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Modelling interference between the geogrid bearing members under pullout loading conditions

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A B S T R A C T

The main interaction mechanisms affecting the pullout resistance of geogrids embedded in soils are the skin friction between soil and reinforcement solid surface and the bearing resistance which develops against transversal elements. As regards bearing resistance the interference mechanism plays an important role: this can occur when the spacing between transversal members is lower than a threshold value, depending on the extensions of active and passive surfaces mobilized on bearing members.

Based on the result of several large-scale pullout tests, a theoretical method to determine the peak pullout resistance of extruded geogrids embedded in a compacted granular soil is proposed. The method takes into account the interference mechanism due to the proximity of the transversal bearing members and works well for soil-geogrid interfaces in which scale effect is negligible.

1. Introduction

To model the behaviour of GRS structures using numerical methods requires knowledge of the constitutive model that should be adopted for reinforcement and soil, along with definition of the interface model. Therefore, it is essential to define the stress–-strain–time relationships of the system's constituent parts (Cardile et al., 2016b; Perkins, 2000) and to model the behaviour of the soil-geosynthetic interface while taking into account the complex mechanisms of interaction. A thorough understanding of these mechanisms could allow the production of geosynthetic reinforcements, optimizing costs and performance (Bathurst and Ezzein, 2015b; Calvarano et al., 2014; Esfandiari and Selamat, 2012; Ferreira et al., 2015; Hatami and Esmaili, 2015; Liu et al., 2009, 2016; Moraci and Cardile, 2008; Moraci and Cardile, 2009, 2012; Moraci and Recalcati, 2006; Mosallanezhad et al., 2016; Pinho-Lopes et al., 2016; Sieira et al., 2009; Suksiripattanapong et al., 2013; Tran et al., 2013; Vangla and Gali, 2016; Vieira et al., 2013; Wang et al., 2014, 2016).

The soil geosynthetic interaction can be very complex. Direct shear tests and pullout tests can simulate both mechanisms in laboratory, using large size devices.

For soil-geotextile interfaces the only mechanism that develops is the skin friction, while for soil-geogrid interfaces the interaction becomes more complex due to the open structure of this type of geosynthetic. The main interaction mechanisms concerning pullout resistance of extruded geogrids embedded in compacted soil are the skin friction between soil and reinforcement solid surface and the bearing resistance that develops against transversal members (Jacobs et al., 2014; Moraci et al., 2007, 2014a; Moraci and Gioffrè, 2006; Palmeira, 2009; Ziegler and Timmers, 2004). Therefore, the ultimate pullout resistance of geogrids has been typically interpreted as the sum of the passive and interface shear components (Jewell, 1996):

$$P_R = P_{RS} + P_{RB} \tag{1}$$

where P_{RS} is the skin friction component of pullout resistance and P_{RB} is the bearing component of pullout resistance.

Generally, the two components are assumed to be independent of each other when it should be considered that one mechanism of interaction affects the other to an extent not yet well understood or quantified.

The first term on the right-hand side of Equation (1), for a geogrid of length L_R and unit width W_R (Fig. 1), may be evaluated

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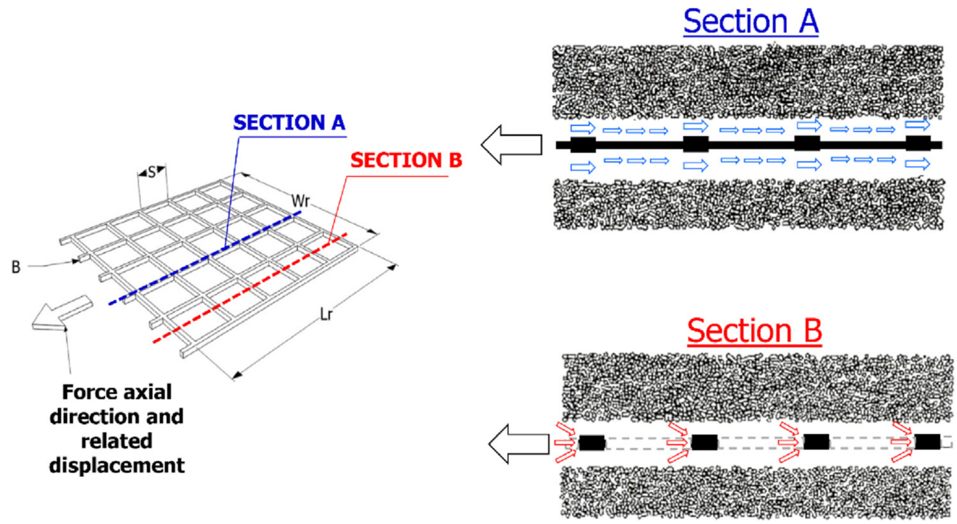

Fig. 1. Schematic representation of grid geometry (Jewell et al., 1985).

using the following expression:

$$P_{RS} = 2 \cdot \alpha_S \cdot L_R \cdot \tau = 2 \cdot \alpha_S \cdot L_R \cdot \sigma_n^{'} \cdot \tan\delta \tag{2}$$

where $\sigma_n^{'}$ is the effective normal stress; δ is the skin friction angle between soil and geogrid; τ is the shear stress acting at soil-reinforcement interface; α_S is the fraction of geogrid surface area that is solid.

According to Jewell (1990), the bearing component of pullout resistance can be evaluated as follows:

$$P_{RB} = \left(\frac{L_R}{S}\right) \cdot \alpha_B \cdot \sigma_b^{'} \cdot B \tag{3}$$

where S is the spacing between the geogrid bearing members; L_R/S is the number of geogrid bearing members; α_B is the fraction of total frontal area of geogrid available for bearing resistance; B is the thickness of the bearing members; σ'_b is the effective bearing stress mobilizing on geogrid bearing members.

To evaluate the bearing stress σ'_b, different failure mechanisms can be used. Jewell et al. (1985) used a punching failure mechanism (lower bound); Peterson and Anderson (1980) used a general shear failure (upper bound); Bergado and Chai (1994) used a modified punching mechanism; Matsui et al. (1996) used a Prandtl failure mechanism.

For granular soils, the bearing stresses σ'_b acting on geogrid bearing members depend on soil shear strength angle, initial stress state, interface roughness and reinforcement depth in relation to the sizes of the bearing members. In spite of this, in the equations proposed by the different authors, the ratio σ'_b/σ'_n only depends on soil shear angle.

Therefore, the pullout resistance of a geogrid is:

$$P_R = 2 \cdot \alpha_S \cdot L_R \cdot \sigma'_n \cdot \tan\delta + \left(\frac{L_R}{S}\right) \cdot \alpha_B \cdot B \cdot \sigma'_b = 2 \cdot f_b \cdot L_R \cdot \sigma'_n \cdot \tan\phi' \tag{4}$$

where f_b is the interaction coefficient under pullout loading conditions.

The coefficient f_b can be obtained as a function of reinforcement geometrical parameters (α_s, α_b, B, S), soil shear strength angle (ϕ'), soil-geosynthetic skin friction angle (δ), and effective stresses acting at the interfaces (σ'_n, σ'_b):

$$f_b = \alpha_S \cdot \left(\frac{\tan\delta}{\tan\phi'}\right) + \left(\frac{\alpha_b \cdot B}{S}\right)' \cdot \left(\frac{\sigma'_b}{\sigma'_n}\right) \cdot \frac{1}{2 \cdot \tan\phi'} \tag{5}$$

In the theoretical Equation (5), there are two components representing both skin friction and bearing interaction.

The interference phenomenon for closely spaced bearing members S (i.e. for small value of the ratio between S and the thickness of transverse ribs B_{eq}) plays an important role in the mobilisation of the bearing resistance. To be more precise, a significant part of the surface of the longitudinal members of the reinforcement is involved in this phenomenon, suggesting that under similar conditions the skin friction (for extruded geogrids it generally represents less than 20% of the pullout resistance) also decreases.

Some researchers (Bergado et al., 1993; Dyer, 1985; Jewell, 1996; Milligan et al., 1990; Palmeira, 2004, 2009; Palmeira and Milligan, 1989) found that the bearing resistance also depends on the ratio between the thickness of transverse rib B_{eq} and the soil mean particle size D_{50} (i.e. scale effect) and on the shape of the transverse rib.

2. Interference mechanism for closely spaced bearing members

When pullout-loading acts on the soil-geosynthetic system the mobilisation of soil passive resistance developed in front of the bearing surface of transversal rib causes a stress increase and causes rotation of the principal stresses (Palmeira, 2004). The pullout displacement of the geogrid implicates that behind each transversal rib the stress decreases forming a disturbed region (softened region), which will affect the maximum bearing strength developed along the following bearing members if they are too close to each other.

Recently, different researchers have analysed the behaviour at the interface using a micro-image analysis system (Bathurst and Ezzein, 2015a, b; Ezzein and Bathurst, 2014; Zhou et al., 2012). The novel combination of technologies allows the measuring of the complete displacement field of reinforcement and/or target particles seeded in the surrounding soil during pullout tests. Zhou et al. (2012), using micro-image analysis captured the interaction mechanisms between sand and the transverse ribs of reinforcement: the geogrid was located close to the glass side wall, so that it might be captured. In order to clarify the interaction mechanisms