Measurement 62 (2015) 187–196

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Novel strip-anchor for pull-out resistance in cohesionless soils

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ARTICLE INFO

Article history:
Received 19 July 2014
Received in revised form 15 October 2014
Accepted 28 October 2014
Available online 5 November 2014

Keywords:
Finite element modeling
Pull-out resistance
Reinforced soil
Retaining wall
Soil reinforcement
Strip-anchor

ABSTRACT

In this research, a novel reinforcing element is introduced. It includes a series of extra elements (anchors) that are attached to conventional steel strips. The new elements increase the pull-out resistance of the reinforcements and reduce the anchorage length. A total of 55 pull-out tests were performed to evaluate the pull-out resistance and optimum geometry of the new system. The effect of the anchor's angle, length and spacing, as well as the influence of the dimensions of the cubic anchors on the coefficient of interaction ratio (CIR_p) were investigated. The coefficient of interaction ratio directly affects the pull-out capacity – the number of anchors on the anchorage length. As a result, the pull-out resistance increased significantly with the addition of new anchors to the conventional reinforced strip. Test results indicated that the use of strip anchors increased the ultimate pull-out resistance under surcharge pressures of 50, 100, 120 and 150 kPa by factors of 7.4, 4.95, 4.3 and 4.3, respectively, in comparison with conventional strips. The finite element method (FEM) was also used to compare and verify the results of the experimental pull-out. It was observed that the results of the FEM were in good agreement with the laboratory test results.

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1. Introduction

Soil reinforcement represents a promising way to improve the stability of embankments, steep slopes and walls. A mechanically-stabilized earth wall is a composite material formed by the combination of soil and metallic or synthetic strips such that it can maintain itself against significant tensile loads. The reinforcing strips give the soil mass an anisotropic cohesion in the direction perpendicular to the reinforcement [1]. The presence of the strips improves the overall mechanical properties of the soil. Generally, the design methods used in these structures are based on internal and external stability analysis and limit equilibrium methods. For internal stability, a common method is based on the verification of the strips' long-term tensile force and the adherence (or bond capacity) at the soil/strip interface [2–4]. Although this method is easy to use, it may result conservative for the geosynthetic reinforcement [5–8]. Besides, this design method straightforwardly allows for the structure's stability to be verified [9].

As stated, current design practice for reinforced soil-retaining walls is based on the limit equilibrium approach. Such reinforced walls must be designed using both external and internal stability criteria. The embedded reinforcement within the soil mass can significantly improve the mechanism of load transfer between the soil and the reinforcement. The design of the reinforcement length should satisfy the minimum required safety of factors for all possible failure modes [6]. Therefore, the pull-out resistance of the reinforcements is one of the prominent factors pertinent to increasing the stability of reinforced soils.

Traditionally, in the design of reinforced-soil projects in Iran, a minimum reinforcement length equal to 70% of the wall height is considered. However, in most cases there is

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http://dx.doi.org/10.1016/j.measurement.2014.10.046
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Nomenclature

S-A	strip-anchor system of reinforcing	δ	skin friction angle between soil and reinforcement
w	strip width	φ	initial friction angle
α	angle of anchor against pullout force vector	C	soil cohesion
l	length of anchor	Ca	skin cohesion between soil and reinforcement
d	spacing between anchor	CIR_P	coefficient of interaction ratio in pullout
a	dimension of anchor's cubic	σ_n	surcharge pressure
PRR	pullout resistance ratio	τ_a	shear stress
C_i	coefficient of Interaction	L	length of strip
σ_v	vertical stress		

not enough space behind the reinforced wall to satisfy such required reinforcement lengths. This may be due to an existing natural rock formation, a man-made shoring system or even the presence of another reinforced soil-retaining wall.

In order to make new advances in the optimization of the design method, it is essential to understand the behavior of these structures. There are many studies that have aimed to extend and optimize the publicly-available design methods. In general, experimental studies are inexpensive and eliminate time-consuming full-scale experiments. These studies have tended to focus on the definition of the parameters of new elements, such as new reinforcement types, new facing panels or even the interface between the soil and new reinforcement types [10–12].

The steel strip is one of the most commonly-used forms of reinforcement. If the load transmitted to the strip exceeds its mechanical resistance, either of two mechanisms may occur: the failure of the material or pull-out failure (Fig. 1). However, in the design of reinforced structures other types of internal instabilities should be considered, such as the failure of connections, the rupture of facing panels and the toppling or sliding of facing blocks, among others. Both of the mentioned failure mechanisms may act progressively, as the collapse of one element results in transferring the load to adjacent elements. This progressive failure process may occur at isolated sections of the strip, with no harm to global stability.

Therefore, it is necessary to perform pull-out tests in order to study the interaction-behavior between the soil and the reinforcement, particularly in the anchorage zone. Thus, these properties have direct implications for the design of reinforced-soil structures. The test method is intended to be a performance test conducted as closely as possible so as to replicate designed or as-built conditions [14].

Pull-out behavior has been studied by several researchers with a view to understanding various factors affecting the pull-out response of reinforcement (e.g., box size, sample size, sleeve length, front- as well as side-wall conditions, and test speed) [15–19]. Bergado et al. [20] and Khedkar and Mandal [21] have also simulated pull-out tests using the finite element method-based software 'Plaxis'. Racana et al. [22] studied the geometric arrangement of reinforcements (i.e., horizontal, vertical and corrugated steel strips) in order to achieve shorter anchorage lengths. They found that the corrugated geometry is better than the other two reinforcement geometries and, from the practical point of view, corrugated strips are suggested for reinforcement, forming a network of geocells filled-in with compacted soil. Bergado et al. [23], Palmeria and Milligan [17] and Nernheim [24] have also investigated on the pull-out capacity of reinforced-soil structures, highlighting that that the geometry of the reinforcement is one of the most important factors in the study of pull-out. Bhattacharya and Couch [25] stated that the effect of drainage conditions on pull-out capacity is another significant factor believed to be responsible for the failure of a number of earth-reinforced structures.

Bergado et al. [26] investigated the pull-out resistance of steel geogrids embedded in poor-quality, cohesive-frictional

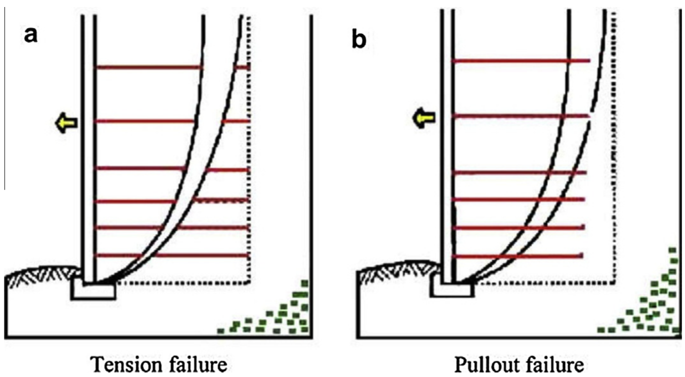

Fig. 1. Internal instability mechanisms (Sieira et al. [13]).

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