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Gabion retaining wall stability – a case study

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Abstract

The paper presents results of numerical analysis of the gabion retaining wall stability. A real, complicated object is analysed. Gabions are modelled using a homogenized Mohr-Coulomb model for mesh and filling. Interface elements are used to allow discontinuous deformation field between adjacent gabions and between gabions and subsoil. A parametric study of the influence of the mesh and joints between gabions strength on the stability of the structure is performed. Different modelling approaches are compared. Numerical simulations were performed using ZSoil v25 Finite Element Method (FEM) system. Efficiency of the proposed approach is shown.

Keywords: gabion, retaining wall, FEM, stability

1. Introduction

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). Bridges abutments and small hydrotechnical structures can also be built from gabions

Despite their simplicity, the numerical modelling of the interaction between a gabion retaining wall and the soil is complicated. The main sources of complications are nonlinear behaviour of the soil (both the retained soil and the gabion filling) and the interactions (friction) between the steel mesh and the soil, and between adjacent gabions (analysed by Bergado et al., 2003). Joints between gabions and their limited strength are another source of complications – this problem was analysed by Grodecki (2017).

The complicated behaviour of twisted hexagonal wire mesh is analysed by many researchers. Laboratory static tensile tests and their numerical simulations are used by Agostini et al. (1987), Bergado et al. (2003)), Bertrand et al. (2005, 2008), and Grodecki (2020).

The use of ultimate soil pressure theory (identical to that for conventional gravity retaining walls) is often advised for stability calculations of the gabion retaining walls, identical with the case of concrete or masonry retaining walls. Usually, only two possible failure modes are considered – overturning and horizontal sliding.

Numerical modelling of real gabion walls is a subject of a study by Grodecki and Urbański (2018). Tests of full-scale gabion walls and their numerical simulations are presented in Agostini et al. (1987), Bertrand et al. (2008), Grodecki (2021), and Jayasree (2008).

Gabions are usually modelled as an elastic continuum. In some works (Bathurst and Rajagopal (1993), Jayasree (2008), Grodecki (2021), Grodecki and Urbański (2018)), homogenised Coulomb-Mohr model for gabions (mesh and filling) is used. This approach allows to model another failure mode – shearing failure of the filling and mesh tensional failure.

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", a problem analysed by Grodecki (2017)). The retained soil is usually modelled using the Coulomb-Mohr elastic – plastic model. The plane strain assumption is usually used. The problem of estimating the friction parameters was analysed by Bergado et al. (2003).

The main goal of this article is to present the methodology used and the results of the numerical analysis of the stability of a complex gabion retaining structure. Results of the parametric study of the influence of the mesh and the

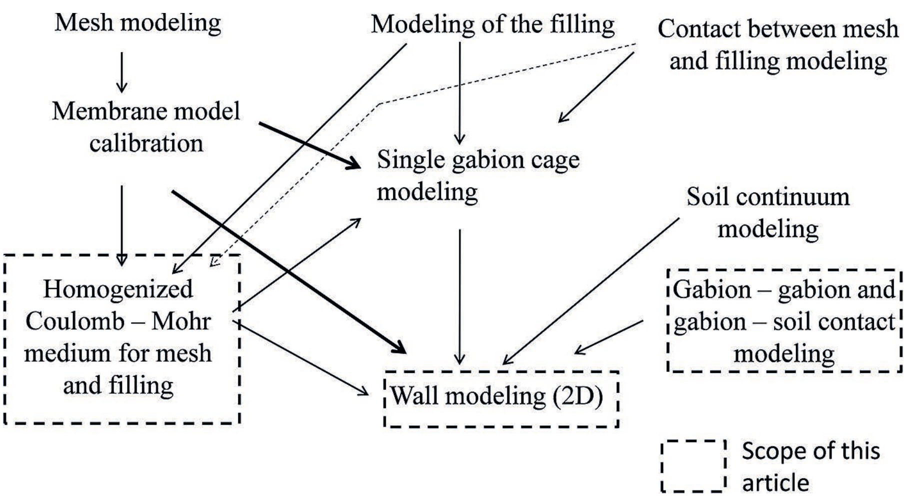

Fig. 1. Scope of this article in the field of gabion structure testing and modelling (own elaboration)

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joints between gabions strenght on the stability of the structure are presented. The scope of this article in the field of gabion structure testing and modelling is shown in Fig. 1.

2. Numerical simulations

A complicated construction with two stepped retaining walls was analysed. Both walls have a height of 2 m; each consists of five layers of 0.5 × 0.5 m gabions (one layer is buried in the subsoil) – see Fig. 1. The subsoil layers consist mostly of silt, silty clay, and clay (I_L from 0.20 to 0.50). Weathered limestone is present in the deeper subsoil. No groundwater water table was observed.

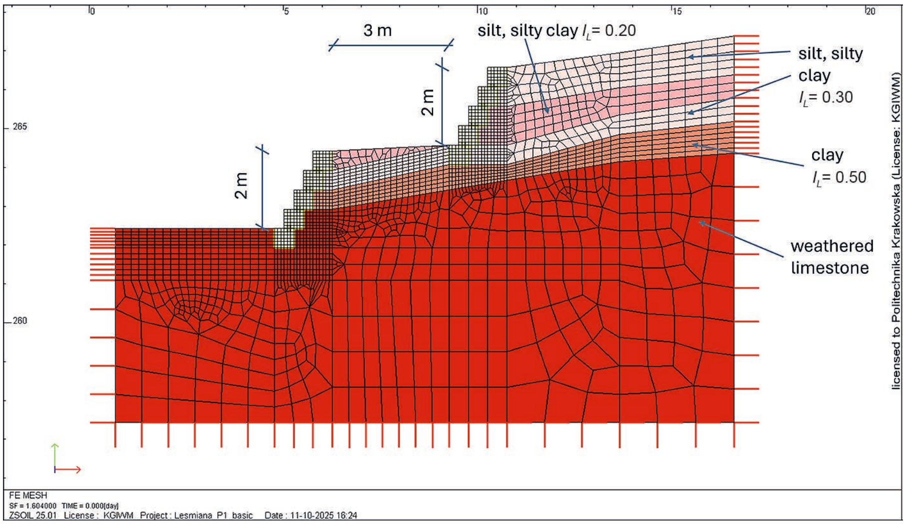

Fig. 2. Numerical model with boundary conditions, geotechnical conditions and most important dimensions (own elaboration)

Numerical simulations were performed using the ZSoil v25 Finite Element Method (FEM) system (characterized in detail by Commend et al. (2022)). The $c - \phi$ reduction method (described by Griffiths and Lane (1999), Matsui and San (1999), Commend et al. (2022)) was used to estimate the Stability Factor SF. All simulations were performed in plane strain conditions. A Coulomb–Mohr elastic-plastic model with “cut-off” (no tension) condition was used for the soil. 2D (plane strain) model was used, because the wall is relatively long (about 35 m) and almost straight.

In order to model a discontinuous deformation field between gabions and between gabions and the subsoil, interface elements were used. Their

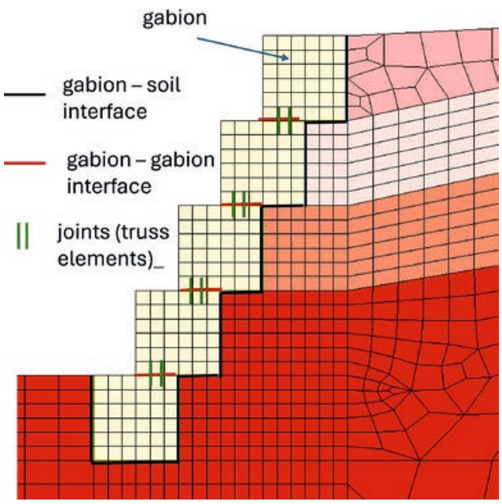

Fig. 3. Numerical model – details in the vicinity of the gabions (own elaboration)

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parameters were estimated according to Bergado et al. (2003) (the friction angle between gabions and between gabions and the subsoil equal to 90% of the internal friction angle) and Grodecki (2017) (the cohesion in the interface elements, responsible for the limited tensile strength of the joints between gabions, estimated to be 40 kPa). Truss elements responsible for modelling the resistance of the joints between gabions to gap opening were used, with the tensile strength of the joints equal to 20 kN/m (as advised by the US standard – American Society for Testing and Materials, 2011; for details see Grodecki, 2017). Details of the numerical model are shown in Fig. 3.

Gabions were modelled as a homogenised Coulomb-Mohr type continuum (mesh + filling). According to Agostini et al. (1987), Bathurst and Rajagopal (1993), and Jayasree (2008) the friction angle of a homogenised continuum is equal to the friction angle of the filling, and some additional cohesion appears as a result of the mesh. Such additional cohesion can be estimated on the basis of large-scale triaxial tests, as proposed by Bathurst and Rajagopal (1993) and Jayasree (2008), from the following equation

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

where: ϕ – friction angle of the filling, c_r – additional cohesion [kPa], $\Delta\sigma_3$ – increase of the hydrostatic pressure in triaxial test [kPa]

$$\Delta\sigma_3 = \frac{2M\varepsilon_c}{d}\cdot\frac{1}{(1-\varepsilon_a)} \quad (2)$$

where: ε_a – axial strain of the mesh at failure, according to US standard (American Society for Testing and Materials, 2011) about 0.06–0.07, ε_c – circumferential strain

$$\varepsilon_c = \frac{(1-\sqrt{1-\varepsilon_a})}{1-\varepsilon_a} \quad (3)$$

where: M – elastic moduli of the mesh [kN/m], d – lowest gabion dimension [m].

Elastic moduli of the mesh M could be calculated from equation:

$$M = \frac{f_t}{\varepsilon_a} \quad (4)$$

where: f_t – mesh tensile strength [kN/m].

Using $\phi = 40^{\circ}$, $\varepsilon_a = 0.07$, $f_t = 20$ kN/m, $d = 0.5$ m value of the $c_r = 50$ kPa was obtained.

Parameters of the soils and gabions used in this study are presented in Table 1.

Table 1. Parameters of the gabion and soil used in the stability analysis (own elaboration)

Material	*E* [MPa]	γ [kN/m$_3$]	ϕ [°]	*c* [kPa]
Silt, silty clay I_L = 0.30	16.5	20.5	13.5	13.0
Silt, silty clay I_L = 0.20	20.5	20.5	15.0	17.0
Clay I_L = 0.50	11.0	19.5	10.0	8.5
Weathered limestone	186.5	21.0	50	0.0
Gabions	200	22.0	40	50.0

For the assumptions presented above, a reasonable value of the Safety Factor (SF = 1.60) was obtained. The stability loss mode is rather complex (see Fig. 4). The upper part of the sliding surface is circular; the lower part is flat; shear failure of the gabion in the bottom wall is observed.

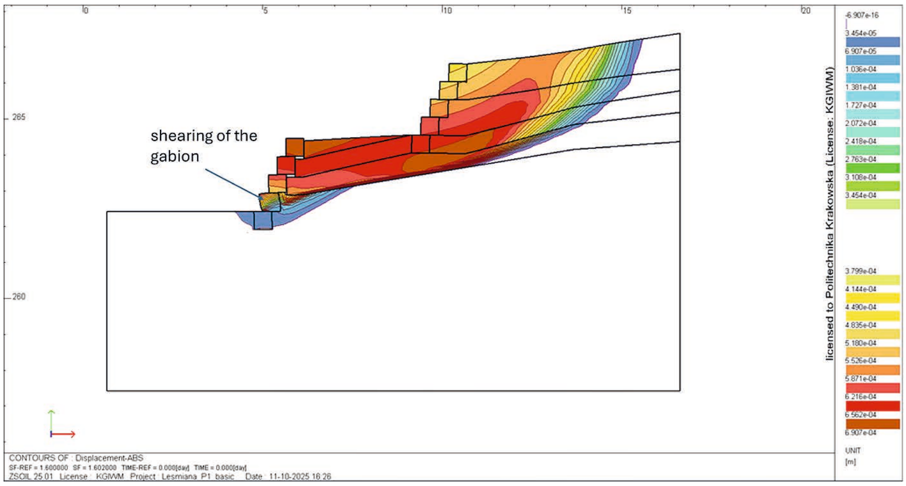

Fig. 4. Stability loss mode (sliding surface), SF = 1.60, Coulomb-Mohr model for gabions (own elaboration)

For comparison of the obtained results, the simulations using the elastic model for gabions were performed. The obtained SF value of 1.65 shows that, for the proposed parameters of the mesh, the influence of the material model for gabions on the stability of the structure is small but noticeable. The sliding surface in the lower part is slightly different – it passes beneath the buried gabion of the lower wall (Fig. 5).

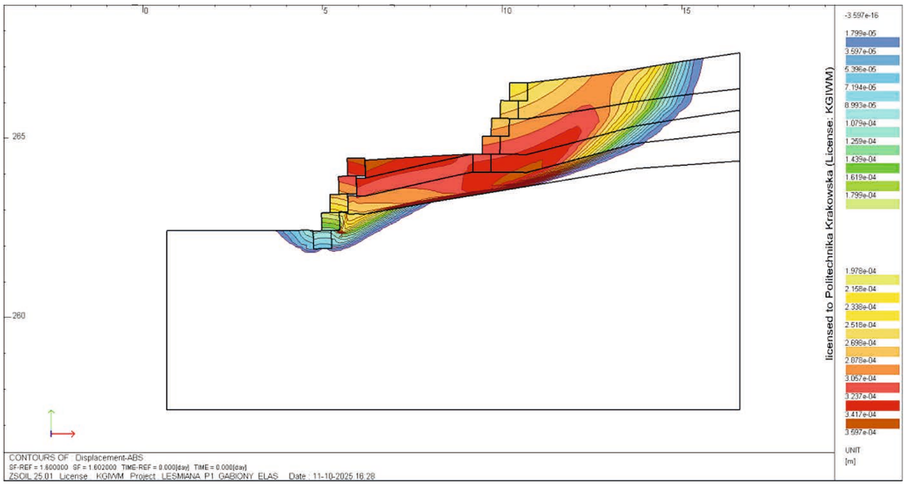

Fig. 5. Stability loss mode (sliding surface), SF = 1.65, elastic model for gabions (own elaboration)

In order to judge whether the mesh and the joints between gabions strength has a significant influence on the stability of the structure, a parametric study was conducted. The mesh strength from 4 to 80 kN/m and the joints strength from 0 (no joints at all) to 50 kN/m were assumed.

The obtained results show almost no influence of the joints strength on the structure stability. Even for 'no joints at all' (a bad design practice!) and the mesh strength of 20 kN/m, the value of SF = 1.55 was obtained – the friction between gabions is large enough to maintain a reasonable stability margin of the structure. Crucial in this case problem of estimating the friction parameters was analysed by Bergado et al. (2003). Information about the choice of the proportion between mesh opening and filling particle sizes should be analysed during detailed design of the structure.

However, a weak mesh leads to a decrease in SF. The minimal value of SF = 1.44 is obtained for the mesh strength of 4 kN/m. This value is independent of joints strength. Stability loss mode is identical, like in Fig. 4.

Increase of the mesh strength up to 70 kN/m together with increase of the joints strength up to 50 kN/m do not leads to significant SF arise. Upper value of the possible SF is, of course, value obtained for elastic model of the gabions SF=1.65. Obtained results are illustrated by Fig. 6.

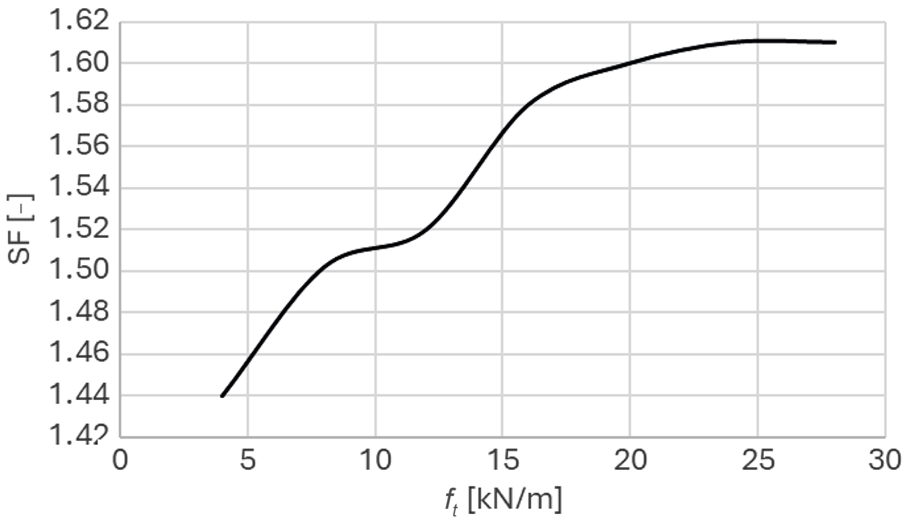

Fig. 6. Stability factor SF as a function of mesh tensile strength f_t (own elaboration)

The obtained results of the performed parametric study lead to the findings described below:

- In this particular case, the strength of the joints between gabions has almost negligible influence on the stability of the structure.
- The strength of the mesh has significant influence on the stability of the wall. The preliminarily assumed mesh strength of 20 kN/m is a reasonable choice – a further increase does not lead to a significant increase in the SF.
- The stability loss mode could change in the lower part with changes in the mesh strength.

3. Final remarks

The presented numerical simulations of gabion wall stability show that such simulations could be a useful engineering tool in the design process of gabion structures. It's worth noticing that in some cases the stability loss occurs together with shear failure of the gabions. Therefore, the limited shear strength of the gabions should be taken into account. For safety purposes and verification of the performed calculations, geodetic monitoring of the displacements of the structure is advised.

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