Chapter 5

PRESENTATION OF RESULTS AND DISCUSSIONS

5.1 GENERAL

For the detailed study of the Risalpur soil and the properties of nylon, laboratory testing is done for the identification of the subsurface soil strata and evaluation of material properties. In the following section discussion on the results of the laboratory tests, which were performed on the Risalpur soil and nylon rope, will be carried out.

5.2 LABORATORY EVALUATION OF RISALPUR SOIL

5.2.1 General

Laboratory tests are performed on the soil samples collected from the site location. The laboratory tests are performed to determine the engineering properties of soil taken from the test pits. Both disturbed and undisturbed samples were collected for the laboratory evaluation of the material properties.

In the following sections discussions will be carried out on the results of the laboratory tests performed on the samples recovered from the test pit.

5.2.2 Field Moisture Content Test

The field moisture content of the samples taken from the test pit is determined as 14.36%, details of which are given in Appendix I (Table 1.1). Generally the moisture content of this area is greatly affected by weather/seasonal changes. It’s important to note the moisture content variation in different seasons.

5.2.3 Field Density Test

For the performance of field density the samples were recovered from the test pit excavated at 3 ft depth. Density of the Risalpur soil comes out to be 118 lb/ft^3. The value of density is slightly towards higher side. Generally soils with higher densities exhibit higher strength.

5.2.4 Specific Gravity Test

For the performance of specific gravity test the samples were recovered from the test pit. The specific gravity value determined is 2.69. As the soil is silty in nature with clay content therefore the value of specific gravity ranges in between clay and sands. Details about the results of the test are given in Appendix I (Table 1.2).

5.2.5 Liquid Limit Test

For the performance of liquid limit test the samples were recovered from the test pit. Results of the tests show average liquid limit (LL) value of 21% for the soil samples as shown in Figure. 5.1. The results of LL and PL are also used for classification of soil and are given in Appendix I (Table 1.3). .

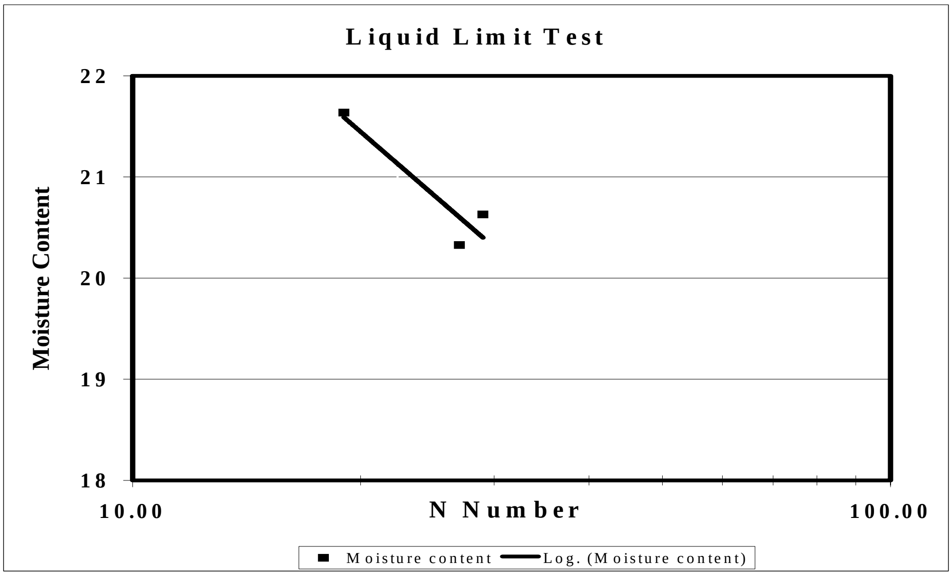


FIG. 5.1. Liquid Limit Test

5.2.6 Plastic Limit Test

For the performance of plastic limit test the samples were recovered from the test pit. The average value of the plastic limit of the soil is in the range of 10.71 %. The results of the test are given in Appendix I (Table 1.4). According to these values of LL and PI, the classification based on unified classification system of soil is CL-ML. It is known as silty clay with low plasticity.

5.2.7 Grain Size Analysis Test

For the performance of grain size analysis test the samples were recovered from the test pit excavated. Figure. 5.2 show the grain size analysis of the soil. Grain size analyses test shows a well-graded soil with particles of all sizes ranging from 0.003 mm to sands. The details for the test are given in Appendix I (Table 1.5).

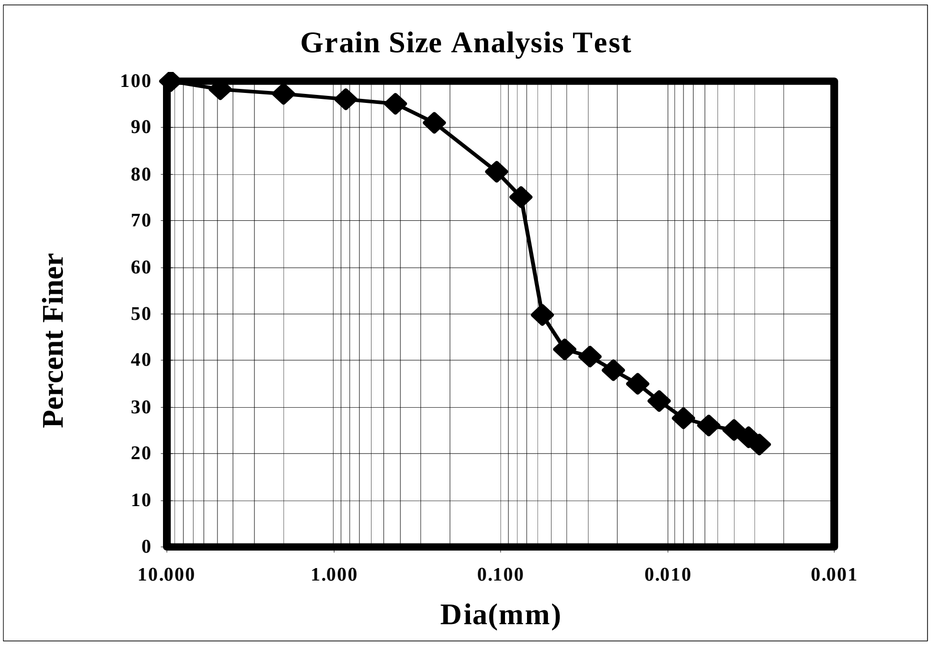


FIG. 5.2. Gain size Analyses Test

5.2.8 Permeability Test

For the performance of permeability test the samples were recovered from the test pit excavated 3 ft depth. Average values of permeability of the soil samples collected from the site is in the range of 3.3×10^{-6} cm/sec, which is on the lower side due to the presence of finer particles. The results of the test are shown in Appendix I (Table 1.6).

5.2.9 Direct Shear Test

For the performance of direct shear test the samples were recovered from the test pit excavated. From direct shear tests, value of cohesion (c) and angle of internal friction (Φ) came out to be 300 psf and 18^{o} respectively (Figure. 5.3).

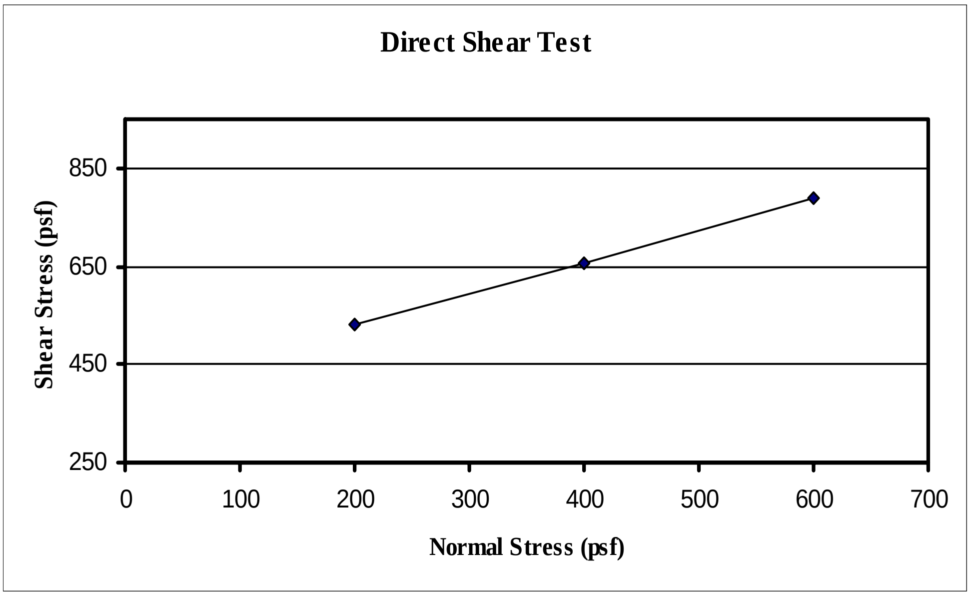


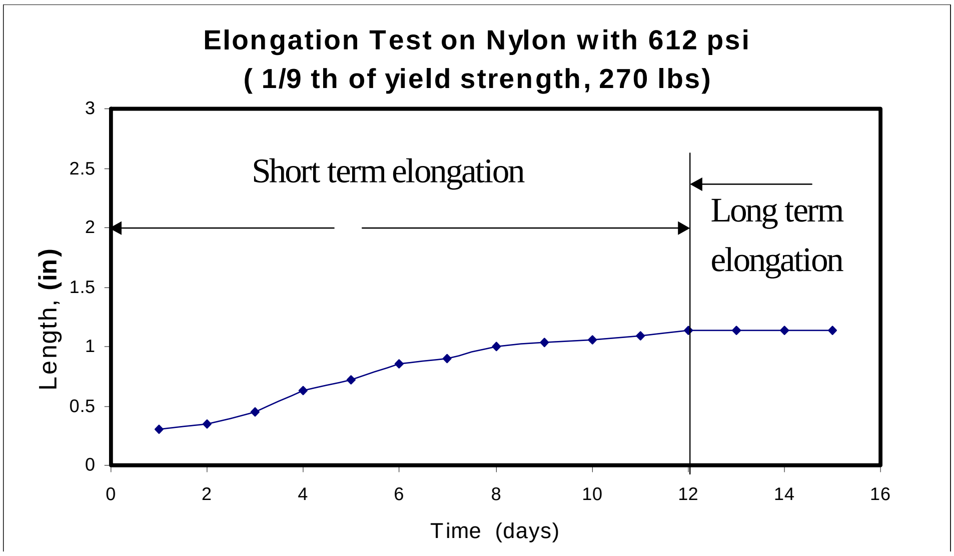
FIG. 5.3. Direct Shear Test

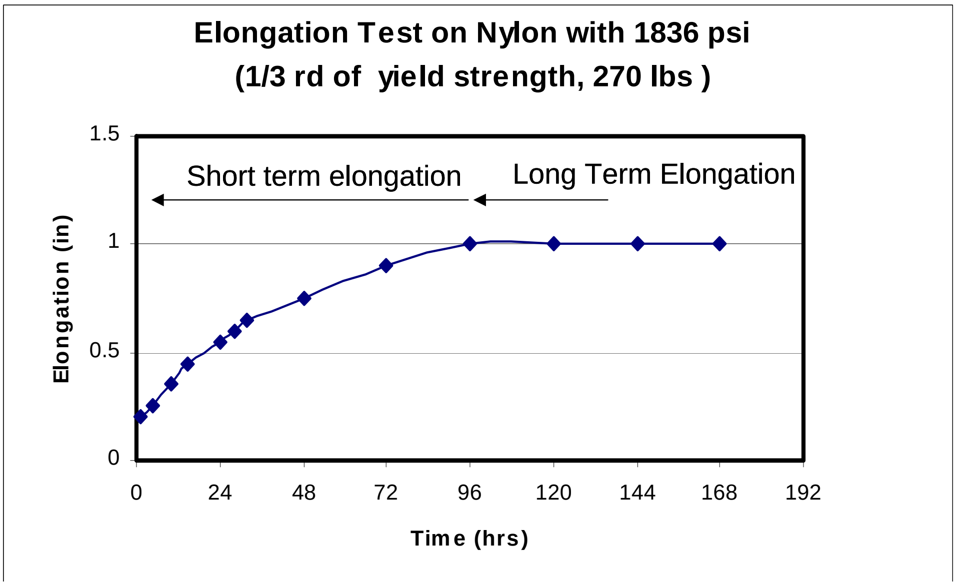
5.2.10 Standard Compaction Test

The standard compaction test was conducted in laboratory on the samples taken from test pit. Three tests were conducted to insure the accuracy of the test. The maximum dry density at optimum moisture content was 112 psf. The values at 95 % of optimum moisture content on the dry and wet of optimum were taken and used in the pullout test.

5.2.11 Elongation Test

For the performance of elongation test nylon specimen of length 12 inches was taken and tested under constant load equivalent to 612 psi, 1836 psi and 4000 psi. The purpose of this test was to check the short-term elongation in nylon. After allowing the initial elongation, readings were taken until the elongation becomes constant. Finally the graph was plotted between the elongation and days as shown in Figure. 5.4. It was observed that the nylon is an extensible polymeric material





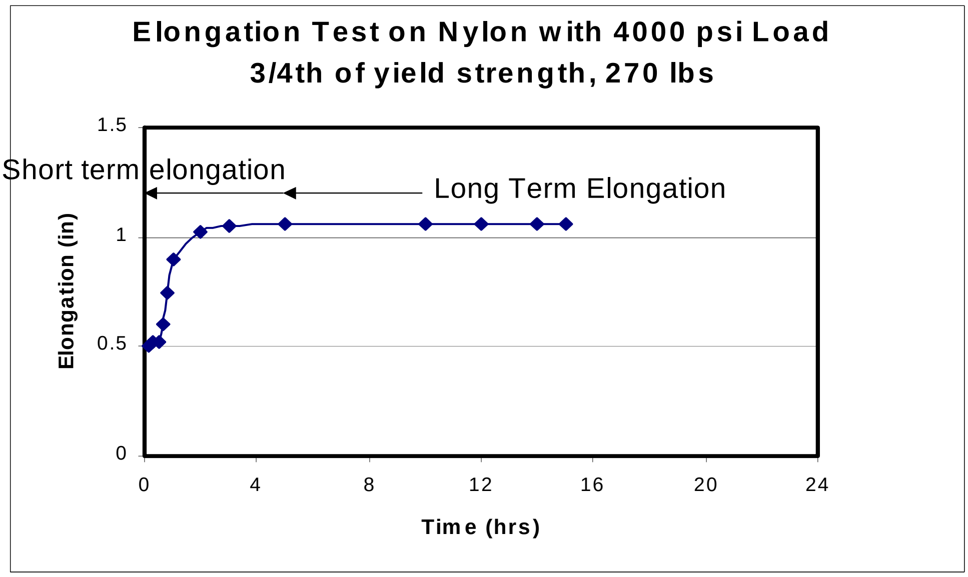


FIG. 5.4. Elongation Test

and the primary stretch/elongation was observed and then it becomes constant and enters into secondary phase of creep which is time dependent.

In Ist graph of Figure. 5.4 the normal stress applied was, 1/9th of the yield strength, i.e. 270 lbs. There is elongation observed up till twelve days then it becomes constant. As the stress was very small therefore elongation test was conducted again with increased stress.

Second elongation test was conducted with stress 1/3rd of the yield strength, as shown in graph the elongation was observed up till four days then it becomes constant.

Third elongation test was carried out with stress 3/4th of the yield strength and the graph was plotted which shows that after 2 hours the short-term elongation was over.

After conducting elongation tests, it was concluded that pre-stretching would be required in the nylon rope to prevent the large deformations in the initial stages. Therefore for pre-stretching, installation arrangements would be required and that is explained in section 5.2.14.

5.2.12 Tensile Strength Test

For the performance of the tensile strength test 8 inches specimen of nylon was tested in the universal testing machine. The speed of the universal testing machine was kept at 5mm/min. The tensile load was recorded with the help of dial gauges and the elongation in the nylon rope was also measured. The results are shown in Figure.5.5. It was observed that the first strand of nylon among the three broke at the 0.12 tons load and the elongation measured was 1.2 inch. Then the rest of the strands broke at 0.24 ton at the elongation of 6 inches approximately. For the design, 1 inch elongation was kept the benchmark therefore the tensile strength used in the design example for calculating the height of embankments was 0.12 tons.

5.2.13 Pullout Test

For the performance of the pullout tests, the apparatus of the test was fabricated. Plastic sheet was placed inside the concrete box and grease was applied on the four sides to minimize the friction between soil and the walls of the concrete box. Then soil was filled in 6 inches thick layers, each layer was compacted using mechanical compactor. The ropes were then fixed into the clamp on one side to measure the pullout resistance offered by the nylon grid under different normal stresses, while on the other side, the rope ends remained free. A thin metallic wire was tied to the joint of the nylon grid to determine the displacement at the free end. Then the normal load was applied simulating the different heights of embankments i.e. 2 ft, 4 ft, 6 ft, and 8 ft and for each normal load horizontal pullout resistance was noted. The vertical loading was applied in four steps with varying over burdens pressures. Figure 5.6 and 5.7 shows the results of the pullout tests performed dry and wet of optimum moisture contents.

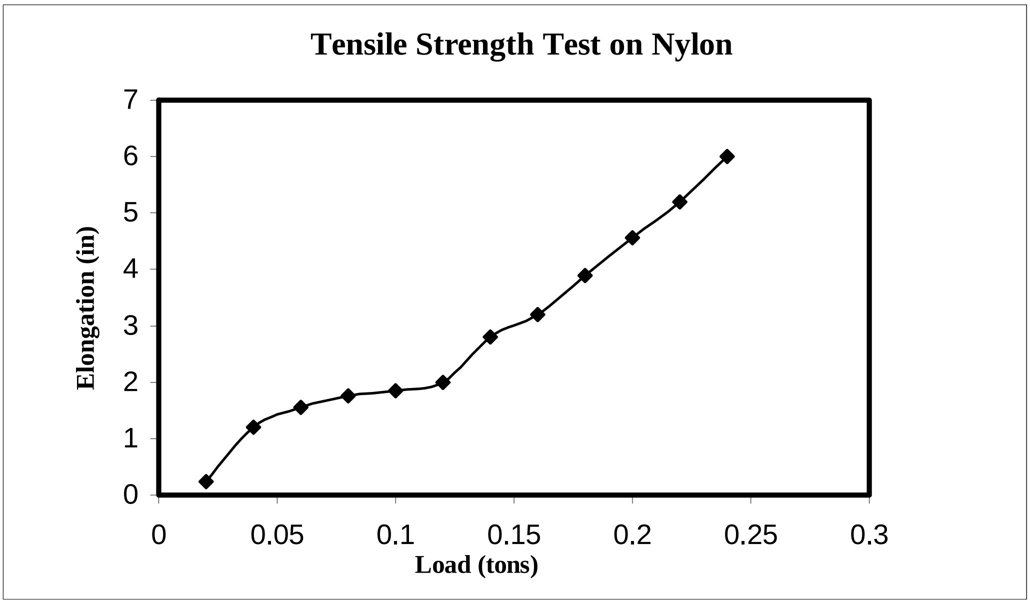


FIG. 5.5 Tensile strength Test

First of all in both the graphs shown (Figure. 5.7 and 5.8) the pullout resistance is increased with the increase in overburden pressures. Which is very evident due to fact the the less pullout force would be required to pullout the nylon grid under low normal pressure and vice versa. The pullout test on dry of optimum moisture content showed more strength than the pullout test on the wet of optimum. The peak strengths achieved by the dry side is clearly more than the peak strengths on wet side of optimum under four overburden pressures as shown in Figure 5.6 and 5.7. Both the Figures can be compared to view the results, the maximum value on dry side for 2 inches elongation is approximately 0.41 tons.

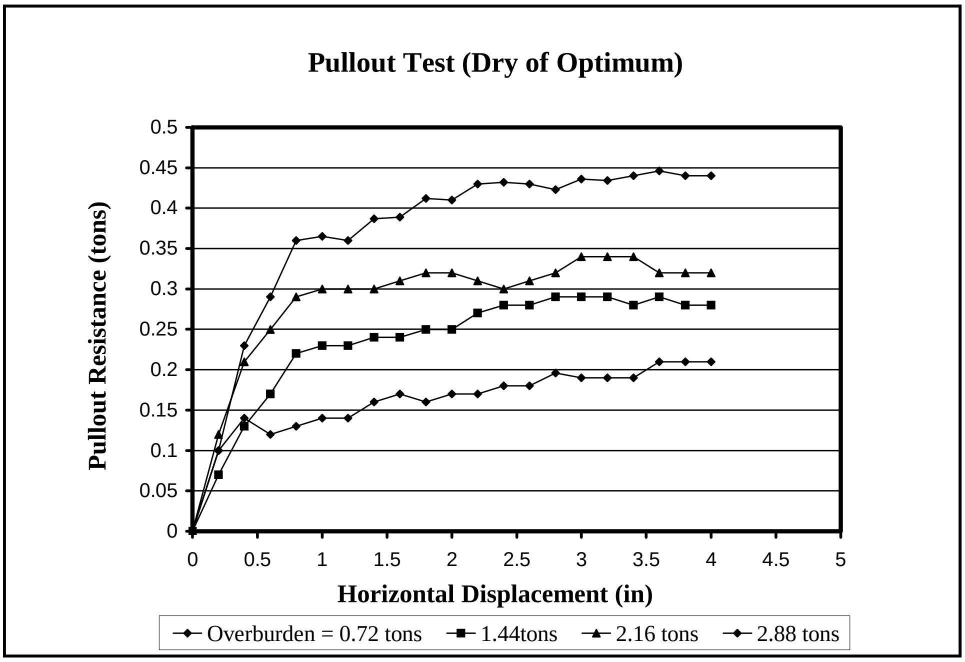


FIG. 5.6. Pullout Tests Under Four Different Overburden Load (Dry of Optimum)

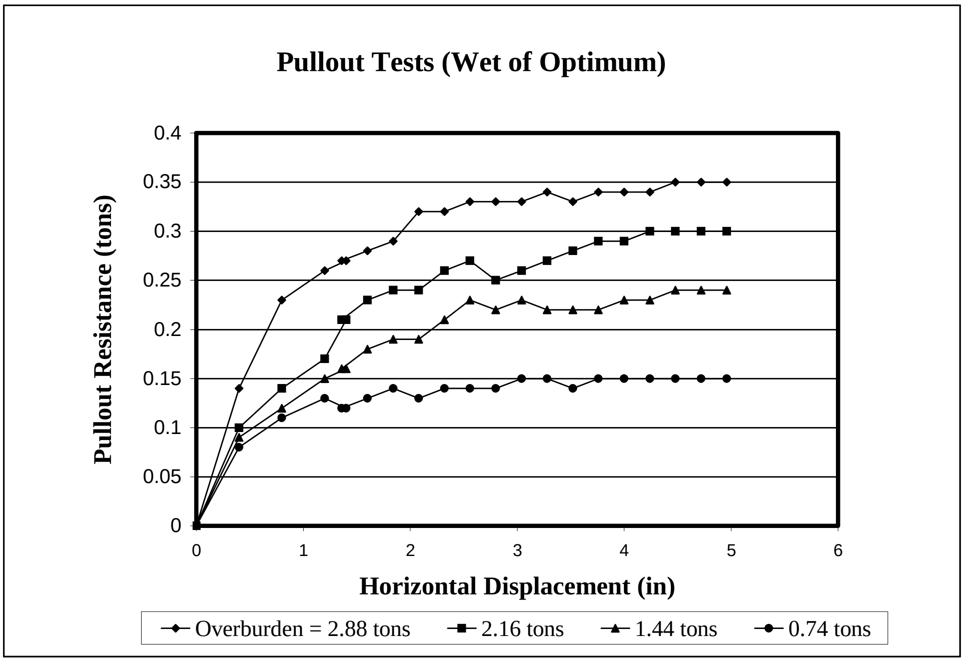


FIG. 5.7. Pullout Tests Under Four Different Overburden Load (Wet of Optimum)

Whereas, the maximum value on wet of optimum is approximately 0.30 tons. This behavior shows that by adding moisture content, it reduces the strength of soil nylon composite due to reduction in friction and interlocking resistance. For the design purposes maximum 1 inches elongation in the rope is considered, after that it is considered as pullout failure of the nylon grid reinforcement. It is also observed that the elongation on the wet side of optimum moisture content was more than the dry side of optimum. Again this is caused by the reduced friction between soil and nylon composite by addition of moisture, which allows the nylon grid to move instead of holding it. The value of maximum elongation on wet side was measured up to 5 inches whereas on the dry side the elongation measured was up to 4 inches. Figure 5.8 shows the increase of pullout resistance with increasing overburden.

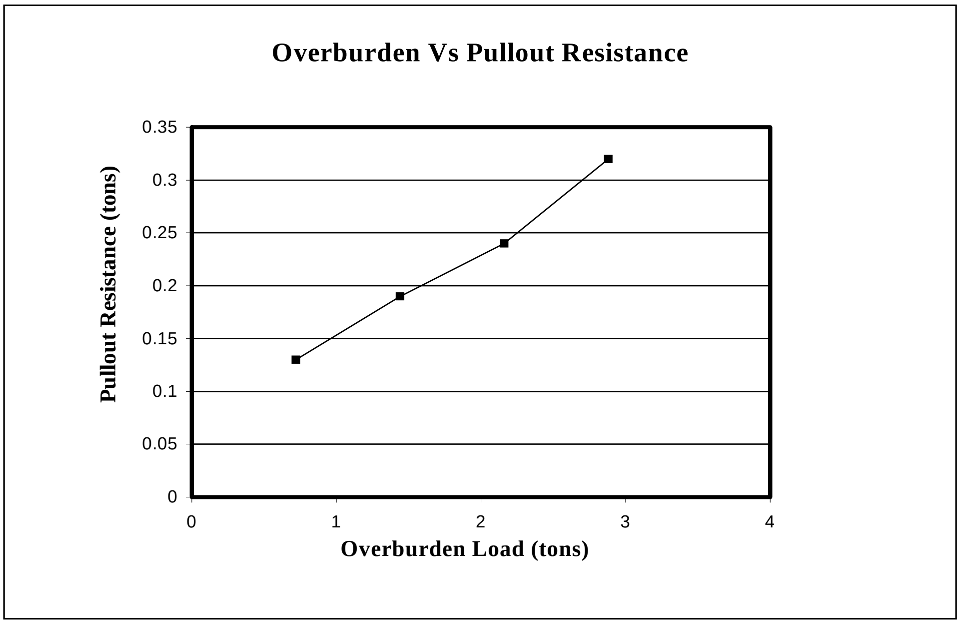


FIG.5.8. Increased Pullout Resistance With Increasing Overburden

5.3 INSTALLATION ARRANGEMENT

After conducting the elongation tests with three different normal stresses (612 psi, 1836 psi and 4000 psi), it was observed that with 612 psi stress nylon specimen showed approximately 1.2 inch elongation in 12 days duration (Figure 5.4) and similarly with the other two normal stresses (1836 psi and 4000 psi) the elongation observed was almost 1 inch in 4 days and 2 hours respectively, therefore, the nylon rope has got the elongation property which may cause the excessive deformation when used as soil reinforcement therefore, to arrest this problem pre-stretching has to be done to prevent the short-term elongation. Nylon rope would be stretched between the facing panels with help of clamp and tackles arrangement as shown in Figure 5.9.

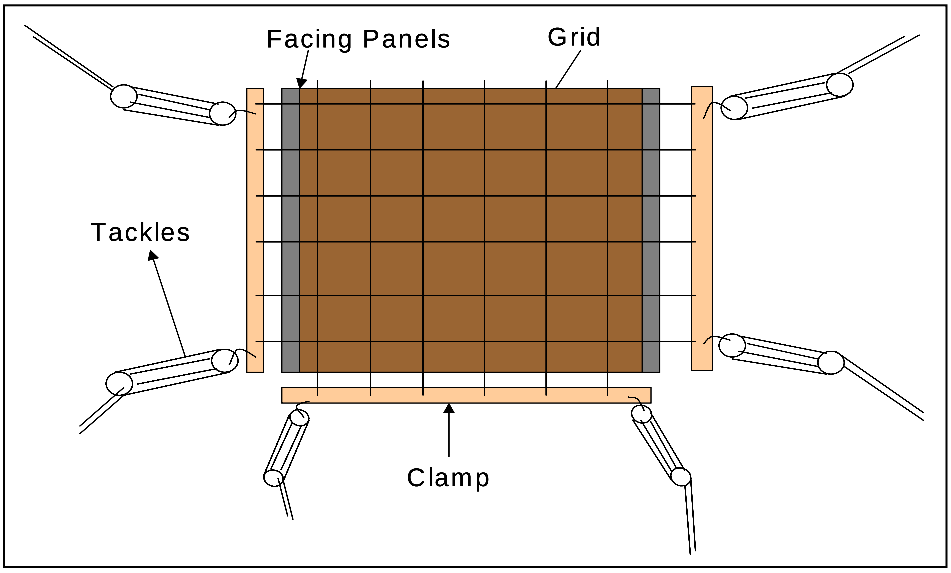


FIG.5.9. Installation Arrangement

After laying the Ist layer of reinforcement the nylon rope would be tied to the clamps and stretched with the help of tackles, so that nylon rope overcomes its initial elongation. The stress required for it's pre-stretching would be taken from elongation test (4000psi). The pre-stretching would prevent the short-term elongation in nylon and then ends of nylon rope would be tied to second layer of the reinforcement. Similarly all the layers would be placed.

The alternative pulling arrangement of nylon rope can be done in following ways.

- Mechanical Jacks
- Dozer Winches
- Vehicles

It is also suggested that if the nylon ropes are pre-stretched in the factory with the help of pulling arrangement as shown in Figure 5.10. The loads would be attached to the ends of nylon rope and by this way the initial elongation would overcome and then it can be laid in the field. This arrangement can ease the method of field pres-stretching.

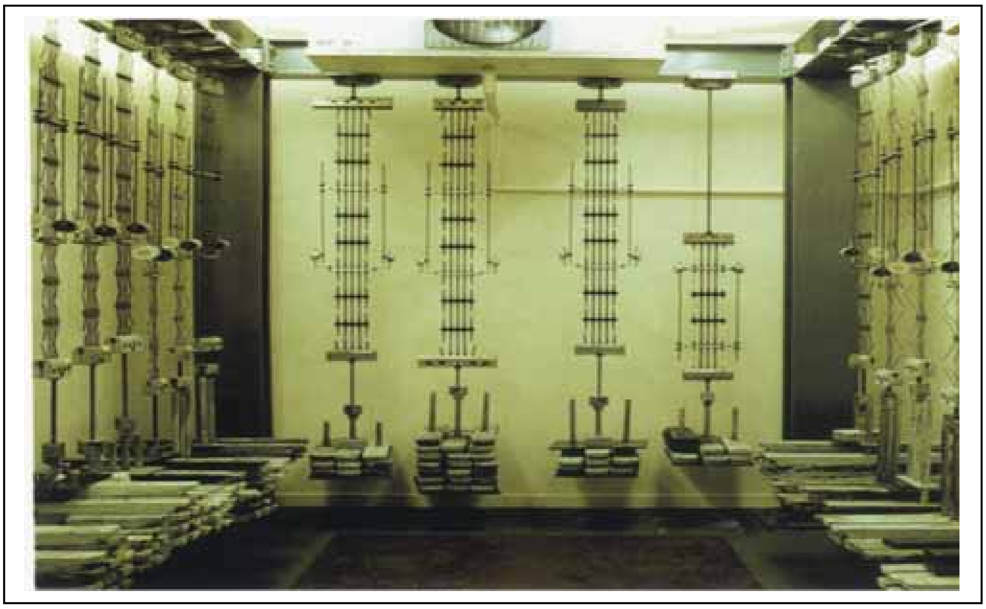


FIG.5.10. Pre-stretching Arrangement in Factory

5.4 COST COMPARISON

In Pakistan the reinforced earthwork is done in Layari Expressway project and Paraweb (synthetic polymer) straps have been used as soil reinforcement. Therefore, for the cost analysis, the Layari Express way project was considered the reference. The bill of quantities of Layari Express way project is attached in Appendix II. After analyzing the cost of the project, it is concluded that major difference between the nylon and Paraweb reinforcement is material cost and custom duties in case of Paraweb reinforcement on the imported items.

The comparison was done for 15 ft (3 X 3 sq.ft) high embankment between nylon and Paraweb reinforcement.

5.4.1 Material Cost of Nylon

- Nylon used in 15 ft high embankment in 6 layers is 252 ft length.
  (Using 6x6 inch spacing grid)
- Cost of Nylon rope is Rs. 3 per foot.
- Material cost of Nylon = 252 * 3
- Approxiamtely Rs. 800.
- Plus Rs. 200 for fabrication and tackles cost.
- Total Cost = Rs 1000.

Whereas the cost of Paraweb reinforcement for 15ft high embankment is approximately Rs 3,000. Also the custom duties on the imported items are Rs 25,000,000. Therefore nylon is cheaper than the Paraweb reinforcement because its locally available and material cost is also cheap for the same height embankment.

5.4.2 Material Cost of Steel

5.5 DESIGN EXAMPLE

In the design example, it is required to calculate the height of soil embankment without reinforcement and then using the active lateral earth pressure theory, the height of reinforced soil embankment with Risalpur soil strength parameters (c and ϕ) and the tensile strength of the nylon.

DATA:

T_s = Tensile Strength of Rope = 0.12 ton

ϕ = Angle of Internal Friction of Soil = 18^o

γ = Unit Weight of Soil = 120 lb/ft^3

c = Cohesion = 300 lb/ft^2

Ka = Active Lateral Earth Pressure coefficient.

Z_c = Height of the embankment without reinforcement.

Depth/Height of Tension Crack

$$Z_c = \frac{2c}{\gamma\sqrt{K_a}}$$

Where,

$$K_a = \frac{1 - \sin\phi}{1 + \sin\phi}$$

$$K_a = \frac{1 - \sin 18^0}{1 + \sin 18^0}$$

$$K_a = 0.53$$

So,

$$Z_c = \frac{2 \times 300}{120 \times \sqrt{0.53}}$$

$$Z_c \approx 7\,ft$$

Active Lateral Thrust:

P_a = T_s = Tensile Strength

$$P_a = \frac{1}{2}\gamma H^2 K_a - 2cH\sqrt{K_a}$$
$$200 \times 5 = \frac{1}{2} \times 120 \times H^2 \times 0.53 - 2 \times 300 \times H \times \sqrt{0.53}$$
$$31.8H^2 - 439.7H - 1000 = 0$$

Solving the above quadratic equation,

H = 16 ft

This means that the unsupported height of CL-ML soil with above strength parameters is up to 7 ft. After reinforcing it with nylon of tensile strength 0.12 ton, the height is raised to 16 ft.

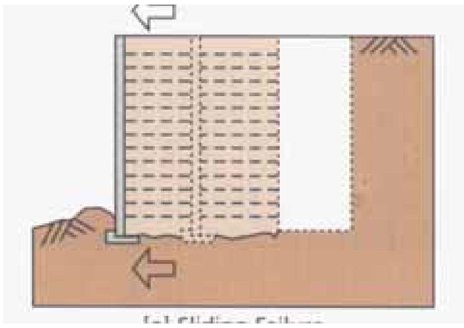
5.6 DESIGN EXAMPLE OF RETAINING WALL

A 15 ft high retaining wall, using CL-ML soil as backfill and nylon grid reinforcement. Retaining wall is checked for its stability. Soil parameters used are:

ϕ = Angle of Internal Friction of Soil = 18^o

γ = Unit Weight of Soil = 120 lb/ft^3

c = Cohesion = 300 lb/ft^2



Check for Outward Stability:

Using Earth pressures and earth retaining structures equation.

$$FOS = 2\mu\left(\frac{\gamma H + ws}{Ka(\gamma H + 2ws)\left(\frac{H}{L}\right)}\right)$$

Where

H = Height of the retaining wall

L = Length of the reinforcement

Ka = Active lateral earth pressure coefficient

Ws = surcharge

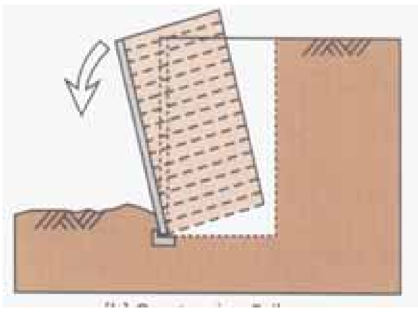
μ = bond coefficient

For FOS = 2

We get the length of reinforcement L = 30 ft

Check for the Overturning Stability:

Using Earth pressures equation.



$$FOS = \frac{3(\gamma H + ws)}{Ka(\gamma H + ws)\left(\frac{H}{L}\right)^2} \geq 2$$

After putting the values the FOS = 5 $\geq$ 2

Check for the internal Stability:

Using the tension failure equation.

$$T = K \times S_v(\gamma Z + w_s) + Ka(\gamma Z + 3w_s)(Z / L)^2$$

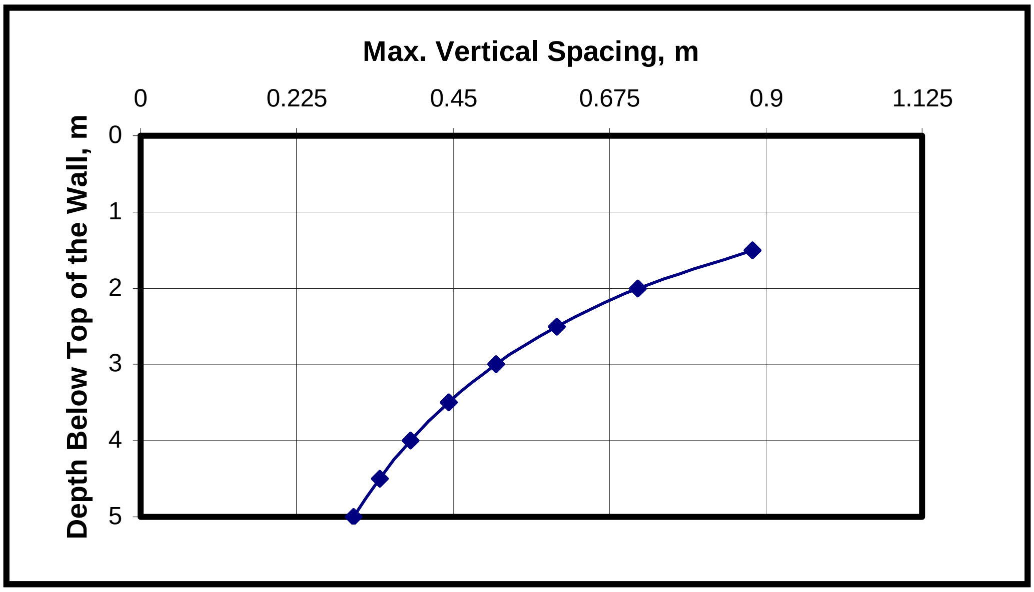
Where

T = tensile strength of the reinforcement

Sv = Vertical spacing between the reinforcement

Z = Depth below the top of the wall

Putting the values in the equation, we get the maximum vertical spacing between the reinforcement.



Max. Vertical Spacing, m
0
0.225
0.45
0.675
0.9
1.125
Depth Below Top of the Wall, m
0
1
2
3
4
5