An Experimental Study on Mild and Tor Steel as Soil Reinforcement

by

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Introduction

Reinforced earth is a *construction method of recent origin wherein* soil fill is strengthened by inclusion of metallic and non-metallic stirrups, fibres or nets (Lee et al. 1973). The earth and reinforcements are made to be a coherent mass by the development of sufficient interfacial shearing resistance, with the reinforcements carrying the tensile stresses within the soil. In one sense reinforced earth is akin to reinforced concrete i.e. in both the cases the function of the reinforcing element is to overcome the basic deficiency of the low tensile strength of the base material. The mode by which the synergetic effects are provided are different. In the case of reinforced concrete it is essentially through bonding whereas in reinforced earth it is through the friction around reinforcement.

Reinforced earth construction offers a great promise as an alternative and economically viable solution to a diversity of technically challenging problem in civil engineering. A reinforced earth structure behaves as a coherent gravity mass which avoids stress concentrations in the foundation soils, distributes forces evenly within the whole mass without loss of structural effectiveness and withstands significant differential settlements. When such site conditions as poor foundation soils, limited access for construction, aesthetic and environmental considerations and short construction seasons exist, reinforced earth is often the only economically feasible solution.

Generally, the reinforced earth technique has been utilized by two methods: (*i*) insitu and (*ii*) placement.

In the first case the existing structure is not disturbed and the soil is reinforced by inserting the reinforcement by various methods. In the second case, the reinforcement is placed layer by layer and soil filled and compacted simultaneously.

The economy of the reinforced earth mostly depends upon the frictional strength of the reinforcement and the soil. The inistu application of torsteel as soil reinforcement is referred by Nagaraj et al. (1982). It has been shown that torsteel can be used very effectively in reinforced earth construction. However, there is no study which gives the relative

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performance of mild steel and torsteel as reinforcement. In this investigation the frictional property of torsteel has been compared with ordinary mild steel bar through pull-out tests. The investigations have been carried out on 3 different sands at 3 different densities.

Test Apparatus

The apparatus used for pull-out tests is described by Sridharan and Singh (1984). It essentially consists of a box (made out of 6 mm thick mild steel plate) of size 305×76×102 mm with removable top platen of size 303×74 mm. The box has a side hole of dia. 40 mm (on one of the 76×102 mm face) through which the reinforcing material could be inserted. The required normal load can be applied on the cover plate by a self straining loading frame with a screw jack. The normal load can be measured by a proving ring of 2 ton capacity. The whole box with self straining loading frame and proving ring smoothly fits onto the conventional triaxial loading frame. The reinforcement can be suitably connected to a vertical proving ring which measures the pull-out strength to a maximum value of 500 kg. The reinforcing material in vertical position (Fig. 1 a) can be pulled out at the required speed and the pull-out load can be measured by means of another proving ring and pull-out length by a dial gauge. The position of the reinforcement inside the box along with the soil sample is shown separately in Fig. 1(b).

Test Procedure

The required soil is compacted to the bottom half of the box, the reinforcement is placed carefully and the top half of the box is compacted with soil. After placing the cover plate the required normal load is applied. The whole box with self straining loading frame and a proving ring is transferred on to the conventional triaxial loading frame. The reinforcing material is vertically pulled out and pull-out load and pull-out length are measured simultaneously. During the test, care is taken to keep the reinforcement at the centre and in vertical position.

Loose density (1.34 g/cm^3) was obtained just by pouring the sand *freely while medium density* (1.40 g/cm^3) was obtained by pouring the sand giving small vibration manually. In the case of highest density (1.59 g/cm^3), the soil was subjected to vibration for about 1 minute. Care was taken not to spill the soil from the hole while filling the sand, placing the rod and while applying the normal load. It was assumed that with the provision of the top plate, the normal load was uniformly distributed.

Soils and Reinforcements Used

Soils

Three different sands were used in various conditions (Table 1). They are (*a*) well graded sand passing through IS 2.36 mm sieve and retained on IS 212 micron sieve—Soil A; (*b*) Well graded sand passing through IS 2.36 mm sieve and retained on IS 75 micron sieve—Soil B; and (*c*) Well graded sand passing through IS 150 micron and retained on IS 75 micron sieve—Soil C. Figure 2 shows the particle size distribution of the three sands used in the experimental programme.

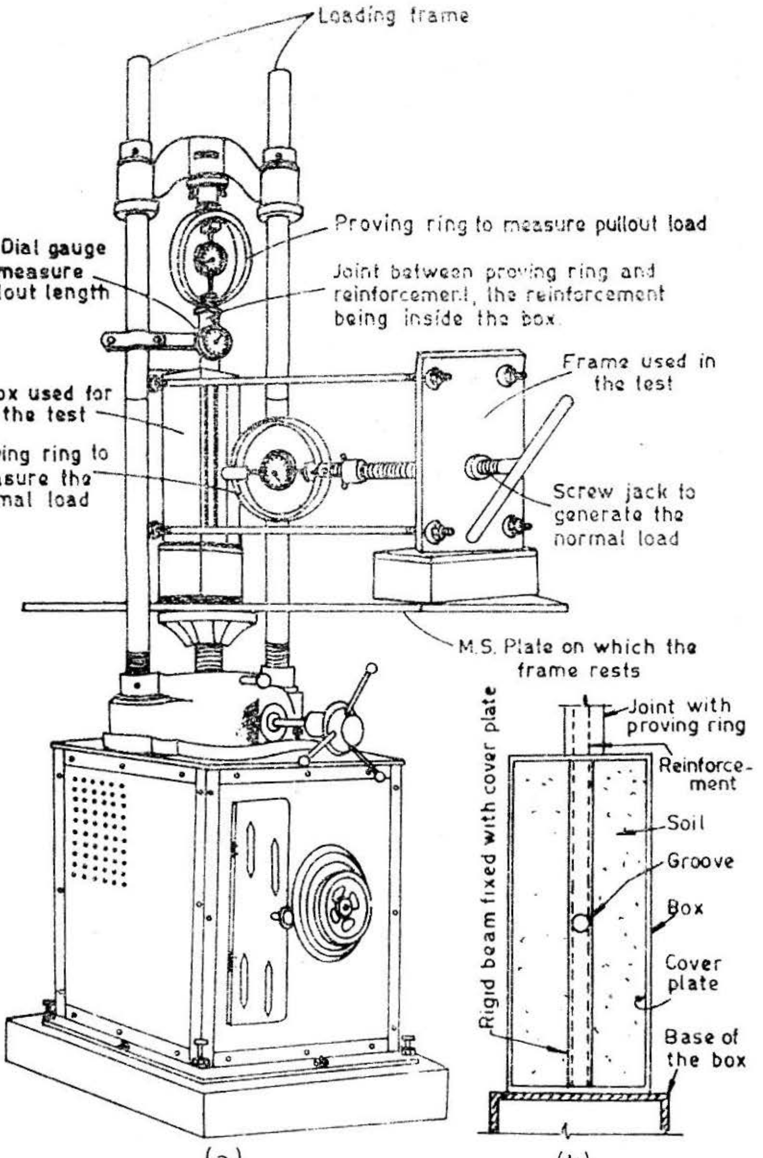

FIGURE 1 The Apparatus (After Sridharan and Singh, 1984)

All the three sands have been tested at two densities i.e. 1.34 g/cm^3 and 1.40 g/cm^3. The relative densities of all the three soils A, B and C at these two densities are 20 percent and 34 percent, 15 percent and 31 percent, 25 percent and 41 percent respectively. Soil-B has been tested at an additional density of 1.59 g/cm^3 also for which relative density is 71 percent. For the different soils at different densities, drained angle of shearing resistance (ϕ_d) and cohesion (c_d) have been found out using box shear apparatus at the same strain rate at which the pull-out test was conducted.

TABLE 1

Soils Used

Sl No.	Soil Designation	Details
1	A	Sand passed through I.S. 2 36 mm sieve and retained on I.S. 212 micron sieve. In between the particle size distribution is well graded (Fig. 2).
2	B	Sand passed through I.S. 2.36 mm sieve and retained on I.S. 75 micron. In between the particle size distribution is well graded (Fig. 2).
3	C	Sand passed through I.S. 150 micron and retained on I.S. 75 micron sieve. In between the particle size distribution is well graded (Fig. 2).

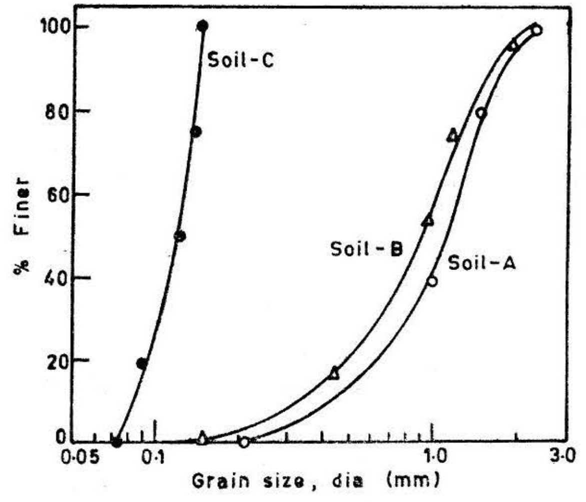

FIGURE 2 Grain Size Distribution of Soils

Reinforcements

Two types of reinforcements viz. a smooth 12 mm dia. mild steel bar and a 12.5 mm dia. torsteel have been used for the comparison purposes.

Calculation of Pull-out Test Results

Suitable normal loads which are usually encountered in the field were chosen. The respective pull-out stress (σ_P) were found experimentally. From the normal stress (σ_N) vs pull-out stress (σ_P) relationship, friction angle (ϕ_μ) and adhesion (c_a) between soil and reinforcement have been evaluated.

In general, the tangent of the angle of friction (tan ϕ_μ) is defined as the friction coefficient (f^*) between soil and reinforcement (Richardson

1975, Schlosser and Elias 1978, Dash, 1978 and Bacot et al. 1978). But this definition of friction coefficient does not take into consideration the adhesion value, if it exists. Hence in the case where adhesion value has been found, the friction coefficient has been evaluatee as shown below:

$$f^* = \frac{C_a}{\sigma_N} + \tan\phi_\mu \quad \text{(Soil-reinforcement)} \qquad \ldots (1)$$

$$f = \frac{C_d}{\sigma_N} + \tan\phi_d \quad \text{(Soil-soil)} \qquad \ldots (2)$$

where f = friction coefficient between soil and soil.

In all the experiments, more than four normal loads were used to obtain ϕ_μ and C_a. For purposes of comparison and to obtain f^* and f values, a normal load of 1.5 kg/cm^2 was used.

For a particular set of tests on a reinforcement, the average pull-out length ($\triangle$L) was obtained by summing up the pull-out length corresponding to peak (at failure) for all the normal loads and dividing by the total number of such tests.

In case, the material used as reinforcement with smaller Young's modulus 'E' (e.g. geotextile) this pull-out length will be the total pull-out noted less the deformation of the material. In case of tor steel, the deformation of the tor steel in comparison to the pull-out length is very small hence it has been neglected.

Test Results and Analysis

1. Loose Density

The pull-out test results on loose density (i.e. 1.34 g/cm^3) with M S bar and Tor steel as reinforcements for 3 soils (A, B and C) are presented in Table 2 and Fig. 3.

It is clear from Table 2 that for loose density condition, the friction angle (ϕ_μ) is essentially constant showing a little decrease as the soil becomes finer, which is similar to the result obtained for the angle of shearing resistance of the soil which decreases marginally from 42.5 to 40°. The friction coefficient (f^*) decreases from 0.240 to 0231. The pull-out length ($\triangle$L) does not bear any definite relation as it varies from 0.28, 0.24 and 0.48 percent for soil A, B and C respectively.

With Torsteel as the reinforcement, there is a definite decrease in the friction angle from 25.5 to 21.0° from sand-A to sand-C and also resulting in some adhesion value. The friction coefficient decreases from 0.490 to 0.424 for soil A to C. The pull-out length also shows a definite trend and it decreases from coarse to fine sand i.e. it decreases from 1.73 to 1.08 percent.

Figure 3 shows the relation between pull-out length and pull-out stress. It can be noticed here that the pull-out length at failure for M S bar is very small in comparison to Torsteel. At low strain levels the difference in pull-out stress between torsteel and mildsteel bar is negligible but

TABLE 2

Pull-out Tests Results with Loose Density
Soil density—1.34 gm/cm³, Pull-out speed = 0.3048 mm/min
Moisture content—airdried
Effective—length of the reinforcements = 30.5 cms

Sl No	Reinforcement	Soil	ϕ_d degrees	C_d kg/cm²	$\tan\phi_d$	f	ϕ_μ degrees	C_a kg/cm²	$\tan\phi_\mu$	f*	$\frac{\phi_\mu}{\phi_d}$	$\frac{f^*}{f}$	$\triangle L$ mm	$\triangle L$%
1	12 mm dia. smooth M S bar	A	42.5	0.00	0.916	0.916	13.5	0.00	0.240	0.240	0.32	0.26	0.84	0.28
2	,,	B	42.0	0.00	0.900	0.900	13.5	0.00	0.240	0.240	0.32	0.27	0.74	0.24
3	,,	C	40.0	0.00	0.839	0.839	13.0	0.00	0.231	0.231	0.33	3.28	1.45	0.48
4	12.5 mm dia. Torsteel	A	42.5	0.00	0.916	0.916	25.5	0.02	0.477	0.490	0.60	0.54	5.27	1.73
5	,,	B	42.0	0.00	0.900	0.900	24.0	0.02	0.445	0.458	0.57	0.51	4.37	1.43
6	,,	C	40.0	0.00	0.839	0.839	21.0	0.06	0.384	0.424	0.53	0.51	3.30	1.08

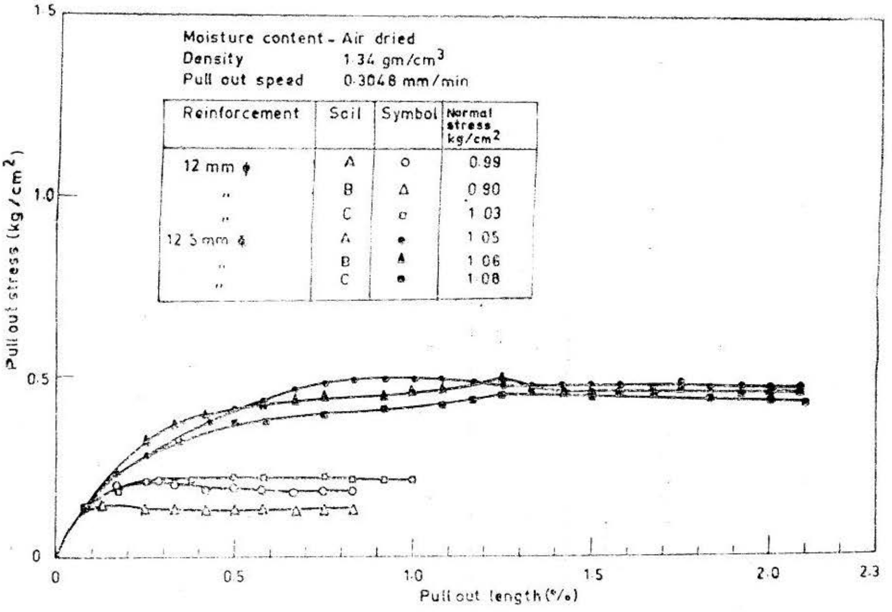

FIGURE 3 Pull-out Length vs Pull-out Stress Curve for Loose Density

after 0.3 percent of pull-out length, pull-out stress for torsteel is almost double than that of mild steel smooth bar for the same pull-out length. Also, the residual strength for torsteel is more than that of mild steel bar.

2. *Medium Density*

Table 3 and Fig. 4 present the pull-out test results with medium density (i.e. 1.40 g/cm^3). The friction coefficient in case of mild steel decreases from 0.374 to 0.335 as soil becomes finer (as has been noticed for loose density). In the case of torsteel, the friction coefficient decreases from 0.753 to 0.596 which is in accordance with the results obtained with loose density. The pull out length in the case of mild steel bar increases (from 0.70 to 0.93 percent) as the soil becomes finer but in the case of torsteel as seen earlier (with loose density), the pull out length decreases from 1.97 to 1.11 percent as the soil becomes finer.

From Fig. 4 it is seen at low strain levels the difference between torsteel and mild steel is marginal upto a pull out length of 0.3 percent but beyond that, the difference in frictional strength between the two is quite large i.e. torsteel gives higher pull out stress for the same pull out length. The residual strength is also more for torsteel than mild steel bar.

3. *High Density*

The pull out test results are presented in Table 4 and Fig. 5. It is seen (Table 4) that there is tremendous difference between the frictional strength of mild steel and torsteel at high density i.e. the friction coefficient for mild steel is 0.934 while for torsteel it is 2.27. The frictional strength of torsteel is higher than that of soil itself. This is attributed to the

TABLE 3

Pull-out Test Results with Medium Density
Soil Density = 140 g/cm , Pull-out speed = 0.3048 mm/min
Moisture content = airdried
Effective length of the reinforcements = 30.5 cms

Sl No	Reinfor-cement	Soil	ϕ_d degrees	C_d kg/cm²	$\tan\phi_d$	f	ϕ_μ degrees	C_a kg/cm²	$\tan\phi_\mu$	f*	$\frac{\phi_\mu}{\phi_d}$	$\frac{f^*}{f}$	ΔL mm	$\Delta L\%$
1	12 mm dia. M S smooth bar	A	44.0	0.00	0.966	0.966	20.5	0.00	0.374	0.374	0.47	0.39	2.13	0.70
2		B	42.0	0.00	0.900	0.900	19.0	0.00	0.344	0.344	0.45	0.38	2.39	0.78
3	,,	C	43.0	0.00	0.933	0.933	18.5	0.00	0.335	0.335	0.43	0.36	2.85	0.93
4	12.5mm dia. Torsteel	A	44.0	0.00	0.966	0.966	35.5	0.08	0.700	0.753	0.80	0.78	5.99	1.97
5	,,	B	42.0	0.00	0.900	0.900	30.5	0.08	0.589	0.642	0.73	0.71	5.33	1.75
6	,,	C	43.0	0.00	0.933	0.933	28.5	0.08	0.543	0.596	0.66	0.64	3.39	1.11

TABLE 4

Pull-out Test Results with High Density
Soil-B, Density = 1.59 g/cm³
Moisture content—airdried, Pull-out speed = 0.3048 mm/min.
Effective length of the reinforcements = 30.5 cms

Sl No	Reinfor-cement	ϕ_d degrees	C_d kg/cm²	$\tan\phi_d$	f	ϕ_μ degrees	C_a kg/cm²	$\tan\phi_\mu$	f*	$\frac{\phi_\mu}{\phi_d}$	$\frac{f^*}{f}$	ΔL mm	ΔL %
1	12mm dia. smooth M S bar	46.5	0.13	1.053	1.140	27.5	0.62	0.521	0.934	0.590	0.82	11.33	3.71
2	12.5mm dia. Torsteel	46.5	0.13	1.053	1.140	52.0	1.48	1.280	2.27	1.12	1.99	6.35	2.08

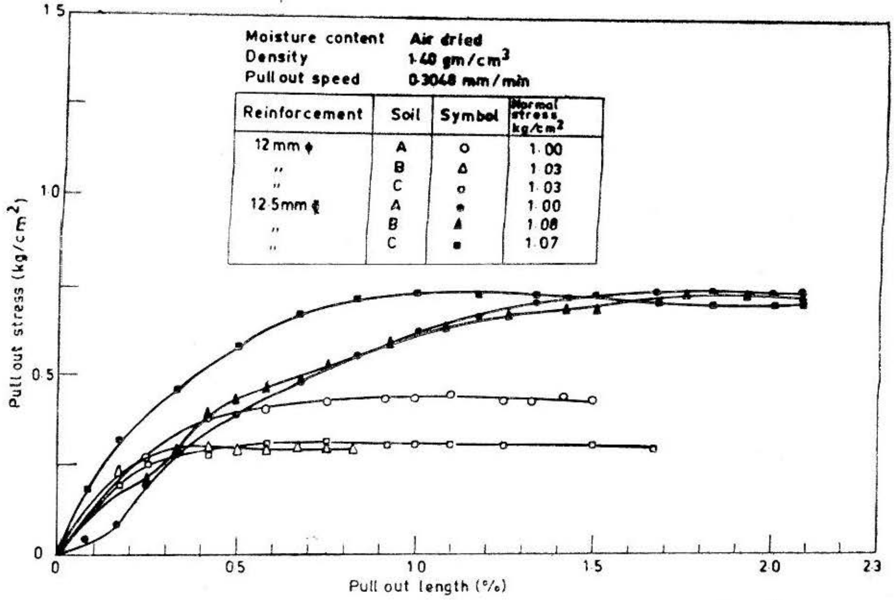

FIGURE 4 Pull-out Length vs Pull-out Stress Curve for Medium Density

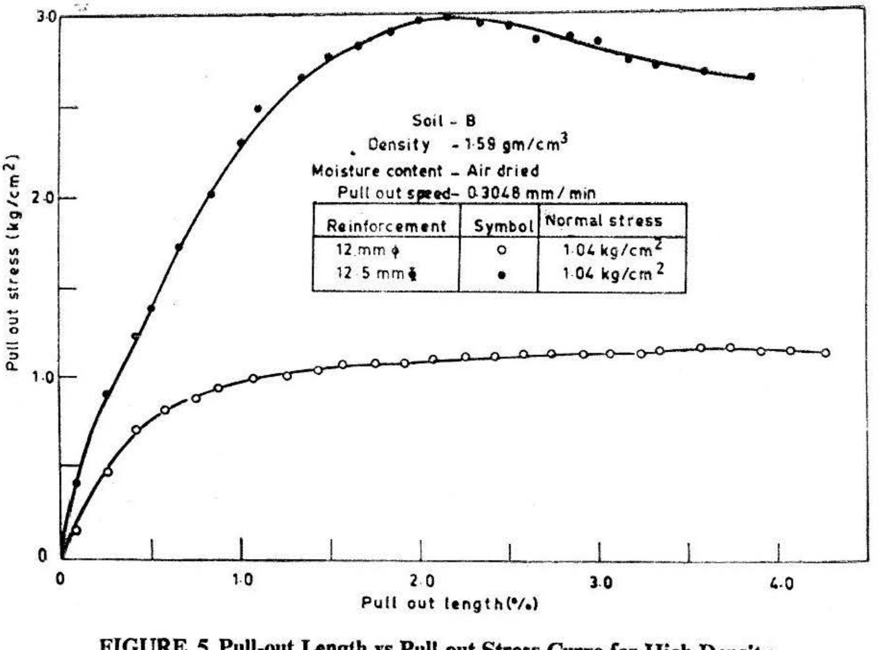

FIGURE 5 Pull-out Length vs Pull-out Stress Curve for High Density

TABLE 5

Comparision of Pull-out Test Resulss
Pull-out speed—0.3048 mm/min
Moisture content—Airdried

Sl No	Soil Density gm/cm³	Soil	f^*		$\frac{f^*_{torsteel}}{f^*_{M.S.\ Bar}}$	ΔL mm		$\frac{\Delta L_{Torsteel}}{\Delta L_{M.S.\ smooth\ Bar}}$
			M S smooth Bar	Tor-steel		M.S smooth Bar	Tor steel	
1	1.34	A	0.222	0.490	2.21	0.84	5.27	6.28
2	,,	B	0.240	0.458	1.91	0.74	4.37	5.93
3	,,	C	0.249	0.424	1.70	1.45	3.30	2.28
4	1.40	A	0.374	0.753	2.01	2.13	5.99	2.81
5	,,	B	0.344	0.642	1.87	2.39	5.33	2.23
6	,,	C	0.335	0.596	1.78	2.85	3.39	1.91
7	1.59	B	0.934	2.27	2.40	11.33	6.35	0.56

dilation effect. Interestingly, the pull out length for mild steel at this density is 3.71 percent while for torsteel it is 2.08 percent only. As mentioned earlier, for loose and medium density, the pull-out length of torsteel was higher than mild steel. It shows clearly that torsteel should be preferred over mild steel.

From Fig. 5 it is evident that even for small pull-out length, torsteel gives higher pull-out stress than that of mild steel. In the beginning, the difference is not much but after nearly 0.4 percent pull-out length, the difference becomes almost more than double.

Conclusions

Table 5 presents a comparison between the frictional properties of mild steel and torsteel. It is seen that the frictional strength of torsteel is almost double in the case of loose and medium density for all the three sands and 2.4 times in the case of high density. Hence torsteel should be preferred.

The pull-out length is quite high (2 to 6 times for loose density and 2 to 3 times for medium density) for torsteel than that of mild steel. But interestingly, at high density the pull-out length for torsteel is only one half of the mild steel. These results indicate that the reinforced earth structures should be permitted to have some deformation.

From this investigation it is clear that torsteel has always more frictional strength (nearly 2 to 2.5 times) than that of mild steel bar. It has got more scope in reinforced earth and it is quite suitable for insitu reinforcement.

Though the experiment gives details about a single reinforcement and does not deal with the group effect of the reinforcements if spacing is larger, the group effect will become almost negligible.

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