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PULLOUT BEHAVIOR OF STEEL REINFORCEMENTS USED FOR MECHANICALLY STABILIZED EARTH STRUCTURES

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Abstract: The pullout behavior of mechanically stabilized earth (MSE) structures is very complicated and depends on many parameters which related to the backfill soil properties, the reinforcement characteristics and the interaction between them. This paper investigates the pullout behavior of many soil reinforcements under static and repeated loading. Four types of steel reinforcements were studied; Strip, W-shaped, ribbed and punched. The results obtained show that the change of the shape of reinforcement may improve the pullout resistance of MSE structures. Therefore, the best performance was obtained by the ribbed and the punched reinforcements, under static loading as well as repeated loading.

Keywords: *chalcedonite, density separation, raw material processing*

1. INTRODUCTION

MSE structures were increasingly used for the construction of earth retaining walls and embankments slope. MSE structures resulted from the association of metallic or geosynthetic elements with soils. Incorporating of reinforcements in soils was became an interest solution in civil engineering area. The main role of these additives is improving the bearing capacity of soils and/or limiting the deformations of existing structures

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(Meddah, Merzoug 2017). MSE structures offer time saving, cost economy and ease of construction. The principle of functioning of MSE structures is based on the verification of the long term tensile force developed in the reinforcement and the adherence between the soil and the reinforcement (Hanna, Touahmia 1991; Khedkar, Mandal 2009; Moraci, Cardile 2009; Touahmia 2014; Tatsuoka et al. 2014). The incorporation of the reinforcements ameliorates the overall mechanical properties of the soil, and the design methods used in these structures are based on verification of the internal stability as well as the external stability (Tatsuoka et al. 2014; Abdelouhab et al. 2011).

Soil reinforcements are diversified considering their materials constituted and their shapes. According to their elasticity, the reinforcements can be classified into two types: inextensible materials (wire mesh, steel strip, bar mat and welded wire or steel mesh) and extensible materials: geotextiles and polymers (Tin et al. 2011; Mosallanezhad et al. 2015). The bearing capacity of reinforced backfill is based mainly on the interaction between the reinforcement and the soil. Two procedures are usually used to study and to quantify the mechanism of this interaction: (i) sliding of soil in direct shear over the reinforcement (ii) pullout the reinforcement from the soil (Jewell, Milligan 1984; Moraci et al. 2014).

The soil reinforcement interaction is very complex because it is affected by structural, geometrical, and mechanical characteristics of the reinforcement, the mechanical properties of soil and by boundaries and loading conditions (Moraci et al. 2014). In the other hand, reinforcements should satisfy some criteria such as: low deformability, not fragile failure, durability and economy (Meddah et al. 2015). Stainless steel and treated reinforcements are commonly used for MSE structures, which presented several advantages; durable, easily transported, high rate production, resistant stable and easily shaped. Furthermore, for a sustainable construction, there are other criteria related to the soil embankment. In fact, the soil should be satisfying some geotechnical and chemical criteria related to the implementation phase conditions and to the durability requirements.

Study of the behavior of MSE structures are commonly conducted at full-scale (*in-situ*) experimental projects (Bourgeois et al. 2011; Horpibulsuk et al. 2011) or at laboratory on small scale models (Mosallanezhad et al. 2015; Tin et al. 2011; Moraci et al. 2014; Yu et al. 2015), which contained one or many reinforcements. Therefore, full-scale tests are more suitable for a best analysis of MSE structures behavior, but are more complicated and costly. Indeed, the large part of these studies is performed on small scale models. Little information is however available on performance of MSE structures under slow repeated loading, because the largest parts of researches are investigated the case of monotonic loading. Al-Ashou (Al--Ashou 1981) reported that this type of loading might be simulated the effect of heavy traffic construction for a MSE retaining walls and wave loads (for marine structures).

2. EXPERIMENTAL INVESTIGATION

2.1. BACKFILL MATERIAL

The soil used in this study is a sand of dune taken from Boussaâda region in Algeria. This soil is commonly used in Algeria in construction and transportation areas, their physical and mechanical properties are shown in Table 1. Figure 1 shows the particle size distribution and the granulometric characteristics of the used sand. According to the LPC classification (French classification), this sand is considered as poorly graded proper sand. Soil should satisfy some geotechnical criteria (Meddah et al. 2015) in order to be used as a backfill material in MSE structures. According to the requirements of LCPC-SETRA guides (LCPC-SETRA 1979), this sand is accepted as backfill material, because the cumulative passing at 0.08 mm are less than 15%.

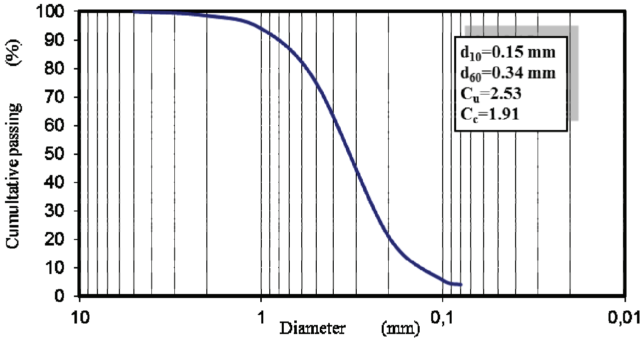

Fig. 1. Granulometric size distribution

Table. 1. Soil properties

Property	Symbol [unit]	Variation range	Average
Dry weight	γ_d [kN/m^3]	18.5–19.5	19
Specific gravity	γ_s [kN/m^3]	24.2–25	24.5
Sand equivalent	ES [%]	84.38–87.23	86.02
Coefficient of curvature	Cc	–	1.91
Coefficient of uniformity	Cu	–	2.53
Friction angle	φ [°]	–	35

2.2. REINFORCING ELEMENTS

Reinforcement elements used for MSE should be resistant and stable for a sustainable construction over their life. All the reinforcements used in this study are made of steel plate with 0.8 mm of thickness. All the reinforcements used in this experimental investigation have a length of 1m. The strip reinforcement was made simply by cutting the plate with sizes of 1000 × 30 mm (Fig. 2a). W-shaped reinforcement with sizes of 1000 × 21.2 mm has been used in this study. This reinforcement was obtained simply by folding the smooth strip as illustrated in Fig. 2b.

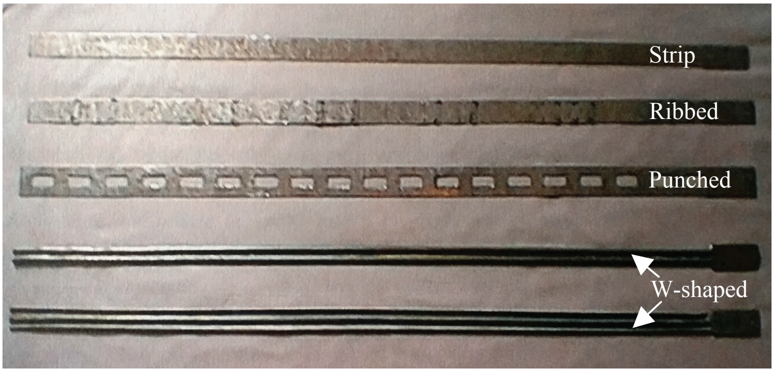

Fig. 2. The aspect of steel reinforcements used

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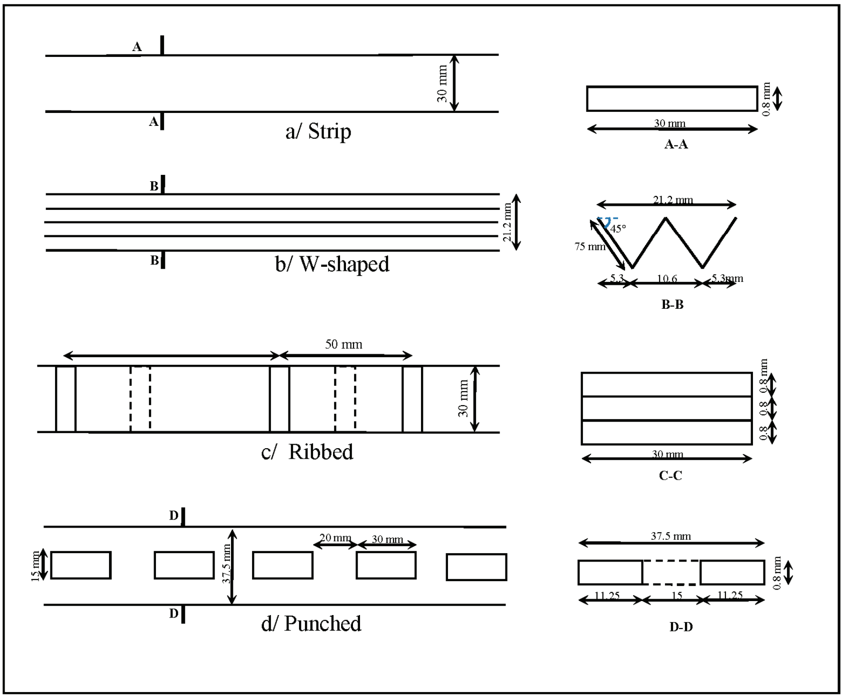

Fig. 3. Geometrical characteristics of reinforcements

The ribbed reinforcement was obtained by welding of ribs prepared from the same plate as shown in Fig. 2c. Punched reinforcement with 1000 × 37.5 mm has been also used in this investigation (Fig. 2d). This reinforcement was obtained by creating of perforations with size of 15 × 30 mm in the strip reinforcement discussed above. Therefore, it should be noted that the strip and the punched reinforcements have the same contact surface with soil. The aspect of the reinforcements used in this investigation is shown used in Fig. 3.

2.3. PULLOUT MACHINE

The test apparatus contained several components such as a pullout box, the loading system and displacements acquisition system (Fig. 4).

Fig. 4. Pullout apparatus

The pullout box was fabricated of rigid steel plate with 60 mm of thickness and has sizes of (1000 × 200 × 300) mm. The lid of the box contained a pressure transducer, water supply valve, pressure supply valve and safety valve. The confining pressure was applied through the air/water chamber fabricated from rubber and related to the pressure producer and to the water tap. The mechanism of pullout force was composed of weights support and lever arm for amplifying surcharges. The acquisition system was made with a dial gauge (1/1000) mm. Repeated loading systems was composed from an electrical engine which can produced 300 rotations per minute and a mechanism of reduction allowed decreasing rotations to 19 cycles per minute.

The pullout machine was equipped with a sliding funnel attached to a threaded shaft, which can reach all points of the box and able to control the fall height of soil. This system has a volume of 12000 cm^3 which represents one-fourth of pullout box. The funnel allowed controlling the density and filling the pullout box with the same compaction energy.

3. RESULTS AND DISCUSSION

3.1. BEHAVIOR OF REINFORCEMENTS UNDER MONOTONIC LOADING

The relationships between the incremental increase of pullout force and the displacements of the reinforcements are shown in Figs 5–7, according to the applied vertical pressure. It should be noted that the weight of the soil above of the reinforcement was added to the applied vertical pressure for calculating the confining stress (σ_{v0}). It clearly can be shown, for each type of the reinforcement, that the increase of the vertical pressure increases the ultimate pullout resistance (Pu). It can be seen also that the pullout behavior was affected by the type of the reinforcement. Therefore, two behaviors

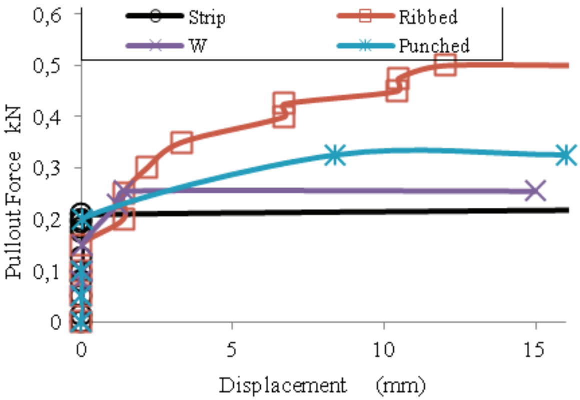

Fig. 5. Pullout behavior curves, $\sigma_v = 25$ kPa

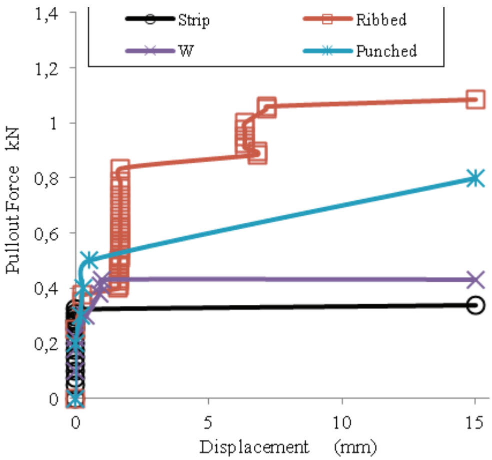

Fig. 6. Pullout behavior curves, σ_v = 50 kPa

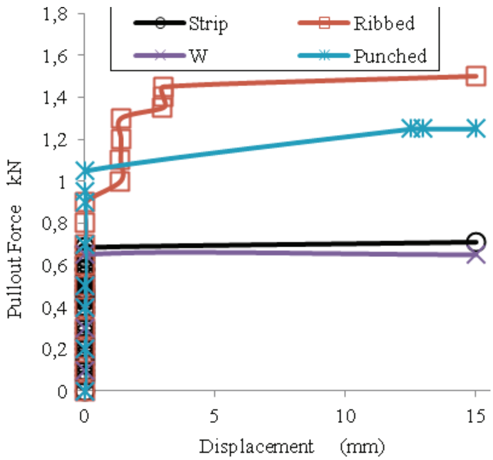

Fig. 7. Pullout behavior curves, σ_v = 75 kPa

were observed; the first one was that of reinforcements having a smooth surface (smooth strip and W-shaped) and the second one was that of ribbed and punched reinforcements. In order to better understand about the effect of the type of reinforcement, both types will be analyzed separately.

3.2.1. STRIP AND W-SHAPED REINFORCEMENTS

From the pullout test results it can be noted that the pullout behavior depends on the applied vertical pressure and the shape of reinforcement. From Figs. 5–7, it can be seen that the adherence failure was made at low displacements and the failure done quickly and unexpectedly. Furthermore, for the W-shaped reinforcement, the failure occurred gradually and at relatively high displacements. This phenomenon may help getting certain ductility suitable for MSE structures.

From the results, it can be noted also that the pullout resistance increases at vertical stresses of 25 and 50 kPa, if the shape of reinforcement is changed from strip to W-shaped, while it decreases for the stress of 75 kPa. This behavior can be explained by the negative effect of some part of the applied surcharge on reinforcement (tangential component), and by the voids created at the corners situated under the W-shaped reinforcement, which reduced the effective contact surfaces between reinforcement and soil.

3.2.2. RIBBED AND PUNCHED REINFORCEMENTS

Results of pullout tests conducted on ribbed and punched reinforcements show a completely different behavior in comparison to that of smooth reinforcements. It clearly can be seen from Figs. 5–7, that the pullout resistance and the shape of load-displacements are highly affected by the change in the roughness of strip reinforcement. For example, at 50 kPa the pullout resistance was ameliorated by 135% if the roughness of strip reinforcement is changed by creating of perforation, whereas it ameliorated by 219% if the roughness is changed by creating of ribs. The different amelioration ratios values are calculated in comparaison with the strip reinforcement (Table 2). The mechanisms of functioning of ribbed and punched reinforcements are shown in Fig. 8. The behavior of theses reinforcements can be explained by the fact that the existence of ribs or perforations in the surface of the reinforcement increases the volume of soil in interaction and prevents the movement of the reinforcement, as shown in Figs. 6 and 7. Therefore, creating of ribs amplifies the dilating zone surrounding the reinforcements which makes a supplementary vertical pressure on the reinforcement. These results are in agreement with previous investigation (Touahmia et al. 1997) conducted on soil reinforced by geogrid strips. The authors have indicated that for smooth reinforcement the load is mobilized by frictional resistance only, whilst for the rough reinforcement both frictional and bearing resistances are mobilized.

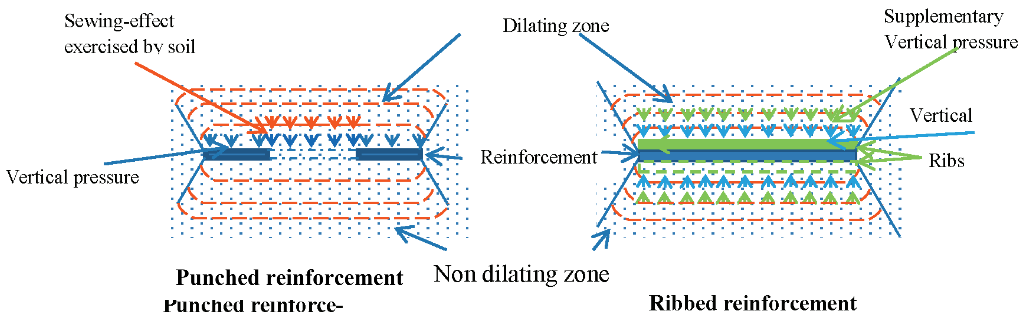

Fig. 8. Principle of functioning of ribbed and punched reinforcements

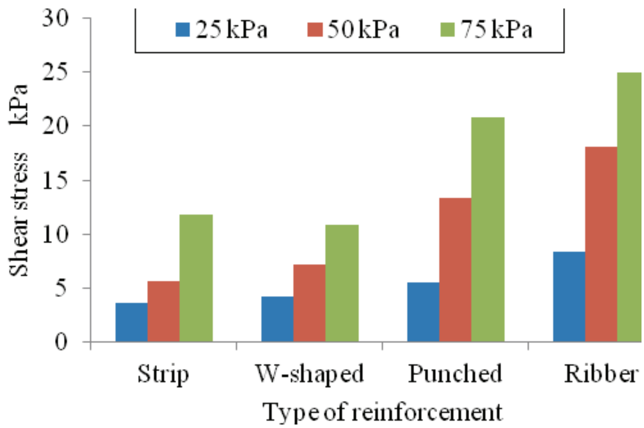

Fig. 9. Shear stress mobilized for different reinforcements

In order to understand better about the effect of the type reinforcement on the shear stress between reinforcement and soil, the maximum shear stress generated τ_{max} is calculated. The results obtained are reported in Fig. 9. It can be shown that the maximum shear stresses generated by the rough reinforcements are higher than that obtained by the smooth reinforcements. For example, τ_{max} for ribbed reinforcement was increased by 111–219%, whereas for punched reinforcement it increased by 50–135%, according to the normal stress applied on the reinforcement. These results confirm that the change of roughness aspect of reinforcement, by creating of ribs/perforations has a positive effect on the performance of MSE construction. In addition, the punched reinforcement presents a supplementary advantage, which assures the continuity of soils between the two facets of reinforcement and creates therefore, a sewing-effect between reinforcement and columns of soil.

Table 2. Pullout test results under monotonic loading

Test name	Reinforcement types	Vertical stress [kPa]	σ_{v0} [kPa]	F_{max} [kN]	Shear stress [kPa]	Pullout resistance amelioration ratio [%]
Str_stat_25	Strip	25	27.4	0.22	3.67	–
Str_stat_50		50	52.4	0.34	5.67	–
Str_stat_75		75	77.4	0.71	11.83	–
W_stat_25	W-shaped	25	27.4	0.255	4.25	15.9
W_stat_50		50	52.4	0.43	7.17	26.5
W_stat_75		75	77.4	0.65	10.83	–8.5
Pun_stat_25	Punched	25	27.4	0.33	5.5	50.0
Pun_stat_50		50	52.4	0.8	13.33	135.3
Pun_stat_75		75	77.4	1.25	20.83	76.1
Rib_stat_25	Ribbed	25	27.4	0.5	8.33	127.3
Rib_stat_50		50	52.4	1.085	18.08	219.1
Rib_stat_75		75	77.4	1.5	25	111.3

3.2. BEHAVIOR OF REINFORCEMENTS UNDER REPEATED LOADING

The behavior of soil reinforcements under repeated loading was also investigated in this paper. The maximum magnitude of the repeated loading was fixed at 60% of Pu, for each type of reinforcement. The choice of this magnitude was based on previous investigation (Al-Ashou 1981), which conducted an extensively study on MSE structures under repeated loading. He has reported that the use of loading magnitude less than 25% of Pu remained MSE construction stable during long periods. Otherwise, the use of loading magnitude higher than 70% of Pu made shorter the life span of MSE structures. The behaviors of reinforcements under repeated loading are shown in Fig. 10. From the results, it can be shown that the behaviors of reinforcements were highly affected by the shape of the reinforcement and by the applied vertical pressure. It can be noted also that the behaviors of reinforcement under cyclic loading differ from those envisaged under static loading. Curves have substantially the same appearance at low confining stress (25 kPa), but by increasing the confining stress to 50 and 75 kPa, it can be noted that curves behavior were changed and the effects of the change of reinforcement shapes was more remarkable. In Table 3, the maximum cycles necessary for mobilizing the pullout resistance (N_{max}) are reassembled. It clearly appears that the rough reinforcements are more resistant to repeated loading as the smooth reinforcements; this is due to the effects of ribs and perforation created in the surface of smooth strip, which amplified the dilating zone surrounding the reinforcement. Therefore, the punched reinforcement remained far the most performed for MSE construction.

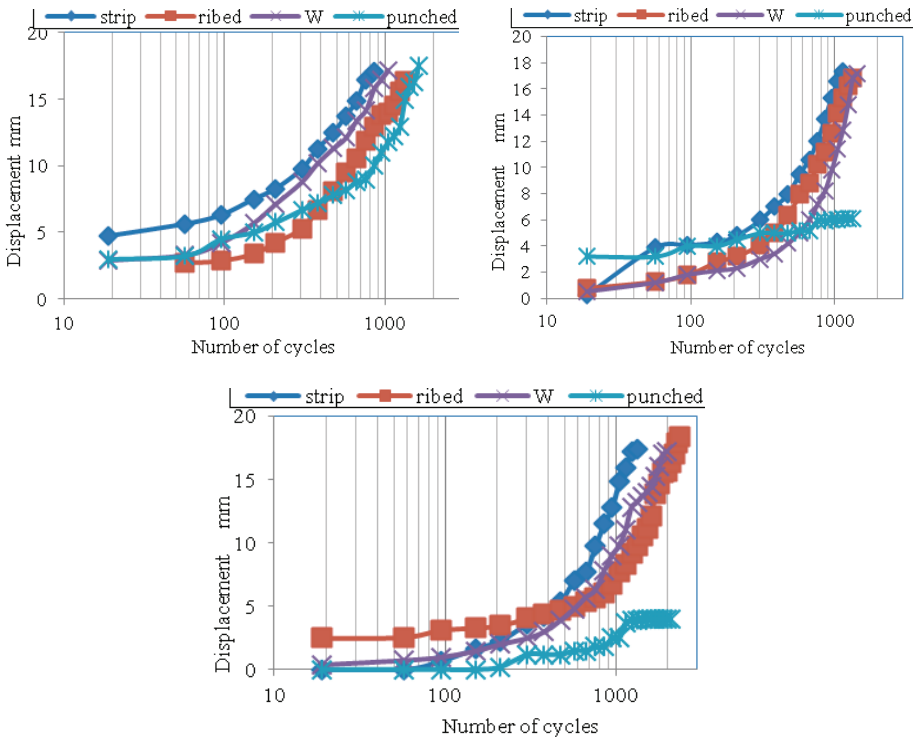

Fig. 10. Pullout behavior for repeated loading

Table 3. Pullout test results under repeated loading

Vertical stress [kPa]	Maximum number of cycles Nmax			
	Strip	W-shaped	Ribbed	Punched
25	855	1045	1330	1615
50	1140	1425	1330	1330
75	1330	1955	2375	2375

4. CONCLUSION

In this paper, the performance of some reinforcement used for MSE structures was experimentally investigated. From the obtained results, it can be conclude that the pullout resistance of MSE structures was greatly affected by the intensity of confining pressure, the shape of reinforcement and its roughness.

Under static loading the best results in term of pullout strength were obtained by ribbed and punched reinforcements. Under cyclic loading the best performance was given by punched, ribbed and W-shaped reinforcements, respectively.

Therefore, the performance of MSE structures was highly affected by the roughness of reinforcements. For the same contact surface, it is more efficient to create ribs and/or perforations in the reinforcement for improving its interaction with soi partciles and amplifying dilating zone surrounding the reinforcement. Finally, to make use these results in situ, it is recommended to build an experimental full scale MSE structures reinforced with punched reinforcement.

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REFERENCES

ABDELOUHAB A., DIAS D., Freitag N., 2011, *Numerical analysis of the behaviour of mechanically stabilized earth walls reinforced with different types of strips*, Geotextiles and Geomembranes, 29 (2), pp. 116–129. Available at: http://www.sciencedirect.com/science/article/pii/S0266114410000932 [Accessed: March 5, 2016].

AL-ASHOU M., 1981, *The behaviour of reinforced earth under repeated loading*. Available at: http://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.236883 [Accessed: February 17, 2016].

BOURGEOIS E., SOYEZ L., LE KOUBY A., 2011, *Experimental and numerical study of the behavior of a reinforced-earth wall subjected to a local load*, Computers and Geotechnics, 38 (4), pp. 515–525. Available at: http://dx.doi.org/10.1016/j.compgeo.2011.02.017

HANNA T., TOUAHMIA M., 1991, *Comparative behaviour of metal and Tensar geogrid strips under static and repeated loading*. In: Geosynthetics Conference, Atlanta, Georgia, USA. Available at: http://trid.trb.org/view.aspx?id=1177064 [Accessed: February 17, 2016].

HORPIBULSUK S. et al., 2011, *Performance of an earth wall stabilized with bearing reinforcements*, Geotextiles and Geomembranes, 29 (5), pp.514–524. Available at: http://dx.doi.org/10.1016/j.geotexmem.2011.05.002.

JEWELL R., MILLIGAN G., 1984, *Interaction between soil and geogrids*. In: Symp. on Polymer Grid Reinforcement in Civil Engineering. Science and Engineering Research Council and Netlon Limited. Available at: http://www.icevirtuallibrary.com/doi/abs/10.1680/pgr.02425.0005 [Accessed: February 17, 2016].

KHEDKAR M.S., MANDAL J.N., 2009, *Pullout behaviour of cellular reinforcements*, Geotextiles and Geomembranes, 27 (4), pp. 262–271. Available at: http://dx.doi.org/10.1016/j.geotexmem.2008.12.003.

LCPC-SETRA, 1979, *Les ouvrages en terre armée, recommandations et règles de l'art Ministère.*

MEDDAH A., MERZOUG K., 2017, *Feasibility of using rubber waste fibers as reinforcements for sandy soils*, Innovative Infrastructure Solutions, 2 (1), p. 5. Available at: http://dx.doi.org/10.1007/s41062-017-0053-z

MEDDAH A., SAHLI M., SAFER S., 2015, *Etude de l'effet de la rugosité des renforcements sur le comportement des massifs en terre armée*. In: Journées d'étude de Génie Civil. M'sila University, Algeria, pp. 54–59.

MORACI N. et al., 2014, *Soil Geosynthetic Interaction: Design Parameters from Experimental and Theoretical Analysis*, Transportation Infrastructure Geotechnology, 1 (2), pp. 165–227. Available at: http://link.springer.com/10.1007/s40515-014-0007-2

MORACI N., CARDILE G., 2009, *Influence of cyclic tensile loading on pullout resistance of geogrids embedded in a compacted granular soil*, Geotextiles and Geomembranes, 27 (6), pp. 475–487. Available at: http://dx.doi.org/10.1016/j.geotexmem.2009.09.019

MOSALLANEZHAD M., BAZYAR M.H., SABOOR M.H., 2015, *Novel strip-anchor for pull-out resistance in cohesionless soils*, Measurement, 62, pp. 187–196. Available at: http://www.sciencedirect.com/science/article/pii/S0263224114005156 [Accessed: May 31, 2015].

TATSUOKA F. et al., 2014, *Geosynthetic-Reinforced Soil Structures for Railways in Japan*, Available at: http://link.springer.com/10.1007/s40515-013-0001-0

TIN N. et al., 2011, *Factors affecting kinked steel grid reinforcement in MSE structures*, Geotextiles and Geomembranes, 29 (2), pp. 172–180. Available at: http://dx.doi.org/10.1016/j.geotexmem.2010.10.013

TOUAHMIA M., 2014, *Interaction mechanisms of soil-geosynthetic reinforcement*, Int. J. GEOMATE, 7 (13), pp. 969–973. Available at: http://www.geomatejournal.com/user/download/215/969-973-3164-Mabrouk-Sept-2014.pdf [Accessed: February 17, 2016].

TOUAHMIA M., ROUILI M., HANNA T., 1997, *A comparison of Geogrid Strips und Metallic Reinforcing Strips unter Static und Repeated Loading*. In: Geosynthetics Asia 97. pp. 337–641.

YU Y., DAMIANS I.P., BATHURST R.J., 2015, *Influence of choice of FLAC and PLAXIS interface models on reinforced soil-structure interactions*, Computers and Geotechnics, 65, pp. 164–174. Available at: http://dx.doi.org/10.1016/j.compgeo.2014.12.009