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FAILURE MODES OF GABION RETAINING WALLS

MECHANIZMY ZNISZCZENIA MURU OPOROWEGO Z GABIONÓW

Abstract

The results of numerical simulations of the destruction of gabion retaining walls are presented. Special attention is paid to distinguishing possible destruction modes.

Keywords: gabion, retaining wall, FEM, stability.

Streszczenie

W artykule przedstawiono rezultaty symulacji numerycznych zachowania się muru oporowego z gabionów. Zwrócono uwagę na możliwe mechanizmy zniszczenia.

Słowa kluczowe: gabion, mur oporowy, MES, stateczność

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Symbols

ε_a – axial strain at steel mesh failure [–]
ϕ – internal friction angle [deg]
γ – soil bulk unit weight [kN/m^3]
c – cohesion [kPa]
E – Young modulus [kPa]
f_t – steel mesh tensile strength [kN/m]
M – steel mesh elastic modulus [kN/m]
SF – safety factor [–]

1. Introduction

The main subject of the study is the behaviour of the retaining wall made of gabions. A gabion is a cage, cylinder, or box made of steel wire mesh, filled with rock samples. In civil engineering, gabions are often used to form gravity retaining walls or gabion-faced reinforced soil retaining walls (when the steel mesh used for gabion cages is also used as a soil reinforcement). Despite their simplicity, the numerical modelling of gabion retaining wall-soil interaction is complicated. The main sources of complications are: nonlinear behaviour of the soil (both retained soil and gabion filling), and the interactions (friction) between steel mesh and soil and between gabions.

In engineering practice, stability calculations for retaining walls formed from gabions are usually performed using ultimate soil pressure theory, identical with the case of concrete retaining walls. The friction between the gabions and the retained soil (on the vertical surface of the wall) and the cohesion of the retained soil is usually neglected, which is on the safe side but could lead to uneconomical design. Usually only two possible destruction mode are taken into account – overturning and horizontal sliding.

When numerical analysis is used, gabions are usually modelled as an elastic continuum. The interface (contact) elements are used to describe the friction between the gabions and the retained soil or the friction between gabions (if the connections between gabions are not “perfect”). This approach fails to identify one of the possible destruction modes – shearing of the filling and tensional failure of the steel mesh. The retained soil is usually modelled with use of Coulomb-Mohr elasto – plastic model. Plane strain assumption is usually used (for example in [4]).

In some works a bit more sophisticated approach (which could be called homogenization approach) is used. Gabions are modelled using the Coulomb-Mohr elasto-plastic model. The friction angle of gabions is equal to the friction angle of the filling, and some additional cohesion is used. The value for additional cohesion is taken from membrane theory and can be verified in triaxial tests. According to [2] and [4] this additional cohesion can be calculated from:

$$c_r = \frac{\Delta\sigma_3}{2}\tan\left(45^\circ + \frac{\varphi}{2}\right) \tag{1}$$

where:
c_r – additional cohesion

$$\Delta\sigma_3 = \frac{2M\varepsilon_c}{d} \cdot \frac{1}{(1-\varepsilon_a)}$$ – increment confining stress

$$\varepsilon_c = \frac{\left(1-\sqrt{1-\varepsilon_a}\right)}{1-\varepsilon_a}$$ – circumferential strain

M – membrane elastic modulus (kN/m)
ε_a – axial strain at steel mesh failure
d – characteristic dimension of the sample (lowest gabion dimension)

Mesh tensional strength does not appear explicitly in such this approach, but we can see that it is a function of axial strain at steel mesh failure and membrane elastic modulus:

$$f_t = \varepsilon_a M \tag{2}$$

In this homogenization approach, the elastic stiffness of the gabions should also be a function of filling and steel mesh stiffness. At this state of the research, the elastic stiffness of the filling (in fact Young modulus E) is used as an approximation of the gabion elastic stiffness – the influence of the steel mesh elastic stiffness is neglected.

Even in simple stability calculations the friction coefficient between gabions and subsoil should be identified. According to [3] it could can be performed using the following equation:

$$\alpha_{ds} \tan\varphi = \alpha_s \tan\delta + (1-a_s)\tan\varphi \tag{3}$$

where:
α_{ds} – friction coefficient between gabion and soil
δ – friction angle between steel and soil
a_s – ratio between steel area and gabion-subsoil connection area
φ – friction angle of the subsoil

If we choose to use the assumption typical in Polish design practice that there is no friction between soil and steel ($\delta = 0$) equation (3) can be simplified to:

$$\alpha_{ds} = 1 - a_s \tag{4}$$

This approach is on the safe side, because it leads to some underestimating of the friction forces between the gabions and the subsoil.

The problem of the friction between gabions is (as far as the author knows) has not yet been not solved to this day. In the absence of joints between gabions, the coefficient of friction between gabions could be tested in the laboratory (direct sliding test). If some steel joints are used to join gabions three different approaches could be used. The first assumes that the connection is “perfect” and that no interface element between gabions are necessary. This approach do not allow the failure of the wall caused by joints failure to be described. The second approach (more conservative) leads to using the Coulomb-Mohr law for the interface elements between gabions, where the friction angle would describe the friction between gabions, and cohesion would describe the strength of the joints. This approach allows failure of the wall due to joint failure to be described, but is not capable of describing the resistance of the joints against opening of the gap between gabions. The third approach (closest to reality) leads to modelling the joints between gabions using truss elements perpendicular to the gabion surface. Friction in the interface elements is then responsible for describing the friction between gabions, and cohesion in interface elements describes the joint resistance against sliding and joints describe the resistance to opening the gap between gabions.

2. Numerical experiment

2.1. Simple retaining wall

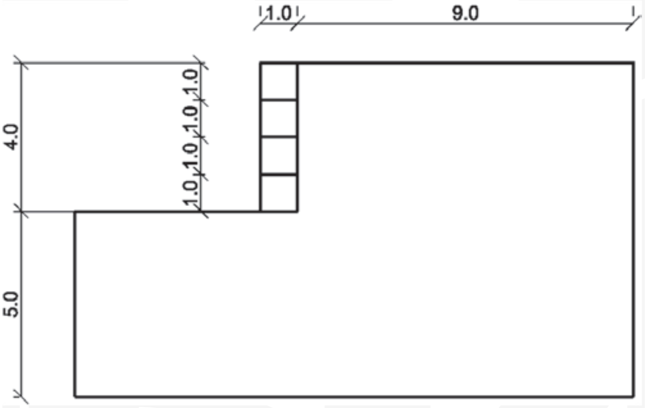

Fig. 1. Analysed object (dimensions in metres)

A stability analysis of a 4 m high model retaining wall was performed. A variety of retained soil and wall property combinations were used to obtain different destruction modes. All numerical simulations were performed in plane strain conditions, using the ZSoil Finite Element Method (FEM) software described in detail in [5] and [7]. The safety factor SF was estimated using the c-f reduction method described in [6]. The interface elements were used between soil and gabions. Filling and steel mesh properties were taken from [4]. The friction coefficient between gabion and subsoil and between gabions was calculated according to equation (3). No joints between the gabions were taken into account. The Coulomb-Mohr elasto-plastic model was used for retained soil and gabions. Additional cohesion for gabions was calculated as described in Chapter 1.

The stability loss modes obtained are presented below. The first shows overturning (typical of retaining soil with small cohesion and high friction angle), the second – horizontal sliding of the whole wall (typical of retained soils with high cohesion and low friction angle), the third – horizontal sliding of the part of the wall (top gabion) (could happen when there are no joints between gabions or there are joints without friction and a weak layer at the top of the structure appears), and the fourth – shearing of both retained soil and gabion (typical of weak gabion filling and weak steel mesh).

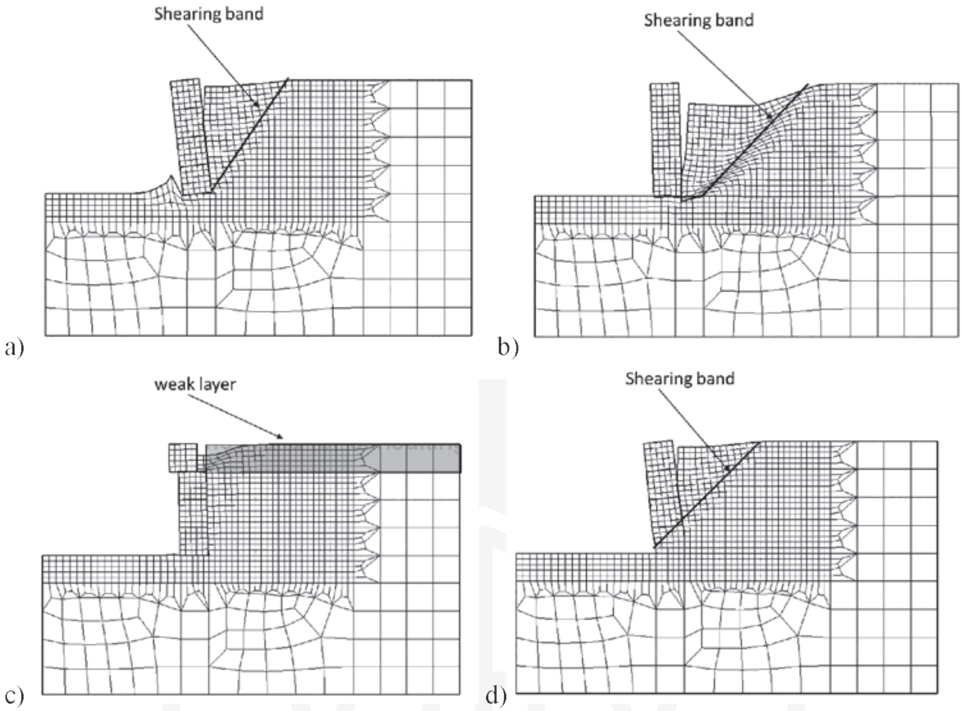

Fig. 2. Typical stability loss modes a) overturning, b) horizontal sliding of the whole wall, c) horizontal sliding of the part of the wall (top gabion), d) shearing of retained soil and gabion

For simplicity, this same value $E = 100$ MPa of the Young modulus for gabion and retained soil was used. The ratio between the tangent of the friction angle of interface and tangent of the friction angle of the soil or gabion was set to 0.95, cohesion of the interface was set to 0. Other parameters used in the simulations are listed below.

Table 1

Parameters used in the simple retaining wall stability analysis

	Retained soil		Gabions	
Stability loss mode	*c* [kPa]	ϕ [deg]	*c* [kPa]	ϕ [deg]
Overturning	5	35	23	43
Horizontal sliding of the whole wall	20	10	23	43
Horizontal sliding of the top gabion	5 (1 for weak layer)	45 (8 for weak layer)	23	43
Sherearing of the retained soil and gabion	5	35	20	43

2.2. Anti-flood embankment supported by gabions

Numerical simulation of 5 m high embankment behaviour (whose stability was analysed in [1]) was performed.

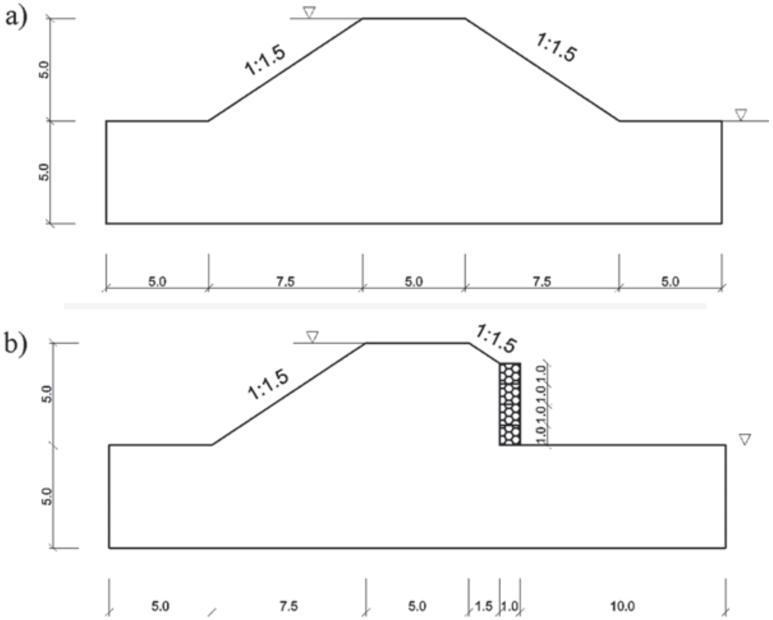

Fig. 3. Analysed embankment (after [1]) a) without gabions b) with 4 gabions

The safety factors obtained were compared with those obtained using the classic Fellenius or Bishop method presented in [1]. For simplicity Darcy`s coefficients for soil and gabions were assumed as equal (no drainage effect produced by gabions). Alternatively, for the highest wall (with 4 gabions) a ratio of 1:100 between Darcy's coefficients for soil and gabions were taken into account, which introduces a drainage effect produced by the gabions. Numerical simulations were performed in the steady state of the flow. The influence of the pore pressure on the mechanical behaviour of the embankment was introduced according to the effective stresses principle.

The results obtained show that safety factors for the embankment without gabions are comparable, regardless of calculation method. However, large differences in safety factors between the classic approach (using the cylindrical sliding surface assumption) and numerical analysis appear when the embankment is supported by gabions. This is because the assumption of a cylindrical sliding surface is not true for retaining structures. This assumption leads to unsafe results (overestimation of the safety factor) being obtained.

The drainage effect produced by the gabions leads to raising of the SF for the embankment from 1.23 to 1.31, which is a noticeable effect. This is due to a lowering of the water free surface in the vicinity of the gabions.

So for hydrotechnical structures the drainage effect of gabions is significant and should be taken into account in stability calculations.

Table 2

Results of the stability calculations for anti-flood embankment supported by gabions

Number of gabions	SF from Fellenius method (after [1])	SF from Bishop`s method (after [1])	SF from numerical simulations
0	1.564	1.605	1.56
2	1.634	1.689	1.53
3	1.543	1.609	1.37
4	1.459	1.522	1.23 (without drainage effect) – 1.31 (with drainage effect)

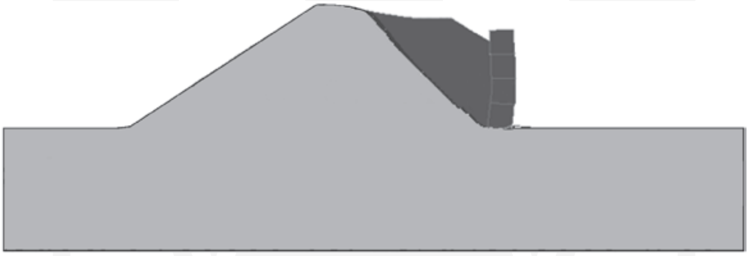

Fig. 4. Sliding surface for embankment with 4 gabions

3. Final remarks

The results of the numerical simulations described above show the complexity of the gabion retaining wall-soil interaction. Different destruction modes are obtained. Overturning is typical of retained soils with small cohesion but high friction angle, horizontal sliding of soils with high cohesion and small friction angle. Sliding between gabions is obtained where there are no joints between gabions (or joints are weak) and a weak layer of soil appears near the top of the structure. Destruction due to filling shear and steel mesh failure is obtained when weak material is used for filling and weak steel for mesh. The assumption of cylindrical sliding surfaces leads to unsafe results (overestimating of stability factor) being obtained and should not be used in engineering practice. For hydrotechnical structures, the drainage effect of gabions is significant and should be taken into account in stability calculations.

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