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## NUMERICAL MODELLING OF GABION JOINTS

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## MODELOWANIE NUMERYCZNE POŁĄCZEŃ GABIONÓW

### **Abstract**

This paper presents results of a numerical analysis of the stability of a gabion retaining wall. The main objective of the paper is to identify how different methods of the modelling of gabion joints affect the stability of the structure.

**Keywords:** gabion, retaining wall, FEM, stability

### **Streszczenie**

Praca przedstawia rezultaty analiz numerycznych stateczności muru oporowego z gabionów. Głównym celem jest ocena wpływu sposobu modelowania połączeń gabionów na stateczność muru.

**Słowa kluczowe:** gabion, mur oporowy, MES, stateczność

Symbols

$\phi$  – internal friction angle [deg]

$\gamma$  – soil bulk density [kN/m<sup>3</sup>]

$c$  – cohesion [kPa]

SF – stability factor [–]

## 1. Introduction

The main subject of the investigation is the influence of gabion-to-gabion joints on the behaviour of a retaining wall. In general, there are two forces acting against relative displacements between gabions – friction between gabions and joint resistance. Friction between gabions is described by the friction coefficient. Joints are usually made of steel wire or clips; they are characterised by strength, usually given per 1m of the retaining wall.

Friction between gabions is treated as a special case of friction between the gabion and the soil in this work. According to [3], the friction coefficient between gabion and soil can be estimated from the following equation:

$$\alpha_{ds} \tan \phi = \alpha_s \tan \delta + (1 - \alpha_s) \tan \phi \quad (1)$$

where:

$\alpha_d \tan \phi$  – friction coefficient between gabion and soil;

$\delta$  – friction angle between steel and soil;

$\alpha_s$  – ratio of steel area to total gabion-subsoil joint area;

$\phi$  – friction angle of the subsoil.

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

$$\alpha_{ds} = 1 - \alpha_s \quad (2)$$

Such an approach as that stated above is on the safe side as it leads to some underestimation of the friction forces between the gabions and the subsoil. In this work,  $\delta = 0$  is used and the friction angle of the gabion filling is used to obtain an approximation of the friction coefficient between gabions.

Three different approaches could be used to model the joint behaviour. The first way of modelling assumes that connection is ‘perfect’ and that no interface elements between gabions are necessary. This approach does not allow modelling the failure of the wall caused by joint failure.

The second approach (more conservative) leads to the use of Coulomb-Mohr law for interface elements between gabions, where the friction angle would determine friction between gabions and the cohesion would estimate the joint strength. This approach allows modelling the failure of the wall due to joint failure (during sliding of gabions), but is not capable of modelling the joint resistance to a gap opening up between gabions (Fig. 1).

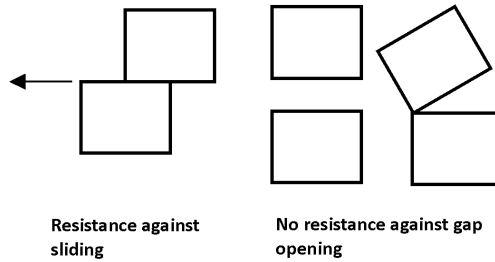


Fig. 1. Effect of the cohesion in the interface elements located between gabions

The required cohesion in interface elements can be calculated from the equilibrium equation of the joint capacity and part of the interface capacity is produced by cohesion:

$$c \cdot B = F_t \quad (3)$$

where:

$c$  – cohesion in the interface element [kPa],

$B$  – gabion width [m],

$F_t$  – tensile strength of joints per 1 m of the wall [kN/m].

This leads to:

$$c = \frac{F_t}{B} \quad (4)$$

The third approach (the closest to reality) leads to the modelling of joints between gabions with the use of two truss elements arranged symmetrically which are perpendicular to the gabion surface (Fig. 2). Friction in the interface elements is then responsible for modelling the friction between gabions, the cohesion in interface elements is an approximation of the joint resistance against sliding (similarly to the second approach) and joints are responsible for modelling resistance to a gap opening up between gabions.

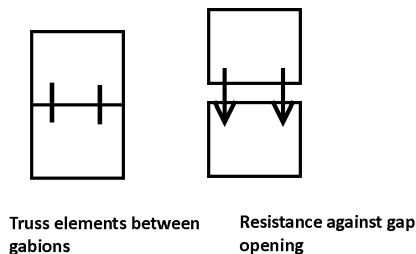


Fig. 2. Truss elements between gabions

Parameters of truss elements can be calculated from the following equations:

- ▶ equality of the joint capacity and ultimate load of truss elements:

$$F_t = f_{tl} \cdot A_1 \cdot 2 / 1m \quad (5)$$

where:

$f_{t1}$  – tensile strength of truss elements [kPa],

$A_t$  – cross-sectional area of truss element [m<sup>2</sup>].

- equality of axial stiffness of joints and truss elements:

$$A \cdot E \cdot 1m = A_t \cdot E_t \cdot 2 \quad (6)$$

where:

$A$  – area of joints per 1m of wall [m<sup>2</sup>/m],

$E$  – Young’s modulus of joints [GPa],

$E_t$  – Young’s modulus of the truss element [GPa].

From the above equations, the known properties of joints are  $F_p, A, E$ ; the unknown properties of the truss elements are  $f_{t1}, A_t, E_t$ . As can be seen, there are two independent parameters of the truss element – ultimate load  $f_{t1} \cdot A_t$  and axial stiffness  $A_t \cdot E_t$ , so one of the three required values ( $f_{t1}, A_t, E_t$ ) could be adopted arbitrarily and two others calculated from above equations.

## 2. Numerical experiment

A stability analysis of a 4 m high model retaining wall was performed. Two variants of the wall were analysed – firstly, with the wall not buried in the subsoil; secondly, with the wall buried in the subsoil to half the height of a single gabion (Fig. 3).

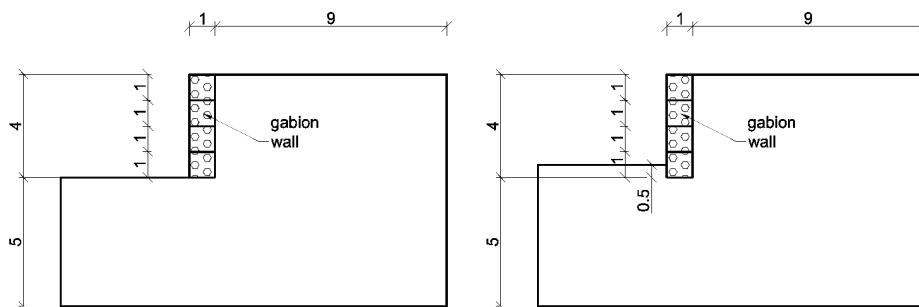


Fig. 3. Analysed object – not buried and buried in the subsoil (dimensions in metres)

A variety of retained soil and joint property combinations were used to obtain different modes of destruction and to judge in which situation the method of the modelling of joints affects the structure’s stability. All numerical simulations were performed in plane strain conditions with the use of ZSoil Finite Element Method (FEM) software, described in detail in [5] and [7]. The stability factor SF was estimated using the c-f reduction method described in [6]. An interface element was used between the soil and the gabions. The filling and steel mesh properties were taken from [4]. The friction coefficients between the gabion and the subsoil, and between the gabions were calculated according to equation (3). The joints between the gabions were modelled using the different approaches described above.

A joint strength of  $F_t = 20.4 \text{ kN/m}$  (minimum value according to ASTM A975 [1]) was used. An elasto-plastic Mohr-Coulomb model was used for retained the soil and the gabions. Additional cohesion for the gabions (which simulates the existence of the steel mesh) was calculated as described in [1] (strain at failure equal to 7% and tensile strength of the steel mesh equal to 20 kN/m were used as the input parameters of the mesh).

The obtained results show that for the wall not buried in the subsoil, the method of joint modelling does not affect the obtained stability factor values. However, for the wall buried in the subsoil to half of the height of one gabion, the situation is more complicated. For walls buried in the subsoil with low cohesion and high friction angle, the method of joint modelling does not have a significant influence on obtained SF values. However, for walls buried in the subsoil with low friction angle and high cohesion, such an influence can be easily seen. For such a wall, additional calculations considering 50% and 150% of minimum joint strength (according ASTM A975 [1]) were performed. The most important parameters of the retained soil and gabions used in such an analysis are presented in the Table 1.

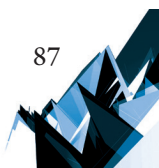
**Table 1.** Parameters of the gabion and soil (with high cohesion and low friction angle) used in the analysis of the influence of joint strength on the stability of a structure

	$c$ [kPa]	$\phi$ [°]	$\gamma$ [kN/m <sup>3</sup> ]
Soil	35	5	20
Gabion	27	43	23
Interface elements between gabions	0 (Approach 1) 20.5 (Approach 2, 3)	40	–
Interface elements between gabions and soil	0	40	–

Truss elements (responsible for the modelling of a joint's resistance to gap opening) with a cross-sectional area equal to  $A = 0.51 \text{ cm}^2$  each and  $f_{st} = 200 \text{ MPa}$  (which gives  $F_t = 20.4 \text{ kN/m}$ , as required by ASTM A975 [1]) were used.

An overview of the obtained results is presented in Table 2.

As can be clearly seen, SF increase due to the existence of joints between gabions is the greatest in Approach 3. Therefore, the influence of joint resistance to gap opening on wall stability is much more significant than the joint resistance against sliding. The total increase in the SF is equal to approx. 7.2%  $((1.64-1.53)/1.53)$ , the increase of the stabilising forces  $(1.64-1.53)/(1.53-1.00)$  is equal to approx. 20.7%. Such an influence is quite significant and could be taken into account in gabion wall design. However, the increase of the joint strength to 150% of the minimum strength required by ASTM A975 ([1]) does not have a significant influence on wall stability. The decrease of joint strength by approx. 50% results in some SF drops. Therefore, according to the obtained results required by ASTM A975 ([1]), the joint strength is reasonable for walls with a typical height of about 4 m.



**Table 2.** SF values obtained from analysis of the influence of joint strength on the stability of a structure

	50% of required joint strength	100% of required joint strength	150% of required joint strength
Ideal connection (no interface elements between gabions)	1.54		
Approach 1 (only friction in contact elements)	1.53		
Approach 2 (friction and cohesion in contact elements)	1.55		
Approach 3 (friction and cohesion in contact elements + truss elements between gabions)	1.61	1.64	1.65

A typical stability loss mode (failure mechanism) of the wall buried in the subsoil is presented in Fig. 4.

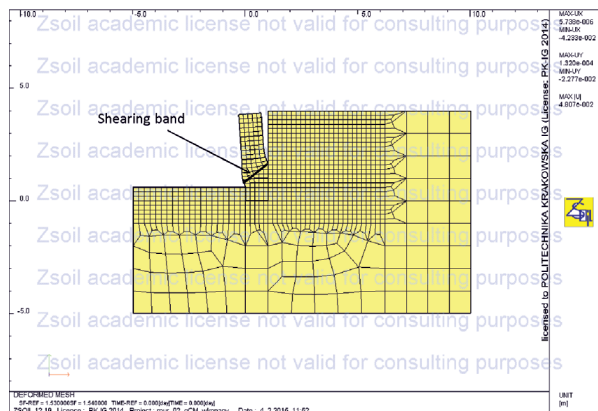


Fig. 4. Failure mode of the wall buried in the subsoil

### 3. Final remarks

The results of numerical simulations described above show that proper modelling of the joints between the gabions could affect the stability analysis results for the gabions buried in the soil with a small friction angle and high cohesion. For other situations, the influence of joints on a structure's stability is almost invisible. ASTM A975 ([1]) provides reasonable requirements for the strength of joints for typical walls with a height of approx. 4 m.

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