

THE DEVELOPMENT OF MACCAFERRI'S MACRES REINFORCED WALLING SYSTEM WITH STEEL STRIP REINFORCING ELEMENTS

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ABSTRACT

Of late there has been resurgence of interest, and in some quarters a preference to using steel inclusions as reinforcing elements in MSE (Mechanically Stabilised Earth) walls. An essential prerequisite for the effective introduction of any newly proposed system is to more accurately understand the pull-out resistance of the reinforcing elements and the specific nature of the reinforcement-soil interaction within the confines of prescribed select backfill requirements; an important concept fundamental to the design process. This paper originally presented at the 18th Southeast Asian Geotechnical Conference looks now at the strip development for Maccaferri Australia's concrete panel and steel reinforcement retaining wall system, referred to as the MacRes System. It examines in detail the pull-out resistance of a newly developed steel strip as soil reinforcement in reinforced soil wall construction. The strip has indentations in an attempt to enhance the pull-out behavior. Large scale laboratory pull-out tests, using a pull-out box of 2 m in length, were conducted and the soil used was a silty sand from a borrow area. The testing program covered a wide range of overburden pressures from 15 to 120 kPa which enabled us to examine whether the calculated friction factor was dependent on the overburden pressure. Special dummy pull-out tests were conducted to correct the measured pull-out force and obtain the actual pull-out resistance. Independent consolidated drained triaxial tests, which measured dilatancy characteristics, were also conducted to characterize the properties of the tested soil.

1 INTRODUCTION

The resistance against the pull-out of the reinforcement is one of the most important design parameters for the design of a RSW supporting a highway. The pull-out resistance (R_{pull}) of a metallic grid or mesh type of soil reinforcement is the combination of the frictional resistance (F_f) developed along its longitudinal members and the bearing resistance (F_b) of the soil against its transverse members, with the latter being the dominant contributor (usually about 90%) [1, 2]. However, for a steel strip reinforcement, F_f is the only contributor to R_{pull} . The published experimental databases for pull-out resistance of steel strip reinforcement are mostly for ribbed or plain steel strips, and the soil used in these studies are largely gravelly soil or clean sand. This paper examines the pull-out behavior of a newly developed steel reinforcement with indentations to hopefully enhance the pull-out resistance.

The pull-out resistance (R_{pull}) of a strip reinforcement can be calculated by the commonly used simplified equation

$$R_{pull} = f \sigma_{vo} A_s \quad (1)$$

where f is the friction factor referred to as the apparent coefficient of friction, σ_{vo} the overburden stress at the reinforcement level inferred by a two-dimensional calculation and A_s the surface area of the reinforcement in contact with the soil. The above equation implies that, for a given scenario, R_{pull} can be calculated if f is known.

The literature shows that, for ribbed steel strips, the value of f increases with reductions in σ_{vo} and this is a very desirable attributes. Texture polyester straps also manifest an increase in the value of f at overburden stress less

than 100 kPa, although the increase may be less than that of a ribbed steel strip [3]. However, the f value of plain steel strips is approximately independent of overburden stress and of relatively low value even if high quality select fill is used. For the newly developed indented steel strip, the issue is whether the indented steel strip reinforcement manifests similar increase in f at low overburden stress.

The main objective of this study was to experimentally investigate the pull-out resistance behavior of an indented steel strip reinforcement embedded in a silty sand and over a range of σ_{vo} . It is to be noted that the measured values of R_{pull} under low overburden stresses are usually small and can be significantly affected by the frictional resistance developed at the exit slit [3], the question is to what extent this frictional resistance contributes to the measured values of f at low overburden stresses. Therefore, the effect of frictional resistance developed at the exit slit on f was investigated by conducting special dummy pull-out tests.

2 TESTED MATERIALS

Tested soil

The soil used in this experimental study was sourced from a potential borrowed area for a highway project in the Upper Blue Mountains, Sydney, Australia. The material could be classified as well-graded silty sand with about 17% of non-plastic fines. The particle size distribution (PSD) curve of the tested soil is presented in Figure 1. The measured optimum moisture content (OMC) was 9.58%. Consolidated drained triaxial tests were conducted on specimens prepared at the same target dry density (i.e., 95% of MDD) and moisture content (i.e., 8%) as the actual pull-out tests. The measured peak friction angle was in the range of 41.8° to 44.9° for the range of initial mean effective stresses from 30 to 200 kPa whereas the measured friction angle at the critical state was 36.5° .

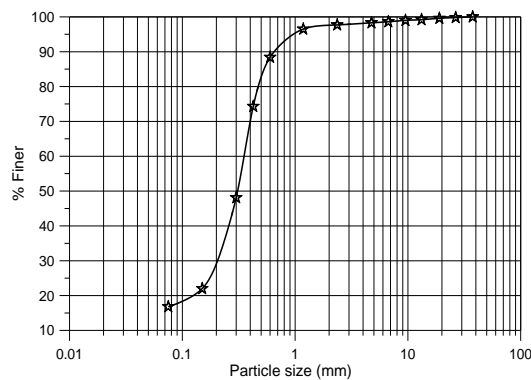


Figure 1: Particle size distribution curve of tested soil

Reinforcement

A galvanized indented steel strip with nominal dimensions of 50 mm wide by 4 mm thick was used as reinforcement. A photograph of the indented steel strip is shown in Figure 2.



Figure 2: Photograph of indented steel strip

3 EXPERIMENTAL SETUP

A steel box 2 m long, 1.1 m wide and 0.4 m high was used as the pull-out box as described by Lo et al. [4]. The testing arrangement of the pull-out box is shown in Figure 3. The total height of the box could be split into two separate halves which was helpful for controlling soil compaction and placement of the reinforcement in the soil mass. The effective size of the pull-out box was adjusted to 1.7 m × 0.7 m × 0.4 m using internal perforated partitions which were lined with geotextile to prevent soil loss through the perforations and facilitate wetting of the soil mass. The contact between the reinforcement and pull-out box (denoted as the exit slit) was specially designed using a latex membrane, rubber sheet and grease. A latex membrane of about 150 mm long with silicon grease was wrapped at the pulling end of the reinforcement. About 100 mm of the wrapped portion was inside the box and the rest outside. A pair of greased rubber sheets was placed between the bottom and top contact surfaces of the reinforcement and pull-out box. A plain steel strip was welded to the indented steel strip just before the exit to further minimize frictional resistance at the exit slit.

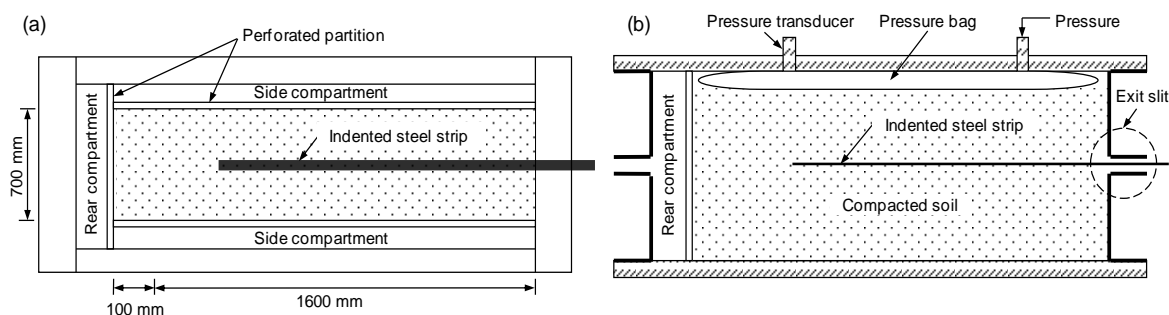


Figure 3: Testing arrangement of pull-out box: (a) plan view; (b) elevation

The end of the weld-on steel strip was connected to the loading train. A hydraulic actuator was used to control “pulling out” of the reinforcement at a displacement rate of 0.065 mm/minute. However, due to inevitable compliance in the loading train and slacks in the connections, displacement at the actuator will overestimate pull-out of the reinforcement. Therefore, the pull-out displacement of the reinforcement was measured by two linear variable differential transformers (LVDTs) mounted on the loading clamp.

The soil for testing was collected directly from the field and delivered to the laboratory in air-tight containers. After determining the moisture content of the soil, if it was necessary to achieve the desired moisture content, the required amount of water was added. The soil was then weighed and stored in airtight plastic boxes. The pull-out box was filled with the soil and compacted in 11 layers. The density was achieved by controlling the weight of the soil for each layer and the compacted thickness. The overburden pressure was applied to the top boundary using a pressure bag filled with pressurized water. The soil mass was then soaked for two days by pouring water into the compartments of the box to replicate the weakened state of the soil due to prolonged wetting which increased the soil’s moisture content by about 2% over the optimum level.

Although the exit slit was specially designed, some frictional resistance might still have existed which could have contributed to the measured pull-out force in the actuator. Thus, dummy pull-out tests were performed at the last phase of every test at a zero overburden pressure and the same displacement rate as the main pull-out tests. In an ideal test condition, the dummy pull-out resistance (P_{dum}) is zero [5], and therefore the values of the measured non-zero P_{dum} were corrections that need to be deducted from the maximum recorded force (F_{max}) to calculate R_{pull} .

4 TEST RESULTS

A total of 8 pull-out tests with a wide range of overburden pressures from 15 to 120 kPa were conducted. The summary results of all pull-out and dummy pull-out tests are presented in Table 1. The force-displacement responses obtained from the pull-out and dummy pull-out tests are presented in Figure 4a and 4b respectively.

Table 1: Summary of pull-out test results and calculated friction factors

Test name	Overburden pressure (kPa)	σ_{vo} (kPa)	F_{max} (kN)	P_{dum} (kN)	R_{pull} (kN)	f (without correction)	f (with correction)
Test-1	65	68.3	13.38	2.37	11.01	1.87	1.47
Test-2	80	83.3	14.26	2.64	11.62	1.62	1.27
Test-3	35	38.3	9.92	2.35	7.57	2.58	1.80
Test-4	50	53.3	12.78	2.21	10.57	2.32	1.80
Test-5	20	23.3	8.25	2.65	5.6	3.75	2.18
Test-6	100	103.3	18.27	2.47	15.8	1.66	1.39
Test-7	120	123.3	16.83	2.47	14.36	1.28	1.06
Test-8	15	18.3	6.76	2.30	4.46	4.10	2.22

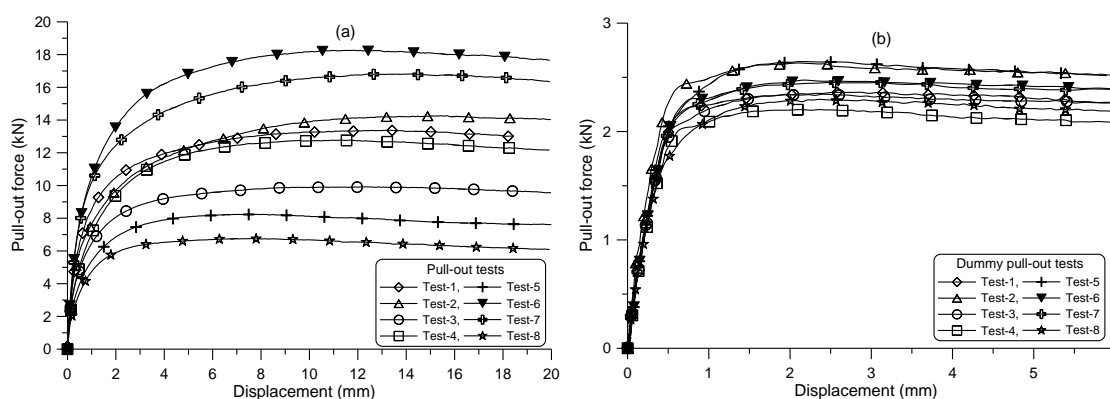


Figure 4: Force-displacement responses obtained from: (a) pull-out tests; (b) dummy pull-out tests

It is evident from the force-displacement responses of the pull-out tests (Figure 4a) that F_{max} for all overburden pressures were mobilized within about an 8 mm displacement of the reinforcement. In the dummy tests, the maximum pull-out forces, being mobilized at about 1 mm displacement (Figure 4b), had an average value of 2.43 kN and a standard deviation of 0.16 kN. This is indicative of the level of control and consistency achieved during testing. Furthermore, maximum pull-out forces were recorded. The values of R_{pull} were calculated by applying the correction for P_{dum} to the measured values of F_{max} .

The values of f for the respective overburden pressures were calculated using Equation (1) and are also presented in Table 1. To investigate the effect of the overburden pressure on f , the calculated values of f were plotted against σ_{vo} and are shown in Figure 5. To assess the effect of P_{dum} , two calculations of f (with and without correction) are presented in the same plot. The dotted line indicates the best-fit curve of variations in f with σ_{vo} when no correction of F_{max} was applied and shows that f dropped from 4.10 to 1.28 for the range of overburden pressures from 15 to 120 kPa. On the other hand, the solid line indicates the best-fit curve of the variation of f with σ_{vo} when the correction for P_{dum} on F_{max} was taken into consideration which shows that f decreased from 2.22 to 1.06 for the same range of overburden pressures. Despite the control achieved, correction for P_{dum} had a significant influence on the calculation of f .

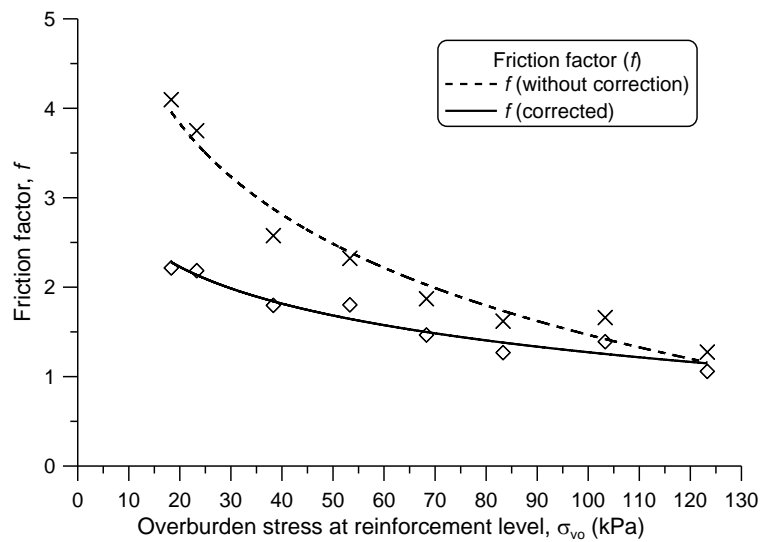


Figure 5: Friction factor versus overburden stress at reinforcement level

Furthermore, the increase in f at low overburden pressures was very significant and could be explained by the constrained dilatancy theory [3]. In Equation (1), σ_{vo} is an average value between strips at the same level and, as the reinforcement was pulled out, the soil adjacent to the strip was sheared due to the indentation of the steel surface. Although, this shearing should lead to dilation of a granular soil, the surrounding soil constrained dilatancy which resulted in an increase in the normal stress acting on the strip. Therefore, the shear stress at failure (τ_f) can be expressed as:

$$\tau_f = (\sigma_{vo} + \sigma_y) \tan \phi = \sigma_{vo} (1 + \sigma_y / \sigma_{vo}) \tan \phi \quad (2)$$

where σ_y is the additional local stress. Thus, the R_{pull} can be expressed as

$$R_{pull} = \tau_f A_s = \sigma_{vo} (1 + \sigma_y / \sigma_{vo}) \tan \phi A_s \quad (3)$$

Thus, comparing Equations (1) and (3) gives

$$F = (1 + \sigma_y / \sigma_{vo}) \tan \phi \quad (4)$$

Equation (4) indicates that, as long as σ_y was significant relative to σ_{vo} , f was not constant despite the interface characteristics ϕ is a constant. It also provides a simple soil mechanics basis that f can exceed $\tan \phi$ as revealed by the experimental results. Furthermore, the increase in f at a low overburden pressure occurred because the value of σ_y / σ_{vo} was more significant at a lower stress. On the other hand, at a high overburden pressure, as the effect of σ_y / σ_{vo} was small, f showed minimal variations with the applied stress. This was consistent with the trend obtained from the experimental investigation which is shown in Figure 5.

5 CONCLUSIONS

The pull-out behavior of an indented steel strip reinforcement embedded in a silty sand was presented in this study. The main conclusions can be summarized as follows.

1. The values of F_{max} were mobilized within about an 8 mm pull-out displacement of this particular type of reinforcement.
2. As the resistance developed at the exit slit had a significant effect on the calculated f values, correction for this resistance was necessary to obtain accurate f values.
3. The value of f varied with variations in σ_{vo} and showed a trend of decreasing with increases in σ_{vo} for the tested range of overburden pressures.

4. At a low overburden pressure, the value of f increased significantly and this was due to the constrained dilatancy effect of the soil.

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