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Effect of the anchoring pattern on the mechanical behavior of anchored mesh systems

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ABSTRACT: Anchored mesh systems constitute a widely adopted protective mitigation measure against rockfall, particularly suitable for highly weathered sub-vertical rock face. These systems are composed of steel wire mesh panels combined with a regular anchoring pattern. In this work, we investigate by means of discrete element simulations the mechanical behavior of the mesh with the commonly adopted quincunx-like (or diamond) anchoring pattern, comparing with what we have already found for the square pattern. The effects of the loading condition and the mesh system properties on the out-of-plane response of the system are evaluated and analytical relationships for quantifying the mesh punching resistance and maximum deflection are proposed. The results allow quick assessment of the suitability of the design choices and provide an insight on the force transmission paths during the loading of the mesh system.

1. INTRODUCTION

Anchored mesh systems represent one of the mainly used structural mitigation measures for both preventing and protecting against either rockfalls or shallow instability in sub-vertical rock faces, in which the disaggregation of the surface part of the slope can lead to local slides and/or detachments of unstable blocks (Bertolo et al., 2009). These structures are composed of steel wire mesh panels combined with a regular anchoring pattern, with the possible addition of high-strength ropes (Marchelli & Giacchetti, 2021). The anchoring system is responsible for the global stability of the shallow weathered layer of the slope, but it can also greatly influence the mechanical behavior of the mesh, that should confine granular debris or unstable blocks into delimited mesh sections. The choice of the geometrical properties of the anchoring system, mainly spacing and pattern, represents a fundamental step in the design of these protective systems. Nowadays, information on the impact of the anchor pattern on the mesh behavior is scarce (Xu et al., 2019) and design choices are therefore mostly based on engineers' work experience.

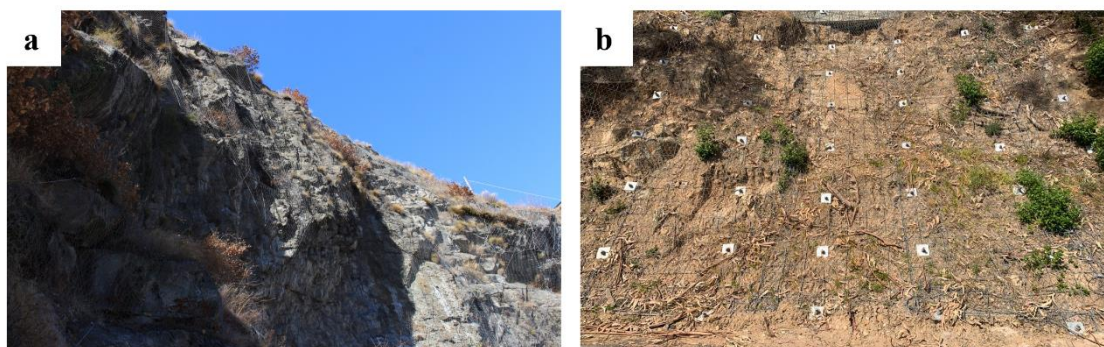


Figure 1 Reinforced drapery meshes with (a) diamond (Hône, Italy) and (b) square (Cannes, France) anchor pattern.

In this work, we analyse the mechanical response of an anchored mesh to a out-of-plane loading condition, as the one caused by the local detachment of a rock block from the slope surface. Firstly, we focus on the effects of the loading conditions (single and multi-block cases) and of the mesh system geometrical properties on its out-of-plane response when adopting a diamond (or quincunx-like) anchoring pattern (Fig. 1a). Then, we present a comparison with the widely adopted square/rectangular anchoring pattern (Fig. 1b), based on data from a previous work (Marchelli et al., 2023, Pol et al. 2021b), highlighting the implications of the pattern geometry on the load transmission inside the mesh and on the mechanical response of the mesh system. As a natural development of previous works by the authors, we derive analytical formulations to forecast the mechanical response of the mesh, starting from the results of the standard laboratory punch test (ISO 17746, UNI 11437).

2.METHODOLOGY

2.1.Numerical model

In this work, the wire mesh is simulated within the framework of the discrete element method. A node wire-based approach is adopted which consists in simulating the mesh as an ensemble of spherical (nodal) particles that are connected by long-range interactions. These interactions account for the mechanical behavior of the wires and are defined starting from user-defined tensile stress-strain curves (see Thoeni et al. (2013) and Pol et al. (2021a)). In analogy with previous studies by the authors a large-scale model of an anchored mesh system is adopted. The reference model consists in a 10.8 m x 10 m system with a diamond anchors pattern, with square anchors of side length $d_{plate}=0.20$ m. The reference anchor spacing is $H=3.6$ m horizontally and $V=5.0$ m vertically (nominal area of 9 m²). Periodic boundary conditions are imposed on the border of the mesh system to simulate the presence of neighboring panels. The same numerical parameters as in Marchelli et al. (2023) are used in this study. Simulations are performed with the open-source code YADE (Šmilauer et al. 2023).

The mesh system is loaded by a punching element which shape follows the requirements of the punch test standard (ISO 17746, UNI 11437): a spherical dome with a diameter $d_{punch}=1$ m. The 8 x10 hexagonal double-twisted steel wire mesh with a nominal wire diameter of 2.7 mm (Maccaferri producer) is considered in the present study. For the “single load” case the punching element is located at the center of the mesh system, while for the “periodic load” case a punching element is placed at the center of each mesh panel. In this work, the mechanical response of the mesh is described with its characteristic force–displacement curve obtained by recording the force acting on the punching element (F) and its displacement (δ). In the periodic case the punching element acting on the central mesh panel is used as reference (negligible variations are observed if referring to the other punching elements). The system failure is caused by the tearing of some wires at the mesh-plate connection with a rapid propagation of the damage throughout the mesh. This translates in a sudden decrease of the force value in the force-displacement curve.

2.2.Parametric analysis

Starting from the reference configuration, a parametric analysis is conducted to estimate the effect of the geometrical characteristics of the mesh system (anchor spacing, anchor plate size d_{plate} , panel aspect ratio H/V) and of the loading conditions (punching element size and single/periodic condition) on the force–displacement response of the mesh. The parametric analysis is performed considering a variation of the problem’s variables which reasonably covers the typical range in common practice (Table 1). For each case, the force–displacement response and force and displacement values at failure, F_r and δ_r , respectively, are considered. Input and output values are normalized (\sim superscript) with respect to reference values (Table 1). The force and displacement values at failure are normalized with respect to the characteristic values obtained from laboratory punch tests ($F_r = 67.6$ kN and $\delta_r = 0.565$ m).

Table 1. Considered layouts for the DEM analyses

| Parameter | Range | Normalized range | Normalization value |
|---------------------------------------|------------------------|------------------|---------------------|
| Horizontal anchor spacing H (m) | 2.2-8.7 (step 0.15 m) | 0.7-2.9 | 3 m |
| Vertical anchor spacing V (m) | 2.5-9 (step 0.15 m) | 0.83-3 | 3 m |
| Anchor plate size d_{plate} (m) | 0.12-0.4 (step 0.04 m) | 0.6-2 | 0.2 m |
| Punching element size d_{punch} (m) | 0.5-2 (step 0.25 m) | 0.25-2 | 1 m |

3.RESULTS AND DISCUSSION

3.1.Mechanical behavior of the anchored mesh

The results of the parametric analysis are reported in Figure 2 in terms of force and displacement values at failure. Results for the diamond pattern are compared to those for the square one (Pol et al., 2021a) for periodic and for single load cases (Marchelli et al., 2023). It can be observed that a larger plate side determines an increase of the force that can be sustained by the mesh panel for both the loading conditions (Figs. 2a-b). This is in agreement with previous works with a square anchor pattern and confirms that the available puncturing resistance of an anchored mesh is controlled by the number of wire elements that are intercepted by the anchor plates. Conversely, the anchor plate dimension has no influence on the final out-of-plane displacement of the system. Concerning the effect of the punching element size, it can be observed that the puncturing resistance of the system is mostly unaffected by a variation of \tilde{d}_{punch} , while the associated displacement decreases when increasing \tilde{d}_{punch} (Figs. 2c-d). The general trend of the force and displacement at failure is similar for the single and the periodic loading conditions. The influence of the panel size and of its aspect ratio, i.e. $AR=H/V$, on the force and displacement values at failure are displayed in the contour plots of in Figure 2(e-h) in terms of \tilde{H}/\tilde{V} . In the plot the dashed blue lines represent cases with a constant \tilde{AR} but different panel's area (or anchoring density), while moving along a red curve one can compare equal-area panels with a different \tilde{H}/\tilde{V} . Firstly, it can be observed that the deflection at failure increases when increasing the panel area, independently of the loading condition. A variation of the panel aspect ratio has instead a different impact on the mechanical response of the mesh system depending on the imposed loading condition. Although there is no monotonic trend, some qualitative trends can be observed. For the periodic load case the maximum force sustained by the system seems to increase when increasing \tilde{AR} (Fig. 2e), even though the variation is not so pronounced. No significant variations of the mesh deflection are observed for equal-area panels when changing the AR . For the single load case an opposite tendency is observed. The force at failure globally increases when reducing AR and an optimum condition seems to occur for \tilde{AR} equal to 0.7. The deflection at failure instead slightly decreases when increasing the panel \tilde{AR} . It should be noted that a different impact of the panel aspect ratio on its mechanical response has been observed when using a square anchoring pattern (see Pol et al. 2021a, Marchelli et al. 2023). This difference is mainly a consequence of the variation of the directions of the force transmission inside the mesh panels when using a different anchoring pattern. This aspect is discussed in Section 3.2.

3.2.Comparison with the square anchor pattern

Figure 3 reports the $F - \delta$ response obtained for different loading conditions (single and periodic cases) and for the diamond and square anchoring patterns (for this last refer to Marchelli et al. 2023, Pol et al. 2021b). It is evident that the system can support a higher puncturing force in the single load case than in the periodic one. This is due to load redistribution with neighboring panels in the former case, while for the periodic case each panel is equally loaded and redistribution among panels is no more possible (Pol et al. 2021a).

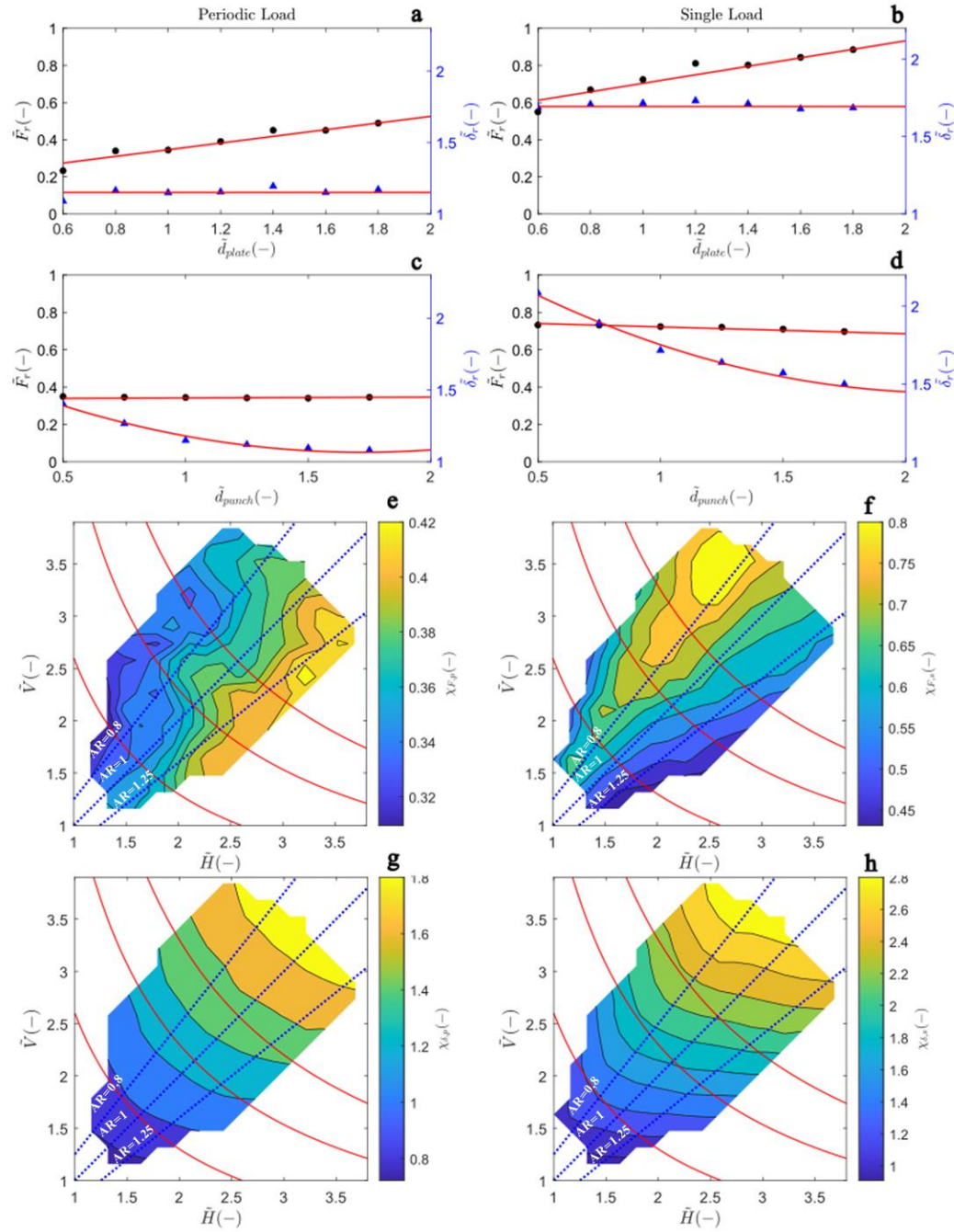


Figure 2. Effects of the system normalized parameter on F_r (black dots markers) and δ_r (blue triangles markers): (a)-(b) anchor plate dimension d_{plate} , (c)-(d) punch dimension d_{punch} . Red and magenta lines represent the considered fits. The contour plots (e-h) show the effects of the panel geometry on F_r and δ_r (solid red lines indicate panels with equal area and blue dashed lines panels with a constant AR). Left (right) column refer to periodic (single) loading conditions.

The anchoring pattern has a significant impact on the transmission of the external force among the mesh wires. Figures 3c-f display the tensile force distribution among the mesh wires f_w , an instant before the mesh failure, for the four cases mentioned above. The force on each wire is normalized (\tilde{f}) with the maximum force value characteristic of the wire type ($f_r=3.03$ kN and $f_r=5.95$ kN for the single and double twisted wire respectively) allowing direct comparison between single and double twisted wires. Major differences are observed in terms of force transmission mechanism inside the mesh for the two anchoring patterns. For the diamond pattern (Figs. 3b,c), two main mechanisms develop: (i) a vertical migration mechanism from the center to the top and bottom anchors, (ii) a horizontal migration mechanism from the center to the middle

height anchors. A diagonal migration of the load between middle height and top/bottom anchors is also observed, but it is of lesser importance compared to the mechanisms mentioned above. It should be noted that the former mechanism favors the force transmission along the direction of the double twisted wires, and being these elements characterized by the highest tensile resistance it allows a better exploitation of the mesh mechanical resistance. This mechanism is enhanced when reducing the ratio H/V between the horizontal and vertical anchor spacing and may explain the improvement of the mesh mechanical response when reducing AR discussed in Section 3.1. For the square case (Figs. 3d,f), a single force transmission mechanism is instead observed: the force inside the panel is mainly transmitted diagonally migrating from the center of the panel to the four anchors. It should be noted that these findings refer to a hexagonal double twisted mesh, and are not representative of different mesh types, mostly due to the differences in the geometry of the elementary cell of the mesh and wire mechanical properties.

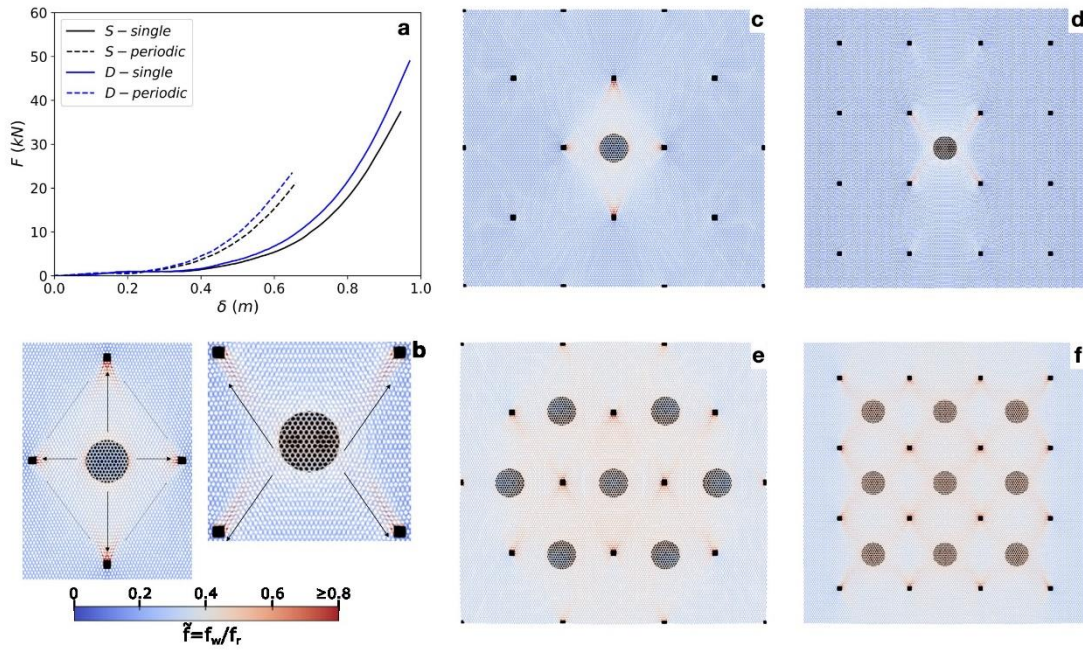


Figure 3 (a) Comparison of the mesh mechanical response between the square (S) and the diamond (D) anchoring patterns. (b) Typical force transmission mechanism for the single load case for the D and S patterns. Force distribution among the mesh wires an instant prior to the mesh failure: (c) single load case for D, (d) single load case for S, (e) periodic load case for D, (f) periodic load case for S.

3.3. Towards field conditions

The previous analyses allow deriving analytical relations that could be combined to estimate \tilde{F}_r and $\tilde{\delta}_r$ for a given geometrical and loading configuration (see Marchelli et al. 2023 for the procedure), thus permitting extension of the experimental results to common on-site configurations. A simple linear transformation is applied, assuming a non-dependence among the effects of the system's parameters. For the periodic and the single load case, respectively, the equations are:

$$\begin{cases} \tilde{F}_r = 8.43(0.18\tilde{d}_{plate} + 0.17)(0.04\tilde{d}_{punc h} + 0.34)\chi_{F,p} \\ \tilde{\delta}_r = 0.87(0.22\tilde{d}_{punc h}^2 - 0.75\tilde{d}_{punc h} + 1.71)\chi_{\delta,p} \end{cases} \quad (1)$$

$$\begin{cases} \tilde{F}_r = 1.91(0.23\tilde{d}_{plate} + 0.47)(-0.04\tilde{d}_{punc h} + 0.76)\chi_{F,s} \\ \tilde{\delta}_r = 0.58(0.22\tilde{d}_{punc h}^2 - 0.97\tilde{d}_{punc h} + 2.50)\chi_{\delta,s} \end{cases} \quad (2)$$

To forecast the mechanical response of a given anchored mesh panel with reference to the out-of-plane loading conditions, the \tilde{F}_r and $\tilde{\delta}_r$ values (Eqns. 1 and 2) are then coupled with relations, one for each load conditions, that allow derivation of the entire $F - \delta$ response. They are defined considering all the cases of the parametric analysis normalized each with respect to F_r and δ_r . The data collapses very well on a single $F - \delta$ curve for each load case. The data are fitted (non-

linear least square regression model) to obtain a master curves described by the following expressions:

$$\begin{cases} \tilde{F} = -0.09\tilde{\delta}^4 + 2.01\tilde{\delta}^3 - 1.2\tilde{\delta}^2 + 0.29\tilde{\delta} & \text{for the periodic case} \\ \tilde{F} = 1.64\tilde{\delta}^4 - 0.76\tilde{\delta}^3 + 0.01\tilde{\delta}^2 + 0.11\tilde{\delta} & \text{for the single case} \end{cases} \quad (3)$$

Note that the effect of the panel's area and aspect ratio are condensed in the parameter χ . Equations (1), (2), and (3) are valid in the range of the parameters considered here and should not be directly used with reference to other mesh types or loading configurations.

4.CONCLUSIONS

The results of this work can be of great help to practitioners during the design of anchored drapery systems allowing quick assessment of the suitability of the design choices. Knowing the surface conditions and prevalent loading case, the proposed analytical relations allow estimation of the force-displacement behavior of the mesh system and provide a useful starting point for the design of anchored mesh systems. Analogous relations were proposed in previous works (Pol et al. 2021b, Marchelli et al. 2023) for the square anchor pattern case. More complex ground conditions as well as the possible effect of the load inclination will be addressed in the future.

5.ACKNOWLEDGMENTS

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6.REFERENCES

- Bertolo, P., Oggeri, C., & Peila, D. (2009). Full-scale testing of draped nets for rock fall protection. *Canadian Geotechnical Journal*, 46(3), 306-317.
- ISO 17746:2016. Steel Wire Rope Net Panels And Rolls - Definitions And Specifications. ISO: Geneva, Switzerland.
- Marchelli, M., & Giacchetti, G. 2021. Reinforced Drapery Meshes: A Design Method Accounting for Retaining Ropes Contribution. *Applied Sciences*, 11(23), 11176.
- Marchelli, M., Pol, A., Peila, D., & Gabrieli, F. 2023. Towards a Hybrid Design Approach of Anchored Drapery Systems. *Geosciences*, 13(5), 147.
- Pol, A., Gabrieli, F., & Brezzi, L. 2021a. Discrete element analysis of the punching behaviour of a secured drapery system: from laboratory characterization to idealized in situ conditions. *Acta Geotechnica*, 16(8), 2553-2573.
- Pol, A., Gabrieli, F., & Bost, M. 2021b. A simple tool for forecasting the mechanical response of anchored wire mesh panels. In *IOP Conference Series: Earth and Environmental Science* (Vol. 833, No. 1, p.012104). IOP Publishing.
- Smilauer, V., Angelidakis, V., Catalano, E., Caulk, R., Chareyre, B., Chevremont, W., ... & Yuan, C. (2023). Yade documentation. arXiv preprint arXiv:2301.00611.
- Thoeni, K., Lambert, C., Giacomini, A., Sloan, S.W. (2013). Discrete modelling of hexagonal wiremeshes with a stochastically distorted contact model. *Computers and Geotechnics*, 49, 158-169.
- UNI 11437: 2012. Opere di difesa dalla caduta massi—Prove su reti per rivestimento di versanti. UNI: Milano, Italy.
- Xu, C., Tannant, D. D., & Zheng, W. 2019. Discrete element analysis of the influence of bolt pattern and spacing on the force-displacement response of bolted steel mesh. *International Journal for Numerical and Analytical Methods in Geomechanics*, 43(12), 2106-2125.