GEOMESH REINFORCED SOIL WALLS – DESCRIPTION AND TESTING

MURS DE SOL ARME AVEC GEOMESH – DESCRIPTION ET ESSAI

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SYNOPSIS: Retaining walls are described in which the soil is reinforced by panels of welded wire mesh sandwiched between two geotextile layers heat bonded to each other, with precast concrete elements used as facing. The wire mesh - geotextile composite used for the soil reinforcement is patented and marketed under the name "GeoMesh". The first large project included 10 separate walls that varied in height from 3 to 15 meters. The walls retain backfill for city streets on a site with 35 degree slopes. Though the streets were still unpaved in 1991-92, when Israel had its wettest winter in 200 years, their performance to date has been extremely satisfactory. Pull-out tests have been performed on Welded Wire Mesh and on GeoMesh in a 30 cm wide by 60 cm long and 30 cm high steel box at vertical stresses up to 300 kPa. Some of the test results are reported in the paper. In all the tests performed to date on 10 cm by 20 cm mesh spacing the pull-out resistance of GeoMesh has been at least equal to that of Welded Wire Mesh.

INTRODUCTION

There are numerous types of reinforced soil structures, which have become economical alternatives to conventional retaining walls. Various materials, usually placed in horizontal layers within the compacted backfill, have been used for reinforcement. These include woven and nonwoven geotextiles, smooth and ribbed steel strips, welded wire mesh, etc.

The subject of this paper is retaining walls in which the soil is reinforced by horizontal layers of welded wire mesh (of the kind used in reinforced concrete) sandwiched between two geotextile layers (top and bottom) heat bonded to each other, with precast concrete panels used as facing . The wire mesh + geotextile used for the soil reinforcement is patented and marketed by Yehuda Welded Mesh Ltd., of Ashdod, Israel, under the name "GeoMesh". The geotextile is non-woven, needle-punched, made of polypropylene and polyester of single layer weight of 235 gm/sq m. To inhibit corrosion the wire mesh is heavily galvanized.

Walls have already been built to heights up to 15 meters at two locations in Israel using precast concrete panels as facing and GeoMesh for soil reinforcement. (See Fig. 1.)

GeoMesh is a comparatively new product, however it is based on welded wire mesh, whose use in reinforced soil walls is well documented in the literature. For example Jackura (1989) describes an 18 meter high wall.

We will briefly describe the first large retaining wall project built with GeoMesh, some of the currently used design procedures, as well as some recently performed (1992) laboratory pull-out tests on GeoMesh embedded in a uniformly graded fine sand. For comparison purposes, pull-out tests were also performed on Welded Wire Mesh (without a geotextile cover) of the same dimensions.

Fig. 1. GeoMesh Reinforced Soil Retaining Wall

DESCRIPTION OF WALLS

The first large project included 10 separate walls that varied in height from 3 to 15 meters. The 15 meter high wall was 150 meters long (2100 sq m of facing) and was built in 45 working days.

The walls retain backfill for city streets in a new housing development on a site with 35 degree slopes. The soil cover was very shallow and the underlying rock was primarily chalk and chalky limestone. There are no indications of any site instabilities. A design had been prepared for mass concrete retaining walls which was bid at very low competitive prices. An alternate GeoMesh reinforced soil wall was submitted and built at a saving of about 25%. When construction started the rate of progress was 30 - 40 sq meters per day for one team but this increased quickly to 60 sq meters per day.

The main precast concrete wall elements were 1.0 meter wide, 1.5 meters high, and 15 cm thick with tongue and groove edges. Each of these 1.5 meter high facing elements are connected to 2 layers of GeoMesh soil reinforcement panels, spaced vertically at 75 cm. The horizontal joints in the wall are staggered and a half height element connected to one layer of GeoMesh is used at the bottom of the wall. The GeoMesh panels are placed contiguously.

In urban areas there is frequently a requirement that as much as the top 2.0 meters should be free of any soil reinforcement. This is achieved by using special L and T shaped elements at the top of the wall that act as cantilevers. The horizontal projection of the elements is connected to a single layer of GeoMesh panels.

A special connection between the GeoMesh panels and the facing is used which is shown in Fig. 2. Triangular shaped "eyes" are embedded in the concrete facing elements. The front of the GeoMesh panel is bent back about 135 degrees at a location so that a transverse bar is at the apex of the loop which together with a shear bar, which is inserted to form the connection, press the "eyes" by scissor action. In full scale testing the above connection has always been stronger then the strength of the longitudinal bars of the GeoMesh.

Fig. 2. Connection between GeoMesh and the wall facing.

Current Israeli specifications for backfill for reinforced soil walls with precast concrete facing elements were adhered to. These specifications require: - maximum size 25 cm, less than 25% passing the #200 mesh sieve, PI < 10, Resistivity > 3000 Ohm-cm, Chlorides < 200 ppm, and sulphates < 1000 ppm.

After completion of the wall, but before the road surface and drainage at the top of the wall had been constructed, Israel had its wettest winter in 200 years. The wall showed no signs whatsoever of movement and water drained freely through many of the joints between the precast wall elements.

Because of the improved drainage due to in-plane permeability associated with the use of GeoMesh panels as soil reinforcement, it is hoped that in the future it will be possible to relax the requirements for backfill and to also allow use of finer grained soils such as those that have been tested by Bergado et al (1992).

DESIGN OF WALLS

The design of the walls called for all of the GeoMesh panels to be uniform in length and to be no less than 65% of the height of the wall. The welded wire mesh used for manufacturing the GeoMesh had 10 cm spacing for the longitudinal bars and 20 cm spacing for the transverse bars. Bar sizes varied from 6.5 mm x 5 mm near the top of the walls to 9 mm x 7mm near the bottom of the 15 meter high walls. The larger diameters are the longitudinal bars. The GeoMesh panel widths were either 1.0 or 1.5 meters, placed one beside the other, forming a continuous reinforcing layer connected at 10cm intervals to the precast concrete facing elements. The vertical spacing between the horizontal layers of GeoMesh was 75 cm.

The internal stability was computed according to FHWA design guidelines (Christopher et al 1990), using the more stringent requirements for inextensible reinforcement. They call for computing the maximum tensile force in the soil reinforcement using horizontal pressures at the top of the wall as high as 3 times active earth pressure reducing to 1.5 times active pressure at a depth of 6 meters, as well as requiring the strength of the connection between the reinforcing panels and the wall elements to be 85% to 100% of the computed maximum tensile force. Additional cross-sectional area was allowed for as sacrificial steel, in order to satisfy corrosion requirements. The pull-out resistance for GeoMesh was assumed to be the same as would be expected for Welded Wire Mesh of the same dimensions. Laboratory pull-out tests on GeoMesh which are described below show this latter assumption to be justified for the dimensions used.

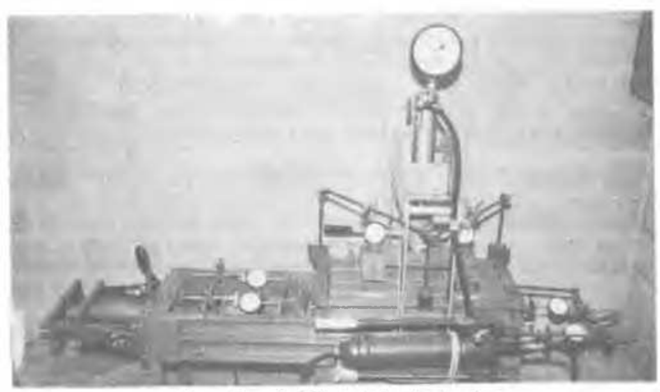

Fig. 3. Pull-out test device

PULL-OUT TEST DEVICE

The dimensions of the inside of the box are 30 cm wide by 60 cm long by 30 cm high. (See Fig. 3.). The pull-out load, which was applied by a hydraulic jack directly to the welded wire mesh (i.e., not to the geotextile), was measured by a load cell. The vertical load, which was applied to the soil by a hydraulic jack acting on a very rigid 30 cm by 60 cm steel cap, was also measured with a load cell. (Both were measured to an accuracy of 0.1kN). The horizontal displacement of the wire mesh was measured with 1/100 mm mechanical dial gages. In almost all the pull-out tests, as failure approached there was a tendency for dilation and it was necessary to bleed the vertical hydraulic jack so as to maintain a constant vertical pressure.

The transverse rods in the wire mesh used for GeoMesh have a spacing of 20 cm, so that there were 3 transverse rods in the box. The longitudinal rods in the wire mesh used for GeoMesh have a spacing of 10 cm so that there were three longitudinal rods in the box. The wire mesh was always positioned in the pull-out box so that the first transverse rod was 15 cm from the front wall of the box leaving 5 cm between the third rod and the back wall of the box as shown in Fig. 4. The transverse rods were 28 cm long which was 2 cm less than the width of the box. The longitudinal rods extended beyond the box at both the front and the back. Grease and polyethylene sheeting were used to line the walls of the box so as to reduce wall friction. The purpose of the above measures was to minimize the influence of boundary conditions and to obtain uniform planar behaviour .

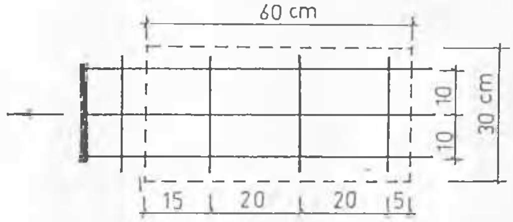

Fig. 4. Position of welded wire mesh in pull-out box.

SOIL USED IN LABORATORY PULL-OUT TESTS

The only soil tested to date has been a washed uniformly graded sub-angular fine sand (SP) having a maximum size of 1.0 mm, and less than 1% finer than 0.1 mm. The laboratory maximum and minimum densities were 16.9 kN/cu m and 14.8 kN/cu m respectively. All pull-out tests were performed on dry sand at the same low density of 15.5 kN/cu m, corresponding to a Relative Density of 35 percent.

The soil was tested in a 30 cm by 30 cm double direct shear device. The peak angle of internal friction (phi) was 34 degrees at a vertical stress of 300 kPa at a displacement of 10 mm, dropping to 32 degrees at 18 mm displacement. At 100 kPa vertical stress both values where about 1 degree higher. The friction was also tested between the sand and the geotextile used in GeoMesh in the same double direct shear device. The geotextile was fastened to top and bottom of a wooden block that was placed in the middle section of the double direct shear device, the top and bottom sections being filled with sand. The shear strengths were almost identical to those reported above.

LABORATORY PULL-OUT TEST PROCEDURES

The horizontal load was applied in equal increments no greater than 1/10 of the estimated failure load. Each load increment was maintained for at least 15 minutes. As failure was approached, as indicated by increased displacement, the displacement was "locked" and the load relaxation measured.

In addition to monitoring the vertical and horizontal loads, the horizontal displacement of the welded wire mesh was measured as well as the vertical movement of the top loading plate. Tests were performed at 52 kPa, 104 kPa and 312 kPa corresponding to depths of embeddment of 2.5, 5.0 and 15.0 meters respectively.

Tests were performed on GeoMesh and Welded Wire Mesh, as well as on the Longitudinal Rods alone and the Longitudinal Rods embedded between a double layer of geotextile. To date 20 pull-out tests have been performed (Wiseman 1992). The results of some of these tests are reported below.

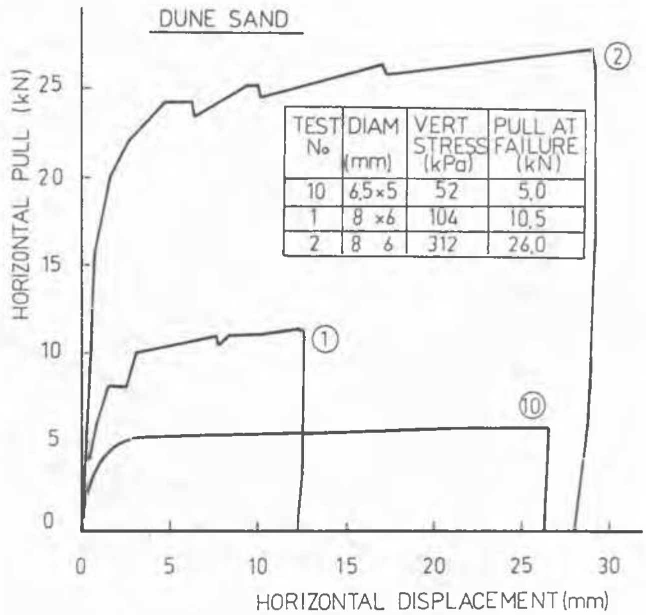

Fig. 5. Load - displacement curves for Welded Wire Mesh

PULL-OUT OF WELDED WIRE MESH

The Load - Displacement curves for 3 pull-out tests to failure on 10 cm by 20 cm Welded Wire Mesh are shown in Fig 5. Shown in Table 1 below are the wire sizes, vertical stress, pull at failure and the computed apparent friction angle assuming that the failure mechanism is planar double shear.

Table 1. Pull-out Tests - Welded Wire Mesh

Test No	Mesh Diam. mm	Vert. Stress kPa	Pull at Failure kN	Tan (phi)	(phi) deg
10	6.5 x 5	52	5.0	.266	14.9
1	8 x 6	104	10.5	.281	15.7
2	8 x 6	312	26.0	.231	13.0

Since the measured (phi) for the sand is about 33 degrees, it may be concluded from the results of the above analysis that the failure mechanism for the Welded Wire Mesh at the 10 cm by 20 cm spacing was not planar double shear.

As reported above, pull-out tests were also performed on longitudinal rods alone. Therefore it is possible to "correct" the total pull-out resistance by deducting the load taken by friction on the longitudinal rods and hence evaluate separately the horizontal bearing capacity of the 3 transverse rods, assuming they each contribute equally to the pull-out resistance.

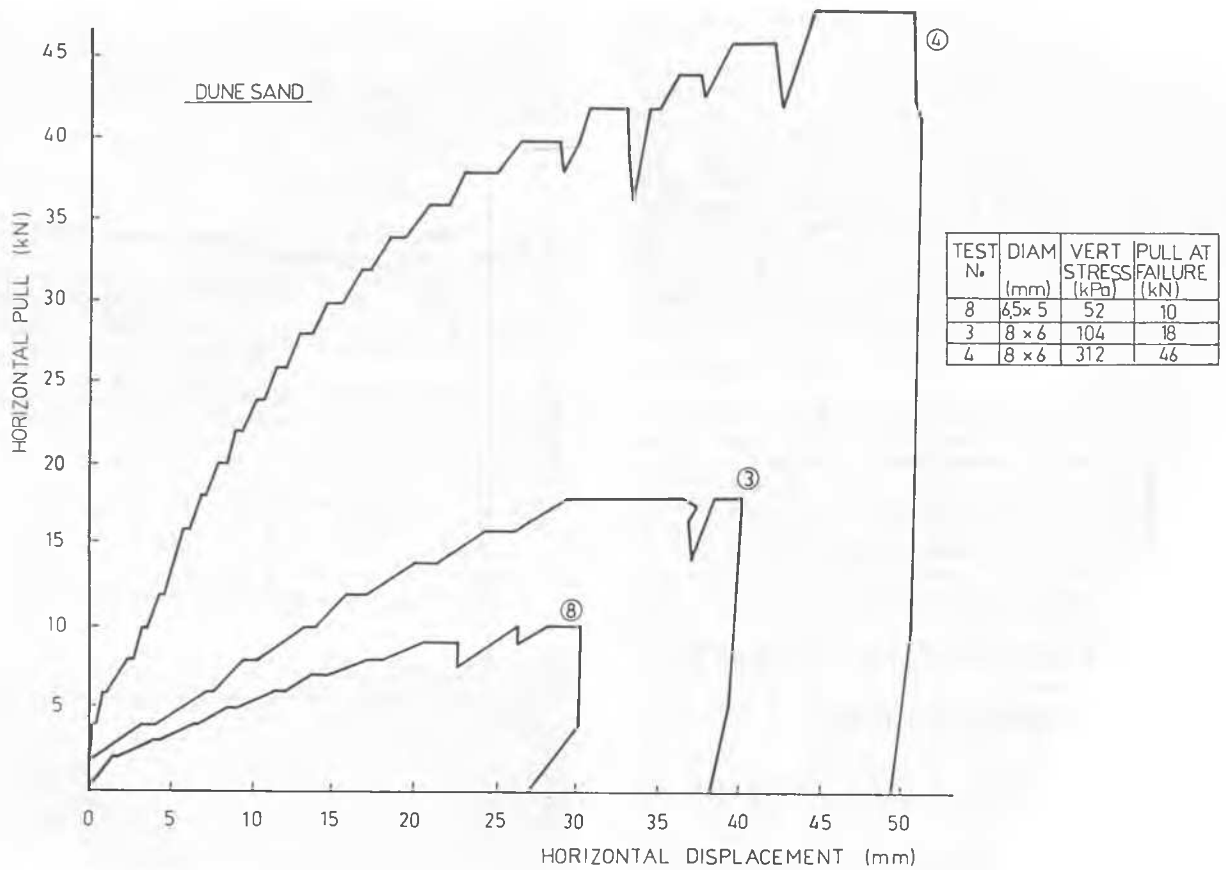

Fig. 6. Load - displacement curves for GeoMesh.

In Table 2 below, the horizontal bearing pressure is assumed to be the Net Failure Load divided by the total bearing area (3 * 28cm length * diameter of the transverse rods). (Nqb) is then taken as this horizontal bearing pressure divided by the applied vertical stress.

Table 2. Bearing Capacity Factors (Nqb) - Wire Mesh

Test No	Mesh Diam. mm	Vert. Stress kPa	Failure Load Total kN	Frict. kN	Net kN	(Nqb)
10	6.5 x 5	52	5.0	1.0	4.0	18.3
1	8 x 6	104	10.5	2.4	8.1	15.5
2	8 x 6	312	26.0	7.3	18.7	11.9

There is a tendency for the (Nqb) values to decrease with increasing vertical stress, indicating the importance of carrying out testing at realistic stress conditions (Juran et al 1988). It may be noted that the above (Nqb) values are within the range of those reported by Palmeira and Milligan (1989) for granular soils with (phi) = 33 degrees.

PULL-OUT OF GEOMESH

The Load - Displacement curves for 3 pull-out tests to failure on GeoMesh are shown in Fig 6. Table 3 below lists the wire sizes, vertical stress, pull at failure and the computed apparent friction angle, assuming that the failure mechanism has been double shear.

Table 3. Pull-out Tests - Geomesh

Test No	Mesh Diam. mm	Vert. Stress kPa	Pull at Failure kN	Tan phi	phi deg
8	6.5 x 5	52	10.0	.534	28.1
3	8 x 6	104	18.0	.481	25.7
4	8 x 6	312	46.0	.409	22.3

These values are considerably higher than the corresponding values for Welded Wire Mesh in Table 1. They approach the values to be expected for a double shear failure mechanism. It should be noted that the above failure values are at displacements much larger than those measured for Welded Wire Mesh.

The failure mechanism in the above tests is not clear. The pull-out load is applied to the wire mesh but it appears that in Test No 8 (see the left side of the photograph in Fig 7) the geotextile moved along with the wire mesh without tearing, and that the failure mechanism was double shear. In other tests, at higher vertical pressures, upon dismantling after pull-out failure, it could be observed that the geotextile behind the first and second transverse rods was torn (right side of Fig. 7). In these cases the geotextile had become folded under the the front of the lateral rods indicating a failure mechanism governed primarily by horizontal bearing failure.

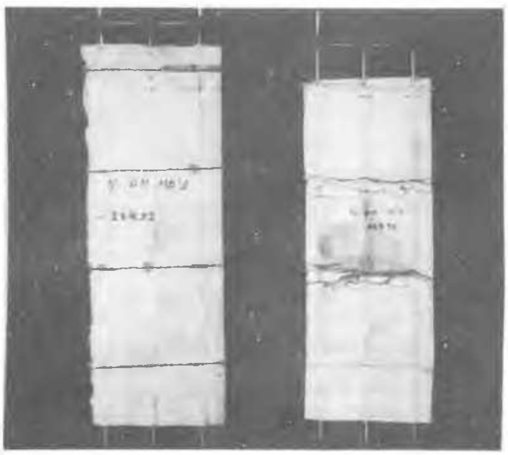

Fig. 7. GeoMesh panels after pull-out testing.

DISTRIBUTION OF PULL-OUT RESISTANCE

8mm by 6mm GeoMesh was instrumented with electrical wire strain gages. The strain gages were mounted in pairs on each of the 3 longitudinal bars, midway between the first and second transverse rods and midway between the second and third transverse rods. (See Fig. 8 showing the location of the strain gages). Pull-out tests were first performed on GeoMesh and then the geotextile was stripped off and the tests repeated on the wire mesh.

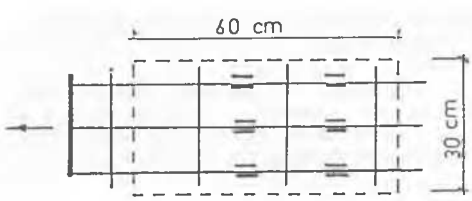

Fig. 8. Location of strain gages.

The load was applied through a rigid yoke to all 3 longitudinal bars. The welded wire mesh is structurally highly indeterminate and therefore no attempt was made to analyse the load in any one longitudinal bar.

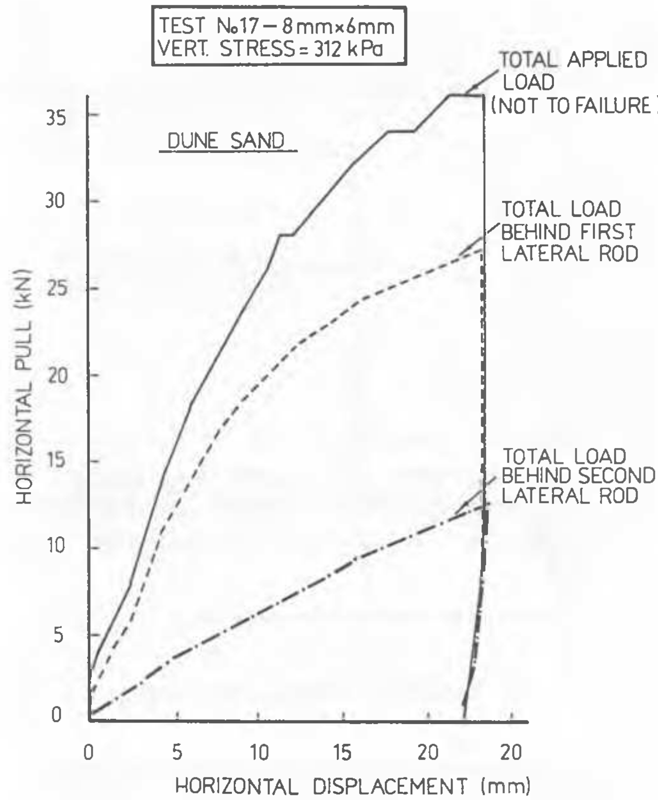

Fig. 9. Distribution of the load for GeoMesh.

Plotted in Figs 9 and 10 are the load - displacement curves for the GeoMesh and Welded Wire Mesh respectively. On each figure there are three load - displacement curves. The upper curve is for the total applied load. The curve below this is for the total load behind the first transverse rod as measured by the 6 strain gages mounted in pairs on the 3 longitudinal bars midway between the first and second transverse rods. The lower load - displacement curve is for the total load measured behind the second transverse rod.

Both for the GeoMesh and for the Welded Wire Mesh, 40 % to 50 % of the resistance to pull-out is concentrated in the vicinity of the middle transverse rod with the remainder approximately equally divided between the front and back transverse rods.

It is important to note that the resistance to pull-out is mobilized at the back rod simultaneously with the resistance to pull-out of the front rod. Furthermore, the proportion of load carried by each transverse rod remains sensibly constant throughout the entire displacement process, though there is a tendency for the distribution to equalize at larger deformations and as pull-out failure is approached.

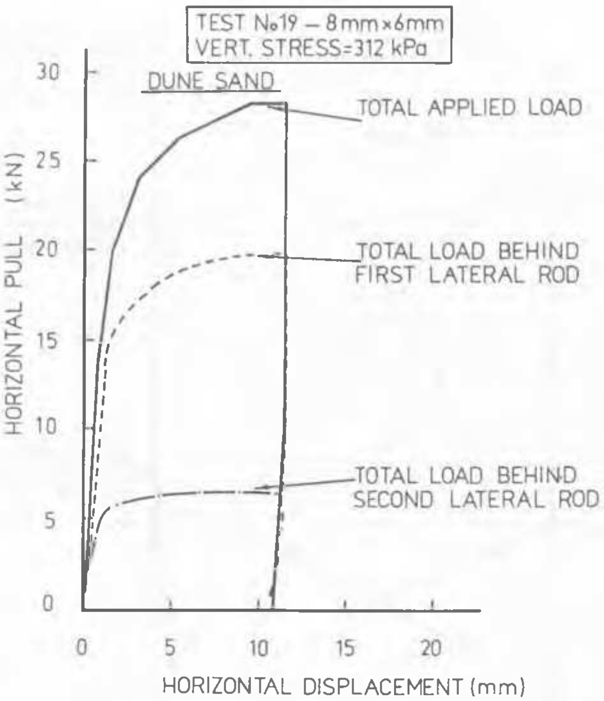

Fig. 10. Distribution of Load for Welded Wire Mesh.

CONCLUDING REMARKS

Experience to date is that Contractors like working with GeoMesh for constructing reinforced soil walls. Even on their first job the fabrication techniques are easily mastered. Furthermore, GeoMesh reinforced soil retaining walls have performed very satisfactorily during Israel's wettest winter in 200 years.

The test results obtained to date, and the comparatively uniform longitudinal distribution of pull-out resistance would appear to indicate the adequacy of the test facility for laboratory pull-out testing of planar reinforcement such as Welded Wire Mesh and GeoMesh.

Though the failure mechanism for GeoMesh is still not firmly established, it would appear reasonable to assume the same failure mechanisms for GeoMesh as for Welded Wire Mesh; namely either double shear or primarily bearing resistance of the transverse rods, depending upon the vertical stress and the in plane rod spacing and diameters.

At large horizontal displacements, the ultimate pull-out resistance of GeoMesh was larger than that of Welded Wire Mesh for the 10 cm by 20 cm spacing and bar sizes tested. The pull-out resistance of Welded Wire Mesh is commonly evaluated at a displacement of 19 mm. (Mitchell et al, 1987, pg 170) At this displacement the relative performance would appear to depend on the vertical stress and the rod diameters. However at this displacement the pull-out resistance of GeoMesh was at least equal to that of Welded Wire Mesh.

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