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The comparative performance of polymer net reinforcement

Performances comparées de renforcement par maillage en polymère

Cette communication présente les résultats d'essais de friction de cinq types d'armatures

INTRODUCTION

In the reinforced earth system proposed by Henri Vidal use was made of metallic reinforcing strips. Although such material has proved to exhibit excellent strength, stiffness and frictional properties, there is considerable concern regarding the effects of corrosion on long term stability. Current design practice allows for the effects of corrosion by specifying an additional thickness to the structural reinforcement. For mild steel reinforcement in wet conditions this thickness is typically one millimetre on each side of the strip for a design life of thirty years, Schlosser (1976). However as the work of Raharinaivo and Preynet, (1975) has shown corrosion rates in a soil environment are extremely variable and unpredictable.

The apparent solution to the problem of corrosion is to use a material which is chemically stable and resistant to deterioration. In the last five years many such materials have become available. These are generally in one of two main forms, either polymer net structures or polymer fabrics, the latter falling into the two broad categories of woven or non-woven fabrics. There is wide use of net structures in the Far East with Japan alone using some nine million square metres in 1976. In Japan there has been general application of net structures including the reinforcement of embankments with steel reinforced net, Horimatsu, (1965). This type of net has now largely been replaced by polymer net. Recent applications of this include both high and low embankments for the Osaka-Tokyo high speed "bullet-train" which runs on embankments up to 12m high reinforced with Netlon CE121. The use of fabrics is more common in Europe and the U.S.A where again there has been application to reinforcement of embankments.

The main problems related to non-metallic reinforcement are high extensibility and low tensile strength associated with long term creep. Recent development has produced materials in which these short comings have been minimised. Among these new materials are the Swedish Teknisk Väv No.600, a woven polyster fabric with a grab tensile strength of 43kN/m at 12% strain, Holtz and Broms (1977) and two British materials, namely Terram RF/12, a woven fabric and FBM5 a net structure. The properties and performance of Teknisk Vav No.600 has already been widely reported elsewhere, Holtz (1977), Holtz and Broms (1977).

With the advent of non-metallic reinforcement must come the recognition of the need for appropriate testing methods. In particular consideration must be given to the relative stiffness of soil and reinforcement the importance of which has been defined by McGowan et al (1978). In the past the determination of soil/reinforcement friction, for metallic reinforcement has been studied using the shear box, Schlosser (1976), Schlosser and Elias, (1978). Since in this case the reinforcement can be considered infinitely stiff compared to the soil the suppression of strain in the reinforcement would not be expected to have a dramatic effect. However, similar techniques have been extended to the more extensible fabrics. Rankilor (1977), Christie and El Hadi (1977). Such testing involves fixing the test piece to a rigid block to prevent rucking of the fabric during shear. In this case the suppression of strains otherwise induced in the fabric will have considerable effects on the soil/reinforcement friction mobilised. It is the aim of this Paper to demonstrate the radical difference in test results obtained from the shear box and a pull-out apparatus.

DESCRIPTION OF PULL-OUT RIG

The pull-out rig consists essentially of a steel box, 500mm long, 285mm wide and 300mm deep, mounted at one end of a plate steel table, Figure 1. At the opposite end of the table is a rigid steel bulkhead which houses a hydraulic tension jack mounted in a horizontal plane at a height equal to the mid height of the steel box. The ram of the jack is fitted coaxially with a 2

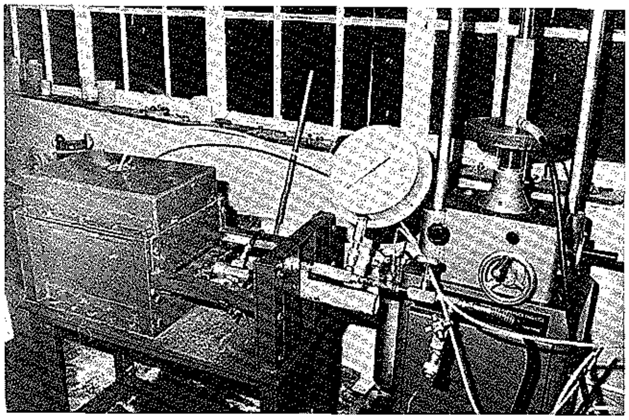

FIGURE 1 THE PULL OUT RIG

tonne capacity tension load cell which in turn is attached to a pair of clamps 285mm wide. In its fully extended position the ram of the jack allows the clamps to touch the face of the steel box where there is a horizontal slit 20mm high running the full width of the box. In setting up the test, the box is filled with soil to a depth of 150mm when a sheet of the material to be tested is laid on top of the soil with approximately 50mm of the test piece projecting out of the box through the slit. When the box is filled to full height the projecting section of the test piece is bolted into the clamps such that none of the test piece is exposed. When hydraulic fluid enters the tension jack it causes the jack ram to move away from the face of the box thus imparting a pull-out load to the test piece. To maintain the required constant rate of pull-out the hydraulic fluid is delivered to the tension jack via a hydraulic hose, from a compression jack being loaded at a constant rate of movement by a 10tonne Wykeham Farrance compression machine. When the compression jack is compressed it expels a certain volume of hydraulic fluid, obviously this same volume of fluid is transmitted to the pull-out jack. Knowing the cross sectional areas of the rams of the two jacks it is possible to derive a direct correlation between the preselected rate of movement of the compression jack and the rate of movement of the pull-out jack. Normal stress is applied using a reinforced rubber bag, with the same plan dimensions as the box, filled with de-aired water which is maintained at the required pressure. The bag which is 100mm deep, is housed in a recessed lid which is bolted to the top of the box during testing. Pressure is applied to the bag using a self-compensating mercury pot constant pressure system connected to the top of the bag via nylon reinforced tubing. In later tests a paraffin volume change gauge was incorporated into the system to permit the assessment of volumetric strains. For normal stresses less than 10kN/m use was made of a simple burette filled with water to the appropriate level. The correct head was maintained during the test using a conventional manually operated control cylinder.

TEST PROCEDURE

Throughout the tests reported here use was made of Boreham Wood Pit Sand. This is a coarse to medium sand with some fine gravel, the grading is fairly uniform with a coefficient of uniformity of 2.8. In all tests the sand was compacted to a dry density of 1.87 Mg/m^3. With a tolerance of ± $0.01Mg/m^3$, this represented a mean relative density of 90%. Compaction was achieved using a Kango vibrating electric hammer fitted with a 100mm x 150mm tamper. This was applied over each layer, which was 75mm thick, for eight minutes. The test piece, which was approximately 275mm wide, was positioned after the first two sand layers had been compacted. This put the test piece at the mid height of the box and in line with the horizontal slit at the front of the box. Some 50mm of the test piece was left projecting out of this slit for connection to the clamps of the pull-out jack. At this stage the embedded length of the test piece was measured to the nearest millimetre. The remaining two layers of sand were placed and compacted bringing the sand flush with the top of the open box. The water bag was placed centrally on top of the sand and then the steel box lid was positioned and firmly bolted down. Normal pressure was then applied via the water bag and time was allowed for consolidation. This proved to be negligible. The clamps on the pull-out jack were moved forward to cover all of the test piece projecting from the box, the clamps were then firmly bolted together. The D.V.M. read-out for the tension load cell was zeroed as was the horizontal movement dial gauge resting on the pull-out clamps. Any slack in the system was taken up by loading the compression jack using the manually operated fine control wheel on the compression machine. When the compression machine was activated regular readings were taken of the D.V.M., dial gauge and paraffin volume change gauge. The tests were carried out at a drained rate of shear of 1mm/min.

PRESENTATION AND DISCUSSION OF RESULTS

Pull out tests were carried out on five types of reinforcement, namely:

i. Plain mild steel, 0.8mm thick.

ii. Sand coated mild steel, 0.8mm thick.

iii. Net structure, Netlon 1168.

iv. Net structure, FBM5.

v. Woven fabric, Terram RF/12.

The sanded steel specimens were formed by applying a thin coat of Araldite epoxy resin to both sides of the steel sheet, these areas were then evenly coated with dry Boreham Wood sand and cured for twelve hours in an oven at 105°C. Netlon 1168 is a net structure formed from strands of unorientated polypropylene approximately 2mm high and having an equilateral triangular cross-section. These strands are melded, base to base, at the intersection points to form a diamond shape net structure with a strand pitch of 6.5mm and total structure thickness of 4mm. FBM5 is again a net structure however, this net is made from uniaxially orientated polyolefin in the form of an orthogonal grid with transverse members approximately 6mm wide and 4mm deep at a pitch of 60mm. The transverse members are joined to one another by longitudinal members approximately 2.5mm wide and 1.5mm deep at a pitch of 11mm. The ultimate tensile strength of this structure is 100kN/m. The fifth material tested was Terram RF/12 which is unidirectional woven polypropylene/polyethylene fabric with a thickness of 0.7mm and a quoted ultimate tensile strength of 120kN/m, Rankilor, (1977).

To aid interpretation of the test results five consolidated-undrained triaxial compression tests with porewater pressure measurement were carried out on 38mm diameter by 76mm high samples of Boreham Wood sand at densities of 1.86Mg/m^3 to 1.88Mg/m^3. The results of these tests, gave a ϕ' value of 35°. This was in good agreement with the results of a series of drained shear box tests which gave a ϕ' value of 34°.

In addition to pull-out tests simple consolidated-drained direct shear tests were carried out using a conventional 60mm x 60mm shear box to determine the angle of bond stress between the reinforcement and Boreham Wood sand. The plain steel and sanded steel were tested by cutting samples that were an exact fit in the shear box. Each sample was in turn placed in the lower half of the box and packed up on 60mm square porous stones to render the upper surface of steel flush with the top surface of the lower half of the box. The upper half of the box was positioned and filled with sand at a density of 1.88Mg/m^3. The samples were then consolidated and sheared in the normal manner. For net structures testing was carried out in a similar manner save for the fact that it was the mid-plane of the net structure that was aligned with the top surface of the lower half of the box. This meant that for both nets there was 2mm of the structure projecting above the surface of the box. The net was cut in such a way that there was no projection to foul the upper half of the box during its travel. The Terram RF/12 sample was tested by mounting the fabric on a 60mm square porous stone to prevent rucking of the sample during shearing. The mounted sample was placed in the shear box to render the upper surface of the fabric flush with the box.

The first material tested was the plain mild steel using specimens with a width, w, of 276mm and embedded length, l, between 460mm and 500mm. In interpreting the results of the test it was assumed that the shear stress, τ, was uniformly mobilised on both sides of the sample and over the full embedded length of the sample. At the end of each test the change in embedded length was checked to ensure that there had infact been relative movement between the sand and the sample over the full embedded length. On this basis, for a pull-out load L :

$$\tau = \frac{L}{2wl}$$

The results for both pull-out and shear box tests are shown in Figure 2.

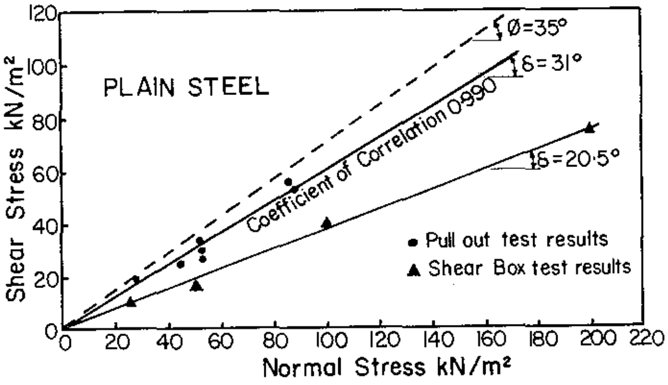

FIGURE 2 SHEAR BOX TESTS - PLAIN STEEL

As can be seen there was some scatter in the results for the pull-out tests, these were therefore interpreted using a linear regression analysis which rendered an apparent angle of bond stress, δ of 31° with a coefficient of correlation of 0.990. The resulting ratio δ/ϕ is constant at 0.89. Results from the shear box tests give a lower value of δ of 20.5° with a constant δ/ϕ ratio of 0.59. This value is in good agreement with the value of 0.55 obtained by Potyondy (1961) carried out shear box tests on smooth steel against dense dry sand. The reason for the higher value of δ/ϕ in the pull-out test is not known however, it is possible that due to the comparative flexibility of the sample there were some undulations formed thus giving a higher pull-out resistance than a perfectly horizontal planar sample. It is interesting to note that Chang and Forsyth (1977) noted a twofold increase in δ when the length of the reinforcement in their field pull-out tests was increased from 1.5m to 4.6m.

Shear box and pull-out test results for the sanded steel are given in Figure 3. These results are presented in a more meaningful manner in Figure 4, which shows the relationship between δ and the normal stress σ. The value of δ is $\tan^{-1}\tau/\sigma$ with τ and σ values taken from Figure 3. As can be seen at low normal stress levels the value of δ reaches 70° - 80° compared to the ϕ value for the sand of 35°. In the shear box the value of δ reduces rapidly with increasing normal stress reaching a value approximately 35° at a normal stress of 100kN/m^2. The reduction of δ with increasing normal stress is less pronounced in the pull-out test with δ still at a value of 47.5° for a normal stress of 100kN/m^2. The magnitude of these δ values is confirmed by Schlosser and Elias (1978) who reported values of 62° and 63° for ribbed and smooth strips respectively when the strips were pulled out under a normal stress of 21kN/m^2. The soil in this case was a gravel with a ϕ value of 46°. The value of δ was reported to become constant at normal stresses in excess of 100kN/m^2. The extremely high values of δ at low normal stress are often entirely attributed to dilatancy. This is a doubtful explanation since work by Cornforth (1972) has indicated that for Brasted Sand, tested under plane strain conditions, dilatancy accounts for an

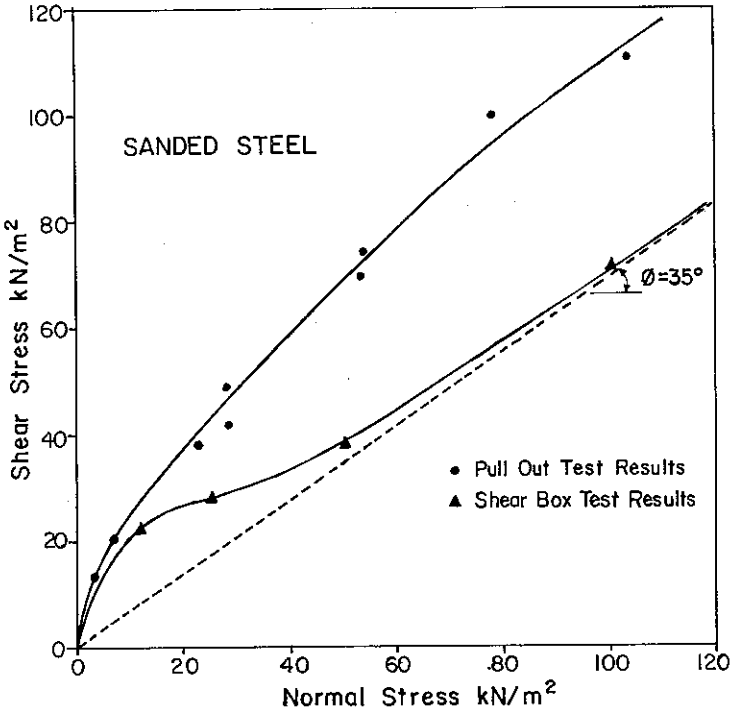

FIGURE 3 TEST RESULTS-SANDED STEEL

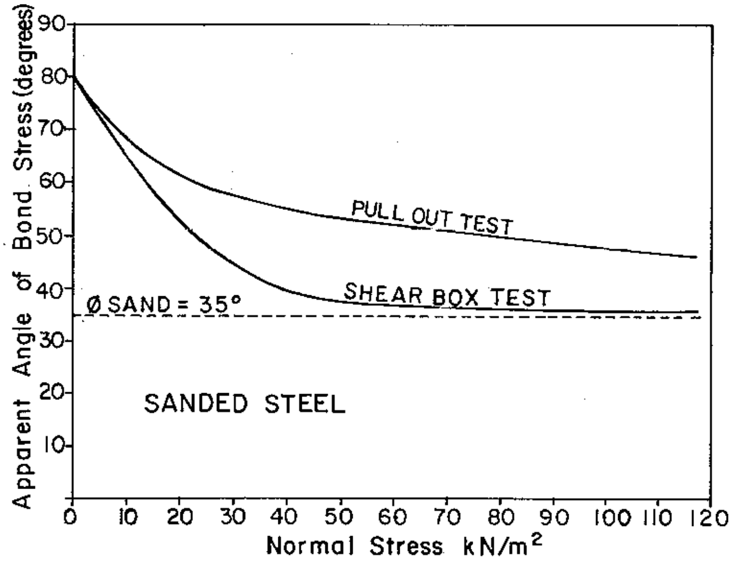

FIGURE 4 ANGLE OF BOND STRESS-SANDEDSTEEL

increase in Ø of up to 17°. In these particular tests δ exceeds Ø by 35° - 45° at low normal stress it is therefore thought that there is some mechanism involved over and above dilatancy. This mechanism will remain undefined until a determination can be made of the stresses and strains generated in the vicinity of a sample undergoing pull-out.

The third series of tests was carried out using Netlon 1168, the results of these tests are given in Figures 5 and 6. No results are given for the shear box tests, which were carried out at normal stressess of 50kN/m^2, 100kN/m^2 and 200kN/m^2, since these showed a great scatter above the Ø = 35° line, which was beyond interpretation. The results for the pull-out tests, Figure 7, gave very promising results at low normal stresses, however, at normal stresses greater than 30kN/m^2 the maximum shear stress mobilised became constant at 21.5kN/m^2. Inspection of the net after testing soon revealed that this was due to a tensile failure of the net just in front of the clamps. The lengths of the net under test were 240mm, allowing for maximum shear stress being developed on both sides of the net this led to an ultimate tensile strength of 10.3kN/m. This was in extremely good agreement with the value of 10.4kN/m reported by Williams (1977). The low tensile strength of the net gave rise to a rapid decrease in the apparent angle of bond stress with increasing normal stress as can be seen from Figure 6. The value of δ dropped to 14° at a normal stress of 85kN/m^2.

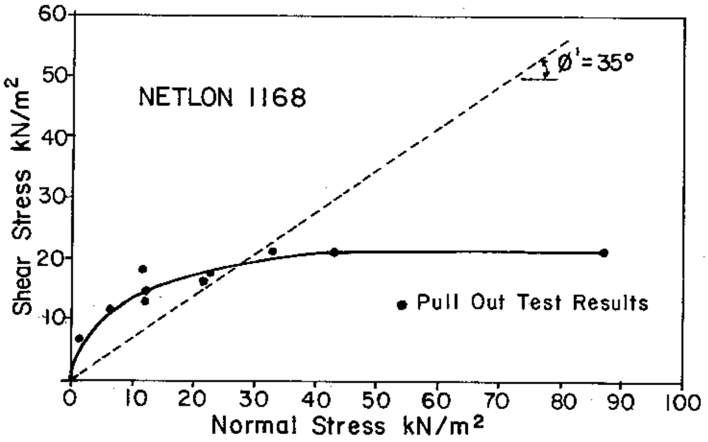

FIGURE 5 TEST RESULTS-NETLON 1168

The second net structure tested was FBM5, test results are given in Figure 7 and 8. At normal stress levels up to 40kN/m^2 the shear box and pull-out tests gave identical values for δ. On comparing the rates of change of volumetric strain, with respect to longitudinal strain, for the two types of test it was found that in the shear box the rate was 0.33 for a normal stress of 25kN/m^2 whereas in the pull-out test the rate was

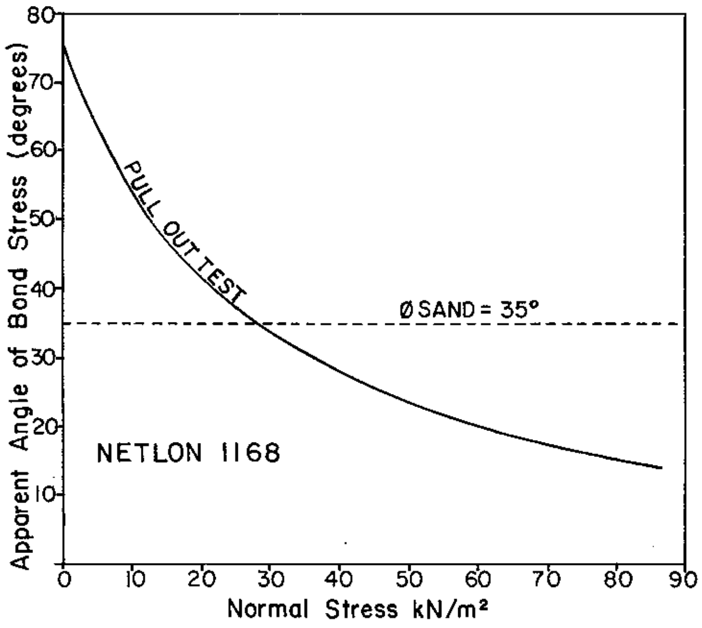

FIGURE 6 ANGLE OF BOND STRESS-NETLON 1168

0.05 and 0.03 at normal stresses of 12.7kN/m^2 and 52.7kN/m^2 respectively. This order of magnitude difference in rates is thought to be due to the fact that in the pull-out test the volumetric strain measured is an average value over the whole depth of the soil under test.

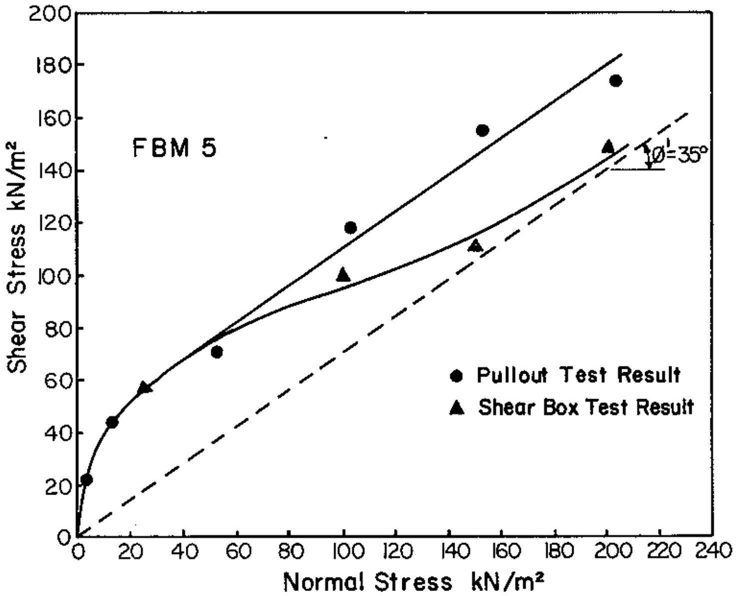

FIGURE 7 TEST RESULTS - FBM5

Since at low normal stresses, the same results were obtained in both types of test, then similar volumetric strains would have been expected in both tests. This leads to the possibility of dilatancy in the pull-out test being restricted to the immediate vicinity of the net. It is interesting to reflect on the fact that if it is assumed that the measured volume increase is restricted to a band of soil 13mm thick on either side of the net, that is approximately the same thickness of soil involved in the shear box test, then the computed rates of change of volumetric strain are almost identical with those derived from the shear box test. Even if the rates of dilation are the same in both types of test this does still not account for the high angles of bond stress. Application of the correction proposed by Bishop (1950) indicates that dilatancy is responsible for less than 1° of the observed values of $\delta = 66°$, for a normal stress of 25kN/m^2. Since the Ø value for the sand is approximately 35° this again indicates the action of some mechanism over and above simple dilatancy.

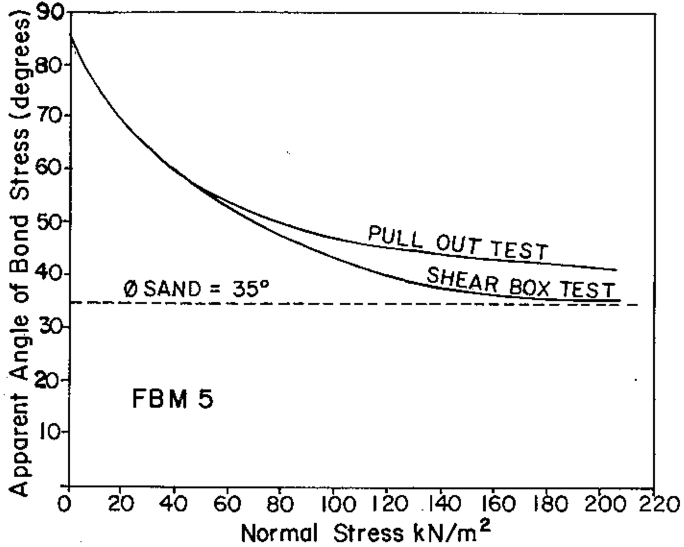

FIGURE 8 ANGLE OF BOND STRESS-FBM5

The fifth and last material to be tested was Terram RF/12 results are given in Figures 9 and 10. Inspection of the results show that the shear box tests gave a value of δ that is independant of normal stress. The measured value of 35° is in very close agreement with the value of 34° indicated by Rankilor (1977). The pull-out test gave rather different results which showed that δ decreased with increasing normal stress, the value of δ dropping to 20° at a normal stress of 200kN/m^2.

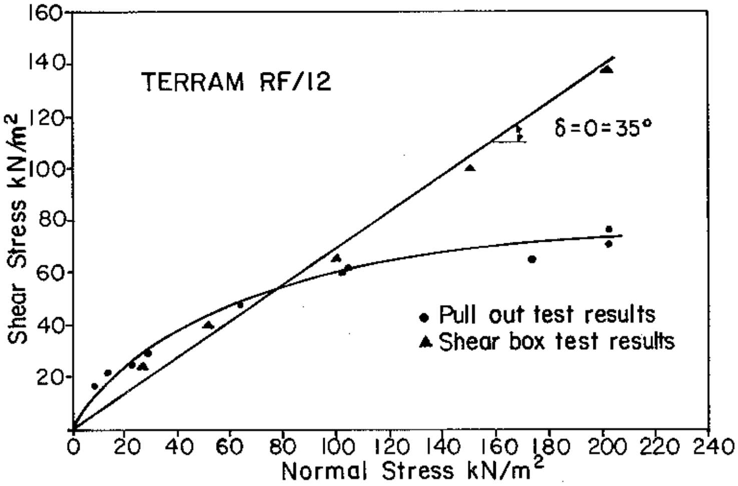

FIGURE 9 TEST RESULTS-RF/12

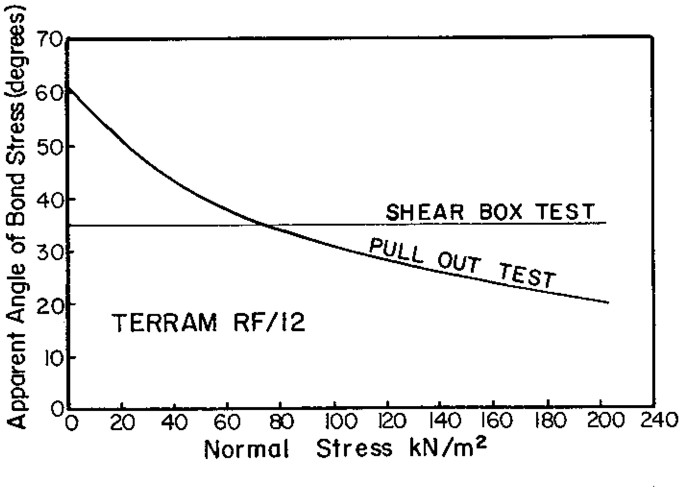

FIGURE 10 ANGLE OF BOND STRESS-RF/12

This performance was not due to tensile failure of the net since in all cases the pull-out load was equal to or less than the recommended working load of 40kN/m. The mechanism of this loss of bond stress is not known however, a likely mechanism is the progressive straightening of the warp as it becomes taut under the applied load. It is thought that this straightening process reduces the amplitude of the asperities formed by the unloaded warp and so gives rise to a loss of planar friction. This mechanism would obviously not operate in the shear box.

COMPARISON OF RESULTS

A comparison of the results for the five reinforcements tested in the pull-out rig is given in Figure 11 in the form of a plot of normal stress vs shear stress. As is clearly shown the steel and FBM5 do not suffer any reduction in shear stress mobilised at failure at normal stresses up to 200 kN/m^2. Conversely the Netlon 1168 and Terram RF/12 show a notable drop off in maximum shear stress mobilised once the applied normal stress exceeds approximately 10 kN/m^2 and 30 kN/m^2 respectively. It is interesting to compare the results obtained by Holtz(1977) from a pull-out test on Technisk Väv No.600, inspection of Figure 11 shows the normal stress vs shear stress curve, as interpreted by the Author, to be of a similar shape to that for RF/12. The maximum shear stress mobilised in these tests would be expected to be somewhat lower since the sand used was compacted to a relative density of 65% compared to the 90% relative density obtained in the tests summarised in Figure 11. The significance of these rest results becomes more apparent from Figure 12 which shows a comparison of angles of apparent bond stress vs normal stress. Since in the case of a reinforced earth wall, the bond length is an inverse function of tan δ it follows from Figure 12 that at normal stress of say 100 kN/m^2 the required bond length of plain steel would be approximately twice that of sanded steel. In using either fabric or net in a reinforcing capacity it is vital that a good bond is maintained between soil and reinforcement. The importance of good bond characteristics is highlighted by Morel et al (1977) who conducted trials using fabric beneath sub-base placed on low bearing capacity soil. It was concluded that due to sliding of the fabric the reinforced areas gave worse performance than those unreinforced.

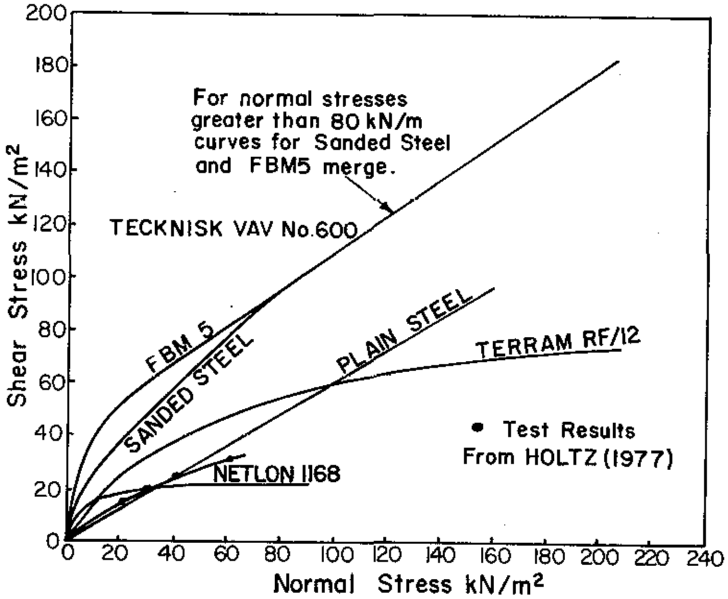

FIGURE 11 COMPARISON OF RESULTS

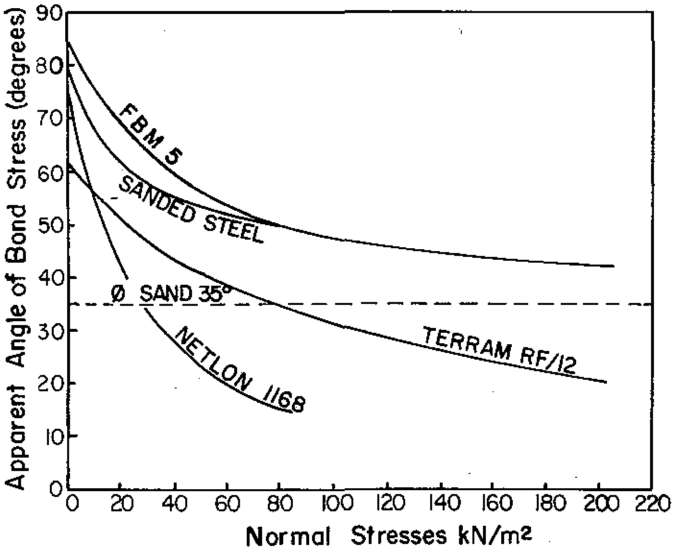

FIGURE 12 COMPARISON OF RESULTS

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