calculations to estimate the bearing capacity of the base and to estimate the internal stability of the wall [3,7].

The external and internal stability of the wall is considered. The external stability of the wall is assessed by resistance to shear, overturning and loss of bearing capacity of the base. The internal stability is checked by calculating the strength in the most dangerous intersections (in the places where gabions are connected to each other) [3].

As shown in fig. 3, the main forces acting on the walls of the gabions are the vertical forces from the weight of the gabions and the lateral pressure of the earth acting on the back surface.

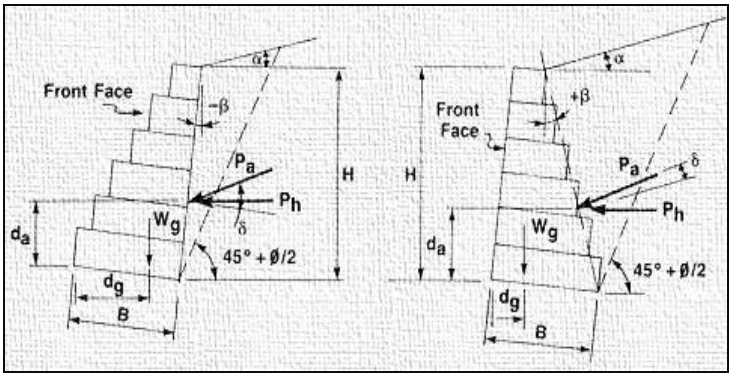

Fig. 3. Construction of the gravity wall: a- stepped front face; b- stepped back face [10]

Calculation and parametric analysis of the retaining wall

The Portuguese program GAWAC WIN 1.0 was used to design the gabion retaining wall. Eight variants of calculations were carried out, the first - with the given initial data (Table 1), the rest - with a change of certain parameters, such as the angle of inclination of the wall, the porosity of the gabions, the height and width of the gabions, the offset of the gabion boxes relative to each other, the presence or absence of geotextiles in based on the design.

The wall construction area is Bragança, Portugal, the backfill soil is sand-gravel, and the gabion filler is granite.

Initial data

Table 1

Symbol	Name of value	Value	Unit of measure
H	Wall Height	7	m
q	Surcharge	5	kN/m
α	Backfill slope angle	20	deg
β	Back Face slope angle	5	deg
φ	Soil friction angle	40	deg
w_s	Soil density	20	kN/m3
w_g	Gabion fill density	18	kN/m3
P_b	Soil bearing pressure	300	kPa
B	Width of the base	4.5	m
δ	Angle of wall friction	5	deg
	Porosity of gabions	30	%
	Presence of geotextile in the base	No	

Table 2

Calculation option	Parameters that were changed:
1	–
2	- Changed the angle of inclination of the wall from 5° to 6°;
3	- increased porosity of gabions from 30% to 40%; - geotextile in the base: available (reduction of friction by 5%);
4	- added the 8th layer, height: H = 8m; - reduced base width: B = 4m.
5	- increased porosity of gabions from 30% to 40%; - geotextile in the base: available (reduction of friction by 5%); - added the 8th layer of gabions, height: H = 8m; - reduced base width: B = 4m.
6	- increased the angle of inclination of the wall from 5° to 6°; - increased porosity of gabions from 30% to 40%; - geotextile in the base: available (reduction of friction by 5%); - added the 8th layer of gabions, height: H = 8m; - reduced base width: B = 4m.
7	- increased displacement of gabions relative to each other from 0.5 m to 0.6 m.;
8	- increased the angle of inclination of the wall from 5° to 6°; - increased displacement of gabions relative to each other from 0.5 m to 0.6 m.

Analysis of the influence of changing parameters on the stability of the gabion retaining wall structure showed that when the angle of inclination of the wall increased to 6° (2nd calculation option), the resistance of the retaining wall against sliding and overturning increased by 9.25% and 6%, respectively. When increasing the porosity of gabions from 30 to 40%, reducing the width of the base to 4 m. and increasing the height of the wall by one row of gabions (up to 8 m.), as well as when inserting geotextiles on the base, the stability of the wall decreased by 12.2% - 50.2% (calculation options 3-6). With the increase in the size of the gabions displacement of each row from 0,5 m to 0,6 m the wall stability against sliding was increased by 29.7%, and against overturning by - 18.4%; an additional increase in the angle of inclination of the wall by 1° increased these indicators to 44% and 28.4%, respectively.

Table 3

Analysis of the stability of the gabion retaining wall

Аналіз стійкості конструкції	Calculation options							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Active thrust:	79.14	75.42	79.14	107.29	107.29	101.71	60.84	56.64
Point of application ref. To x axis	4.68	4.71	4.68	4.21	4.21	4.25	4.87	4.90
Point of application ref. To y axis	1.88	1.79	1.88	2.24	2.24	2.18	1.83	1.75
Direction of the thrust ref. To x axis :	33.00	32.00	33.00	33.00	33.00	32.00	28.10	27.10
Sliding								
Normal force on the base:	429.47	426.54	375.07	392.41	345.79	341.88	413.97	411.04
Point of application ref. To x axis :	2.91	2.96	2.89	2.47	2.42	2.47	3.15	3.20
Point of application ref. To y axis :	0.25	0.31	0.25	0.22	0.21	0.26	0.28	0.34
Shear force on the base	29.05	19.48	33.81	56.00	60.08	50.80	17.65	7.49
Resisting force on the base:	360.36	357.91	298.99	329.27	275.64	272.53	347.36	344.90
Sliding safety coefficient :	6.31	**6.69**	**5.25**	**4.23**	**3.55**	**3.77**	**7.47**	**8.11**
Overturning								
Overturning moment :	124.78	114.54	124.78	201.81	201.81	188.34	98.02	87.99
Restoring moment :	1374.94	1378.52	1207.35	1170.08	1038.09	1033.73	1400.37	1404.03
Overturning safety coefficient	11.02	**12.04**	**9.68**	**5.80**	**5.14**	**5.49**	**14.29**	**15.96**
Stresses acting on found.								
Eccentricity:	0.67	0.73	0.65	0.48	0.43	0.49	0.91	0.97
Normal stress on outer border	179.55	184.94	154.06	166.90	140.71	146.08	0.00	0.00
Max. stress on inner border :	1231.39	1239.20	1203.59	1013.21	980.49	991.79	1260.90	1271.24
General stability. Safety factor	67	60	57	58	56	56	50	51

Conclusions. Designing gabion walls, it is necessary to take into account the negative influence of the following factors:

- ✓ an increased gabion porosity leads to a decrease in the weight of gabion construction and can further increase the risk of overturning;
- ✓ the presence of geotextile at the base of the wall leads to a decrease in friction, which in turn leads to a worse adhesion of the structure to the base;
- ✓ the increase in the height of the structure and the decrease in the width of the base significantly increase the overturning moment and reduce the resistance against sliding.

The positive factors affecting the stability of the structure are an increase in the angle of inclination of the wall and displacement of gabions relative to each other (calculation options 7-8).

References

1. *What are gabion structures? "Liv-energo" Co.,* Ltd. Online. LLC "LIV-ENERGO". 2019.07.22. URL: https://www.liv-energo.com.ua/shho-take-gabionni-konstrukcii/. (date of access: 31.10.2022).
2. Carbon dioxide emissions on the world map: who pollutes the planet the most? URL: https://api.visicom.ua/uk/posts/co2. (date of access: 31.10.2022).
3. *Recommendations for carrying out work, general provisions, temporary technical instructions for the use of gabions for strengthening the ground surface of railways were developed using the materials of CJSC "Gabions Maccaferri"*. Online. Gabions McCaffery. [b. d.]. URL: https://refdb.ru/look/1931277-pall. (date of access: 31.10.2022).
4. *PARFIENTYEVA I.O. and LUGOVSKA T.P. Modern technologies and methods of calculations in construction: a collection of scientific papers - Lutsk* . Lutsk NTU, 2017, No. 7, p. 188.
5. *Gabion fence: advantages, selection and installation - VBud* . Online. VBud. 2019-09-15. URL: https://vbud.in.ua/parkan-z-gabioniv-perevagi-vibir-i-montazh/. (date of access: 31.10.2022).
6. TOMIŠA, A. *Gabion walls - function, application, advantage | Geotech*. Online. Geotech. 2019-05-06. URL: https://www.geotech.hr/en/gabion-walls/. (date of access: 31.10.2022).
7. SAVENKO V.YA., PETROVYCH VV, KASKIV VI, and KASKIV SV. *Development of standards for construction gabions* . "Modern technologies and calculation methods in construction", 2017, No. 6, p. 205–212.
8. INDIAN ROADS CONGRESS. IRC:SP:116-2018. *Guidelines for design and installation of gabion structures* . Online. Kama Koti Marg, Sector-6, RK

Puram, New Delhi-110 022, May 2018. URL: https://www.scribd.com/document/449057904/IRC-SP-116-2018-Guidelines-for-Design-and-Installation-of-Gabion-Structures (date of access: 31.10.2022).

9. *Do-it-yourself gabions - step-by-step instructions - Ekobil*. Online. Ekobil. 2021.11.08. URL: http://ekobil.com.ua/gabioni-svoyimi-rukami-pokrokova-instruktsiya/. (date of access: 31.10.2022).
10. *GABION WALLS DESIGN modular gabion systems*. Online. A Division of CE Shepherd Company 2221 Canada Dry Street Houston TX 77023, [b. d.]. URL: https://www.scribd.com/doc/38637356/MGS-Design-Guide-Gabion-Wall (date of access: 31.10.2022).
11. Korin` T., Manuel Teixeira Braz César, Rotko S.V. ON THE ISSUE OF CALCULATION AND CONSTRUCTION OF GABION RETAINING WALLS. Abstracts of the international practical internet conference of young scientists and students "Innovative processes in the field of road construction". Lutsk, 11/18/2022. URL: https://drive.google.com/file/d/1xce-qlOEQHuURqZOnjxZ_XgYXeNxLhzI/view