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Technical note

A new methodology to assess the structural safety of anchored retaining walls

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ABSTRACT

This paper proposes an assessment technique for the structural safety of anchored concrete panels after anchor ruptures. The methodology was developed using anchored panels located in Gramado-RS, Brazil, where 41 anchors ruptured at different positions. Being the original project of the panels known, their structural safety was evaluated using a finite-element software. Bending moments and punching were verified for each panel and their structural safety was classified into stability levels. The results were compared to in situ observations from technical inspections. The calculation methodology proposed in this research showed to be a useful tool for analyzing the structural stability of anchored panels.

1. Introduction

Landslides have been a major issue in many regions of Brazil in the last years. This phenomenon is more frequent during rainy periods, due to the increase of pore water pressure in the soil caused by seepage flow [1]. This sort of events may occur not only in urban areas (such as the landslides in the state of Santa Catarina, in 2008, and also in Rio de Janeiro, in 2011, both in Brazil), but also on highways and countryside areas.

In such context, the construction of earth retaining structures is required in order to reduce the incidence of these landslides [1]. Many earth retaining techniques have been developed along the last decades, such as soil nailing, ground improvement and anchored walls, which are studied in this paper. According to More [2], anchored walls are the most suitable earth retaining structures when high horizontal lateral pressure caused by high excavations has to be retained.

Ortigao and Brito [1] state that tie-back walls are reinforced concrete structures linked to the ground by steel bar anchors. These anchors are responsible for transferring the lateral pressure from the wall to more resistant ground layers [3]. Therefore, the rupture of an anchor decreases the safety of the slope retained by the wall composing panels, leading sometimes to the collapse of the system and consequently to landslides or rockfalls. However, it is known from the authors experience that these structures may present anchor ruptures in different positions along the facing panels without collapsing. This raises a question on how to assess whether an anchored concrete panel is safe after one (or more than one) anchors rupture.

Hence this paper aims to introduce an assessment technique for the performance of the facing panels after anchor ruptures of an anchored wall system. Although the proposed method is developed using one particular case, it should be seen as a first attempt of developing more accurate methodologies. The paper is divided into five topics: (1) anchored walls, (2) characteristics of the anchored system, (3) calculation procedure and computer simulations, (4) results and analysis and (5) final remarks.

2. Anchored walls

Anchored walls are retaining systems whose effectiveness depends on the good performance of both the wall and the anchors [4]. The anchors consist of post-tensioned steel elements and one of their extremities is usually anchored to reinforced concrete panels, while

Abbreviations: A_s, cross sectional area of steel bars [m^2]; b, bottom dimension of the structure [m]; d, distance from the center of gravity of the tension reinforcement section to the extreme fiber of the compression zone of the concrete [m]; f_{cd}, compressive strength of concrete multiplied by the partial factor of safety (γ_c) [MPa]; f_{ck}, compressive strength of concrete [MPa]; FS_{bm}, actor of safety for bending moments; FS_p, factor of safety for structural punching; f_{yd}, yield strength of steel multiplied by the partial factor of safety (γ_s) [MPa]; f_{yk}, yield strength of steel [MPa]; M_d, characteristic bending moment multiplied by the partial factor of safety (γ_f) [MNm]; M_k, characteristic bending moment [MNm]; x, neutral axis position [m]; α_v, (1- f_{ck}/250), with f_{ck} in MPa; γ_c, partial safety factor for the compressive strength of concrete; γ_f, partial safety factor for the bending moments; γ_s, partial safety factor for the yield strength of steel; ρ, cross sectional area of steel bars / cross sectional area of concrete ratio; τ_{Rd1} and τ_{Rd2}, resisting punching stresses for first and second critical surfaces [MPa]; τ_{Sd1} and τ_{Sd2}, applied punching stresses for the first and second critical surfaces (τ_{Sk1} and τ_{Sk2}) multiplied by the partial factor of safety (γ_f) [MPa]; τ_{Sk1} and τ_{Sk2}, applied punching stresses for the first and second critical surfaces [MPa]

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the other extremity is grouted to a resistant ground stratum. As none of the elements can work individually, a good performance of both wall and anchor is required to preserve the stability of this kind of structure [4]. For this reason, both the anchor-soil bond and the anchor-wall interaction play a fundamental role in the performance of the anchoring system. In certain anchored walls, foundations systems – mainly piles – may be necessary to support the weight of the facing panels [1,3]. Other anchored structures, though, are self-supporting and do not need any sort of foundation. This depends mainly on direction of the anchors, i.e. their angle of orientation with the horizontal. Anchored systems whose anchors are more inclined to the horizontal are more prone to require a sort of footing [1,3].

Despite the several control techniques and qualification tests during construction, which are required by the Brazilian Standard NBR 5629 [5], failures may still occur in anchored concrete panels, either in the anchors or on the concrete structure. According to Hanna [6], an anchor may fail in six different modes: failure of the grout/tendon bond, failure of the ground/grout bond, failure within the ground mass, failure of the tendon steel or a component, failure or bursting of the grout column surrounding the tendon, failure of a cluster of anchors. This group of failure modes (anchor failure) is part of only one of other six failure modes that can occur on the wall: anchor failure, excessive deformation, toe bearing failure, bottom failure, generalized failure and wall failure [1]. Fig. 1 illustrates the six failure modes for tie-back walls. Despite all the aforementioned failure modes, this research aims to give special attention to wall failure, i.e. the failure that may occur on the concrete panels. This kind of failure may occur due to insufficient steel reinforcement or punching failure at the anchor head [1,3] and leads to a redistribution of the anchor loads. In other words, when an anchor breaks, the load that was supported by it will be supported by other anchors.

Stille and Brooms [7] studied this redistribution of anchor loads in a sheet pile wall. That research, which was developed with anchors inclined at an angle of 45° with the horizontal, showed that the rupture of one single anchor is sufficient to change the loads in the remaining ones. The researchers also showed that great part of the load of a ruptured anchor is absorbed by the foundation, mainly due to the increase of friction between soil and wall after the rupture. The friction between soil and wall suffers a considerable increase after one anchor ruptures because the bend between the anchor rows pushes the soil against the structure. Thus, not the whole load of the ruptured anchor is distributed to the neighboring ones. According to them, this phenomenon may lead to divergences between numerical simulations and the actual state of this type of anchoring systems.

3. Characteristics of the anchored system

The studied structure consists of eight anchored concrete panels located on the ERS-115 road, km 38 + 000, between the cities of Taquara and Gramado, in the state of Rio Grande do Sul, southern Brazil. The panels support the highway embankment and were constructed in the end of the 1980s under the supervision of the Department of Highways of Rio Grande do Sul (DAER-RS), after a series of landslides occurred during a rainy season. These landslides reached the highway axis, damaging the pavement and interrupting the traffic.

Each of the eight reinforced concrete panels is approximately 10 m long, 13 m high and 0.35 m thick. An overview of the anchored wall is presented in Fig. 2 and the geometry of the panels is shown in Fig. 3. Vertical displacements in the base of the panels were prevented as they were supported by a resistant residual soil layer. This resistant layer was excavated up to 75 cm in order to support the panels' weight in such a way that the residual soil worked as a direct foundation (Fig. 4). The original anchorage system was constituted of 201 single-bar tendons with a workload of 350 kN each, determined by load tests carried out right after anchor installation. Each single-bar tendon has approximately 6 m bonded length and 3 m to 12 m unbonded length. Support plates with dimensions 25 cm × 25 cm were installed between anchor heads and concrete panels in order to avoid punching. The ends of the tendons are grouted to basalt rock, hence they are assumed to be fixed. During technical inspections carried out in 2013, it was verified that 41 anchors were ruptured or loose, due to advanced corrosion issues. Thus reinforcing works took place in 2014, with the construction of a gabion wall in front of the concrete panels (Fig. 5). The original

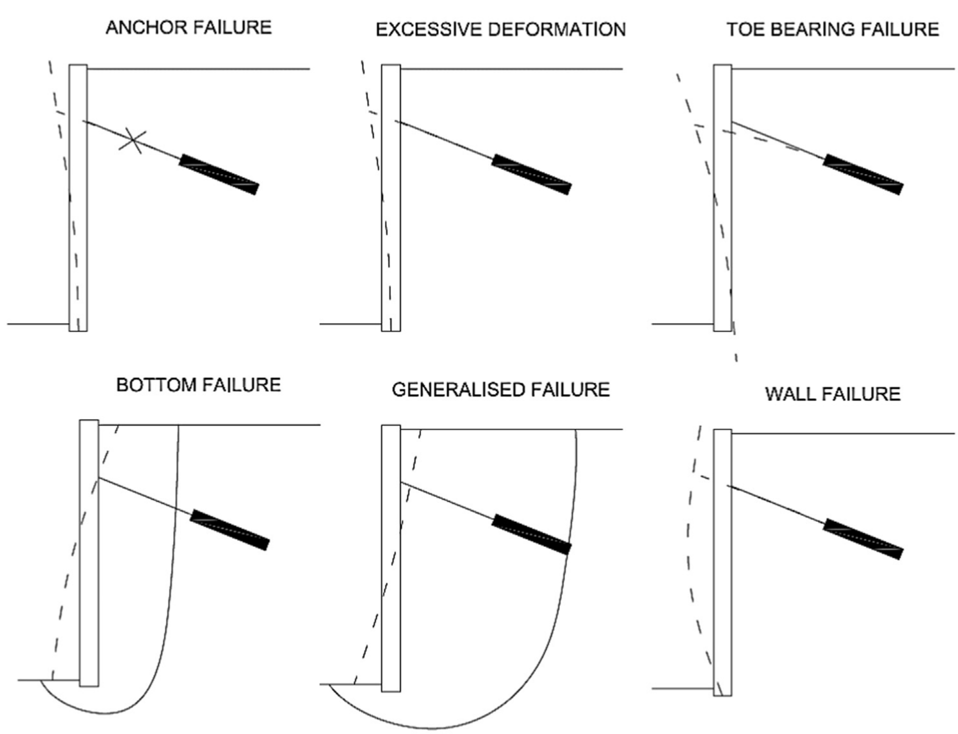

Fig. 1. - Failure modes of tie-back walls (adapted from [3]).