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Friction characteristics of polypropylene straps in reinforced minestone

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ABSTRACT: Tests to determine the friction characteristics of polypropylene strap reinforcement in minestone have been carried out using a large shear box, a laboratory pull-out test, and full-scale pull-out tests. The tests, results, and findings are reported, and differences in behaviour compared with ribbed steel reinforcement are discussed.

1 INTRODUCTION

In the search for new materials suitable for reinforced earth retaining wall construction, the University of Glasgow's Department of Civil Engineering has been investigating, with the assistance of a grant from British Coal's Extra Mural Research Committee, the possibility of using unburnt colliery spoil (minestone) as a fill in conjunction with polypropylene reinforcing straps, since minestone is a readily available fill material found in many areas of the U.K., while polypropylene offers better corrosion resistance than traditional galvanised steel straps.

This paper describes the properties of two minestones and the friction characteristics of two different types of polypropylene reinforcement obtained using shear box tests and pull-out tests. Similar tests on high adherence ribbed steel strips are reported for comparison.

2 MATERIALS

2.1 Minestone

Minestones from Wardley colliery and Wearmouth colliery were used as the fill material, Wardley exhibiting greater cohesion than Wearmouth. The properties of the materials are given in Table 1 and grading is shown in Fig. 1.

Table 1. Properties of minestone.

Property	Wardley	Wearmouth
Moisture content %	9.7	5.6
Specific gravity -	2.37	2.34
Liquid limit %	31.0	-
Plastic limit %	21.8	-
Plasticity Index %	9.2	-
Bulk den.(loose) kN/m^3	13.95	13.00
Opt. moist.cont.* %	10.0	8.0
Max. dry den.* kN/m^3	18.6	18.3
Angle of internal friction deg.	39,46	52
Cohesion kN/m^2	15,18	6
Uniformity coeff.	70	10
Permeability cm/sec	2.8x10^{-3}	2.1x10^{-3}

* 2.5 kg Rammer

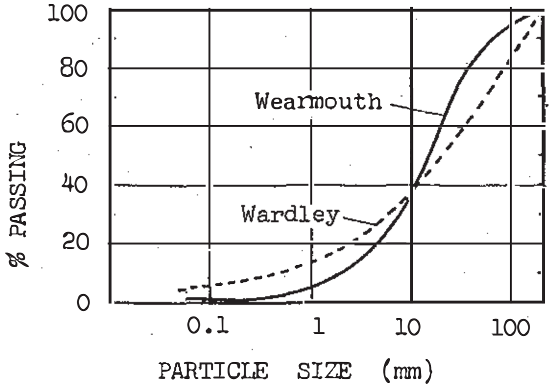

Fig. 1 - Grading curves for minestones.

2.2 Reinforcing straps

The reinforcing straps used consist of tendons developed by I.C.I. and made from ten bundles of high tenacity polyester fibres enclosed in a durable polyethylene sheath. Two types were used viz Paraweb (black) and Paralink (beige). The manufacturers claim that the straps are corrosion resistant against chemicals in the fill, have good resistance to abrasion and are unaffected by water. Paraweb is claimed to be superior to Paralink in terms of its resistance to ultra violet radiation and bacterial attack, while both straps are produced with a slightly roughened surface to enhance their frictional characteristics. Paraweb is 92 mm wide by 3.5 mm thick, while Paralink is 85 mm wide by 2.5 mm thick, and their stated breaking loads are 50 kN and 30 kN respectively. The ribbed steel straps used in some further tests were 40 mm wide by 5 mm thick with a breaking load of 98 kN.

2.3 Strap stiffness and creep

Before carrying out the main series of tests to determine the friction characteristics of the strap material in the fill, their tensile behaviour was studied by direct tension tests on sample lengths clamped at the ends. The results indicated that at loads greater than about 10 kN the polyester fibres began to slip within the sheath despite the clamping, and the ultimate load reached was only about 50% of the breaking load claimed by the manufactures. It appears that a breakdown in friction between the bundles of fibres and the outer sheath prevents the straps from reaching their full potential breaking load.

A point to note, however is that the direct tension tests were performed on samples only up to 300 mm long, whereas in practice longer straps are used, the straps are completely embedded in the fill and subjected to the surrounding earth pressure. The tension tests yielded values of modulus of elasticity of about 0.7 kN/mm^2 for the polypropylene straps compared with 170 kN/mm^2 for the steel straps.

Creep tests on the straps under a load of 2.2 kN gave rise to a creep of 0.12% for Paraweb and 0.23% for Paralink after 20 days, while at 60 days the Paraweb creep had increased to 0.17%.

3 TEST PROCEDURES

3.1 Shear box tests.

A 300 mm x 300 mm shear box was used to determine the coefficient of friction of each strap material. The lower half of the box was occupied by a hardwood block and the strap material was glued firmly to the surface of the block. Fill at natural moisture content and 96% maximum dry density, (corresponding to the measured field value) was placed in the top half of the box, and a normal load applied. The shear force required to cause sliding was then measured using a constant rate of strain of 1.05 mm/min. at normal stresses of 20, 60 and 120 kN/m^2.

3.2 Laboratory pull-out tests.

For this test, a steel box 2m long by 0.4m wide by 0.25m deep was used. The fill was compacted to mid-height in the box, a strap 1.5m long was then placed in position centrally and fed through a slot in the front face. Further fill was placed and compacted level with the top of the box. The top of the box, comprising a rubber membrane below a steel coverplate was then bolted in position. Overburden pressure similar to the normal stresses used in the shear box tests was simulated by air pressure introduced between the rubber membrane and the top of the box, and the strap was pulled at a constant rate of 50 N/minute until failure occurred.

3.3 Field pull-out tests

At Wardley colliery a large open-ended box 5m long by 2m wide by 4.5m high had been constructed by British Coal from rolled steel sections and timber railway sleepers. The box was used to accommodate up to 18 straps at various levels and having different lengths. Placing and compaction of the fill was done via the open end of the box, the straps being fed through the front face. A patented pull-out device, supplied by British Coal, was used to pull out individual straps at a rate of 3 mm/min, with load and displacement being measured.

4 TEST RESULTS

4.1 Shear box

Table 1 presents the results of the shear box tests, not only for Paraweb and Paralink, but also for the high adherence ribbed steel straps.

Table 1 Shear box test results

Minestone	Sh.str. (fill) c^1	ϕ^1	Reinf. straps	c_a kN/m^2	δ deg
Wardley	18	46	Paraweb	10	28
			Paralink	8	26
			Rib Steel	18	41
Wearmouth	6	52	Paraweb	10	29
			Paralink	4	26
			Rib Steel	10	46

The results appear to indicate that the strap friction is not greatly affected by the minestone type, and that the Paraweb is superior to the Paralink although both are inferior to the ribbed steel.

4.2 Laboratory pull-out

Again, ribbed steel straps have been included in the results for the purpose of comparison.

The test results are shown in Table 2. In the case of the laboratory pull-out tests, particularly under overburden pressures lower than about 80 kN/m^2 all straps in Wardley minestone give higher pull-out loads than in Wearmouth. Paraweb gives a higher pull-out resistance than Paralink, both being less than the high adherence steel strap. This is also illustrated in the typical force v displacement curve of Fig. 2

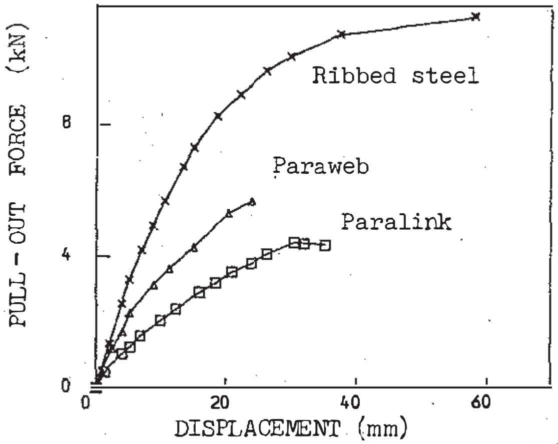

Fig 2 Pull-out v strap displacement from Wardley fill @ σ_n = 60 kN/m^2

4.3 Field tests

The field test results showed a high degree of scatter as can be seen in Fig. 3 for 4m long straps and the effects of different minestones and different strap types could not be easily separated. The results were not unexpected in view of the lower level of control of compaction and placing of the straps compared with laboratory conditions.

Table 2 Laboratory pull-out results

		Minestone fill			
		Wardley		Wearmouth	
Reinforcing straps	Overburden pressure σ_n (kN/m^2)	Displ.(mm) at pull-out	T_{max}(kN)	Displ.(mm) at pull-out	T_{max}(kN
Paraweb	20	15	3.11	20	2.42
Paralink	20	33	3.25	39	2.13
Rib Steel	20	40	8.87	52	4.50
Paraweb	60	24	5.23	22	3.99
Paralink	60	31	3.96	29	3.41
Rib Steel	60	52	11.19	81	4.80
Paraweb	120	26	7.77	39	8.31
Paralink	120	42	5.62	35	7.23
Rib Steel	120	62	11.98	98	12.13

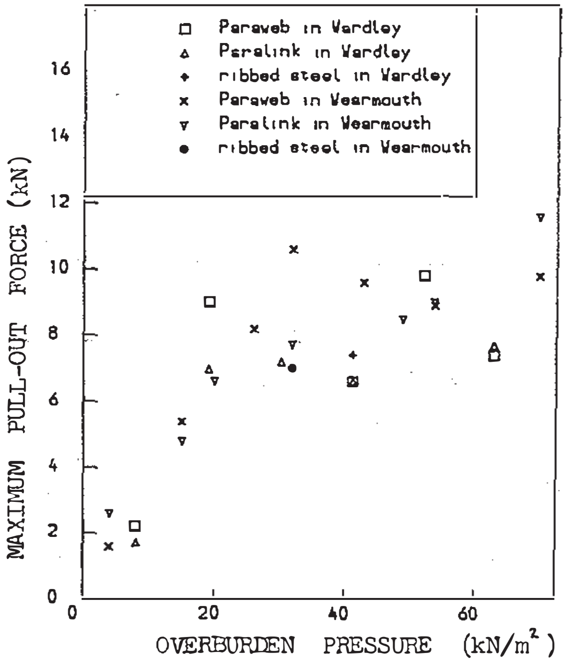

Fig 3 Field pull-out tests

5. DISCUSSION

The design of reinforced earth walls requires a knowledge of the coefficient of friction between the fill and the reinforcement.

In the design method used in the U.K. (Department of Transport 1978) the friction coefficient, μ, can be measured directly in a shear box. Alternatively, the friction coefficient can be taken as $\mu = \alpha \tan \phi'$ where ϕ' is the effective angle of internal friction of the fill and α is a multiplying factor with a value lying in the range 0.45 to 0.5 for metallic reinforcement.

Pull-out tests have been used as an alternative to shear box tests to model the behaviour of a strip subject to tensile load and lead to the apparent friction coefficient

$$f^* = \frac{T_{max}}{\sigma_n .\ 2.b.L.}$$

(Alimi *et al* 1977), where T_{max} is the maximum pull-out load, σ_n is the overburden pressure, and b and L are the strip width and length respectively.

It is possible to relate μ and f^* for a cohesive frictional soil. At any overburden pressure in the shear box,

$\mu = \frac{c_a}{\sigma_n} + \tan \delta$ where c_a = unit adhesion, and δ = angle of frictional resistance. In terms of pull-out of a thin rigid reinforcing strap, length L, width b embedded in a fill under an overburden pressure σ_n, the maximum pull-out force

$$T_{max} = 2.b.L\ \sigma_n\left(\frac{c_a}{\sigma_n} + \tan \delta\right).$$

Hence $f^* = \frac{c_a}{\sigma_n} + \tan \delta = \mu$.

Although the relationship between f^* and μ is theoretically valid, many investigators have shown that comparisons based on shear box and pull-out tests lead to much higher values of f^* compared with μ, especially at low overburden pressures.

Dilatancy and arching have been given as possible causes of the difference (McKittrick 1978;Guilloux *et al* 1979), and other work (Finlay *et al* 1984) has shown that 'free' pull-out compared to pull-out through a slot can result in a reduction in f^* of approximately 28%.

The results obtained from the tests described have been put in terms of μ for the shear box tests and f^* for the laboratory and field pull out tests and are shown in figs 4 and 5 for Wardley and Wearmouth fills. It can be seen from these figures that the f^* values for the polypropylene straps are very much lower than the μ values. This is in direct contradiction to the generally accepted behaviour of metallic and other rigid reinforcing material, and the behaviour must therefore be related to the flexibility and/or elasticity of the reinforcement.

This hypothesis is partly borne out by comparing the laboratory pull-out with the pull-out calculated from the shear box results as shown in fig 6. Since the reinforcing material is rigidly fixed during the shear box test, the pull-out force v displacement behaviour reflects this and actually shows Paraweb and Paralink as giving superior pull-out capacities at lower displacements than the ribbed steel. The actual pull-out behaviour reveals that the polypropylene straps undergo up to three times the displacement necessary to mobilise the maximum pull-out force in the shear box. The much more rigid ribbed steel on the other hand under-

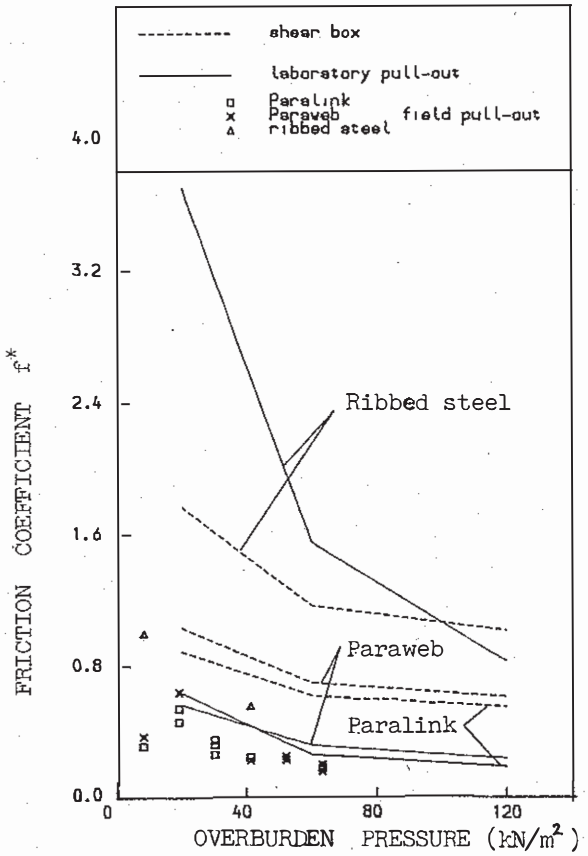

Fig 4 Comparison of friction coefficients in Wardley fill

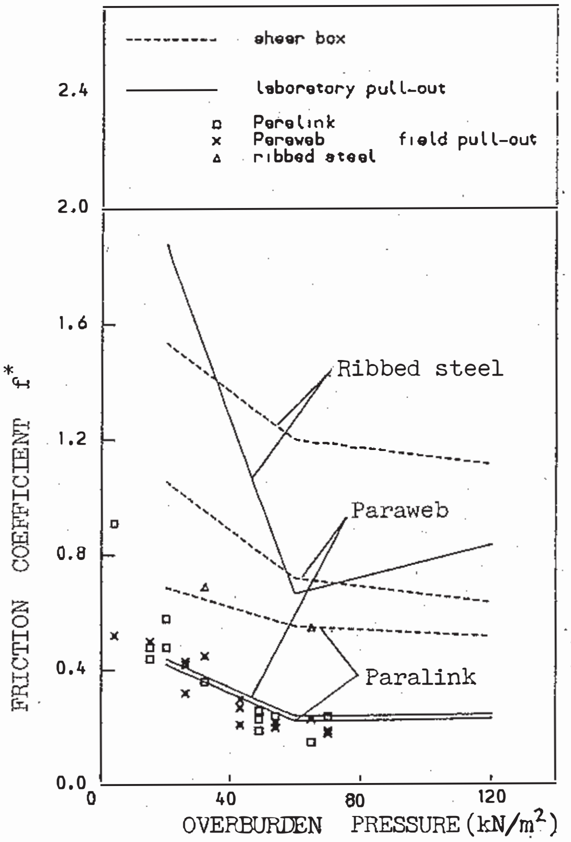

Fig 5 Comparison of friction coefficients in Wearmouth fill

goes about the same displacement in pull-out as in the shear box.

Following up this observation, some tests have been done in which the differential movement along the polypropylene straps has been measured as a pull-out test progressed.

The original intention was to fix strain gauges to the polypropylene straps but it proved to be impossible to find an adhesive which would perform satisfactorily and this approach was abandoned. The alternative approach used was to fix very thin high tensile steel wires to the 1.5m long straps at 0.5m spacing and feed them through holes at the rear of the box then over pulleys with tensioning weights attached. The wire movement was then monitored by dial gauges.

The results from one test are shown in fig 7 and serve to illustrate the behaviour of the straps. At failure, the free end of the strap has only just begun to move although the pulled end has at that time moved through a considerable distance. This behaviour

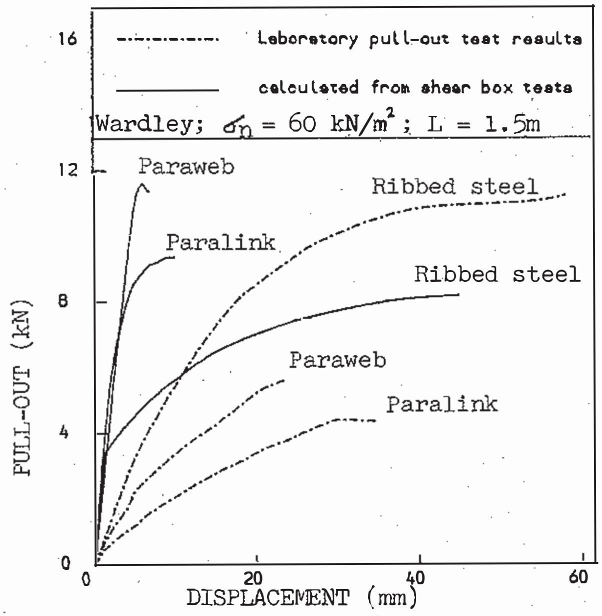

Fig 6 Comparison of laboratory pull-out tests with pull-out calculated from shear box tests

must lead to a departure from the assumption of uniform build-up of frictional force along the strap. The probable distribution is likely to be uniform towards the front end, dropping off to a low value at the free end, thus leading to a reduction in the pull-out force (and f^*) compared with the calculated value. This is confirmed by a calculation based on the limited results of the test shown in fig. 7 which indicates a reduction of about 25% in pull-out force compared with that obtained from the straight shear box values.

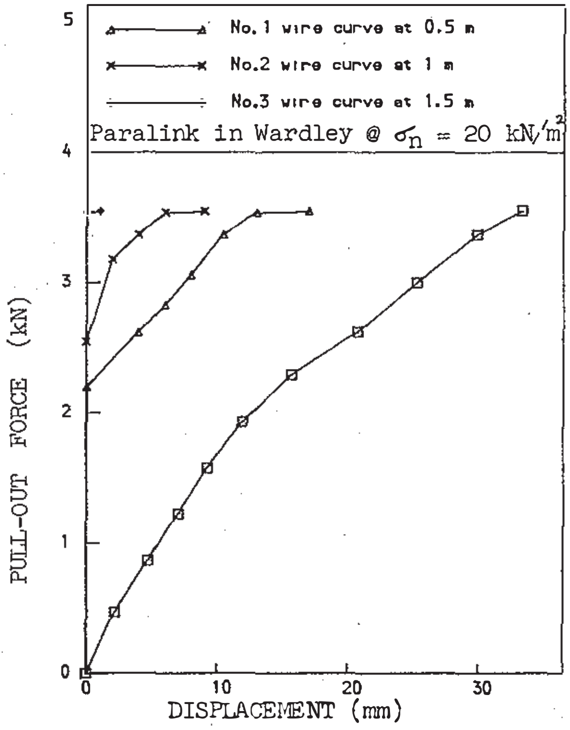

Fig 7 Differential strap movement on pull-out

Figs 4 and 5 also show that for the polypropylene straps the f^* values from field pull-out tests are in reasonable agreement with those from the laboratory pull-out tests whereas the ribbed steel field pull-out f^* values are much smaller.

In terms of design therefore it appears that the field pull-out behaviour of flexible reinforcement is more closely approximated to by laboratory pull-out tests than by shear box tests. The present tests also show that the field pull-out loads for rigid reinforcement are lower than predicted by laboratory pull-out or shear box tests.

Further work is now in progress to study the soil reinforcement interaction rigid and flexible reinforcement.

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