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DESIGN OF GEOSYNTHETIC REINFORCED WALLS AND SLOPES BY TERRAM PROGRAM

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Abstract

This research deals with the design of geosynthetic reinforced walls and slopes subjected to series of static compressive loading tests by the present TERRAM program. The objectives of this study are suggesting an optimum geometry of reinforcement placement to lessen the width of the side slope of slopes.

The effects of the following variables were taken into account: the angles of slope, wall or slope height, surcharge, strength parameters (cohesion and friction angle) and unit weight for all soils involved in the problem (fill, natural soil and foundation soil), friction angle for reinforcement-soil and fill-foundation interfaces, as well as internal and external factors of safety are calculated for different distributions of tensile force in the reinforcement layers according to the different arrangements of reinforcement layers in terms of number, length, and spacing.

Keywords: Reinforced Soil, Geosynthetic, TERRAM Program.

تصميم جدران ومنحدرات ترابية مسلحة بمادة Geosynthetic باستخدام برنامج TERRAM

مدرس مساعد سهاد عبد الستار حسن
كلية الهندسة / جامعة الكوفة

الخلاصة

هذا البحث يتناول تصميم الجدران والمنحدرات المسلحة بمادة geosynthetic والمعرضة لسلسلة من الاحمال الثابتة باستخدام برنامج TERRAM . ألهدف من هذه الدراسة هو اقتراح التصميم الامثل للجدران والمنحدرات الترابية بتحديد مواضع طبقات التسليح التي تساهم في تقليل من العرض الجانبي للمنحدر.

تمت دراسة تأثير المتغيرات التالية على التصميم : زاوية ميل المنحدر، ارتفاع المنحدر، مقدارا لحمل الخارجي، معاملات تحمل التربه (التماسك وزاوية الاحتكاك الداخلي) والكثافة الوزنيه لجميع انواع الترب المستخدمه في التصميم (كتربة الملء والتربة الطبيعية وتربة الأساس) اضافة الى زاوية الاحتكاك الداخلي للسطح الفاصل بين التربه المسلحه وتربة الاساس، فضلا عن حساب معاملات الامان المختلفة كمعامل الامان الداخلي والخارجي لمختلف توزيعات قوى الشد لطبقات التربه المسلحه بحسب اختلاف ترتيب طبقات التسليح من حيث الطول، العدد، والتباعد بينها.

1. Introduction

Soil is a relatively inexpensive and abundant construction material, which makes it ideal for use in construction. Soil is capable of providing very high strength in compression, but virtually no strength in tension. In civil engineering applications, soil usually fails in shear. Like other construction materials with limited strength, soil can be reinforced with foreign material to form a composite material that has increased shear strength and some apparent tensile strength. Metal strips, steel meshes and bar mats, geosynthetics and even bamboo have been used to reinforce soil.

The first modern-day design approach for reinforced earth structures was developed in the 1960's, by the French engineer, Henry Vidal (Das, 1984). The first reinforced earth retaining wall constructed in the United States used metallic strips for reinforcement and was completed in 1972 (Mitchell and Christopher, 1990). The construction of reinforced soil structures, including both slopes and walls, has increased considerably over the last 20 years as the advantages associated with this construction alternative are more widely recognized.

Without reinforcement, a stable slope can be constructed with an inclination angle less than or equal to the internal friction angle of the soil. The reinforced soil mass relies on the tension provided by the reinforcement to maintain stability at steep inclination angles. The mobilization of tensile resistance occurs once the slope experiences some deformation. For static and dynamic loading conditions, excessive deformations of a reinforced slope can occur when the reinforcement stretches, yields, breaks, or pulls out of the soil.

Numerous methods have been developed to design reinforced soil structures for static loading conditions, but considerably fewer procedures for seismic design are available. As the number of reinforced soil structures constructed in seismically active areas of the world increases, and in response to the observed performance of existing reinforced soil structures during earthquakes, the need for development of methods capable of predicting seismically induced deformations has become increasingly apparent. Development of a practical, yet accurate, procedure has been the focus of the research described in this thesis.

2. MSE Walls and Slopes

Reinforced soil structures are commonly referred to as mechanically stabilized earth (MSE) structures. The soil is typically reinforced with relatively light and flexible materials, such as thin steel strips or geosynthetics that are extensible and have high tensile strengths. The reinforcement enhances the shear strength of the soil mass by altering the pattern of the soil stresses. During the construction of MSE structures, layers of reinforcement are placed within the soil backfill.

Dry, cohesionless soils are predominantly used as backfill because of their high strength characteristics and because they allow drainage, thus avoiding the generation of pore pressures in the backfill.

MSE structures can be constructed relatively fast and easily. Large equipment is not needed to install the reinforcement; however, proper installation by well-trained workers is extremely

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important. Reinforced walls and slopes are flexible and do not require a rigid foundation, thus further reducing construction costs. The reinforcement, however, may be susceptible to corrosion, creep and deterioration over time. Additional factors of safety on design are required to account for potential degradation of the reinforcement over time, which can influence material costs.

3. Geosynthetics

MSE structures reinforced with geosynthetics are called geosynthetic reinforced soil (GRS) structures. A geosynthetic, as defined by ASTM (1994), is a “planar product manufactured from a polymeric material.” Geosynthetics can be used for separation, drainage-transmission, protection, filtration, fluid barriers and reinforcement. The primary role of geosynthetics in this research is as reinforcement in the soil matrix. Of the wide variety of geosynthetics available today, a principal category is that of geotextiles.

Geotextiles are permeable textile materials that can be divided into two major groups: woven and no woven. Monofilament, multifilament or fibrillated yarns, or slit films and tapes are woven together to create a woven geotextiles; synthetic polymer fibers or filaments are mechanically heat-bonded or needle punched to create no woven geotextiles. The primary function the geosynthetic determines what type of geosynthetic should be used. This research focuses on the use of geotextiles as reinforcement.

4. Data Entry

For analyzing the problem, needs to enter the geometric properties (wall or slope height and face inclination), surcharge, strength parameters (cohesion and friction angle) and unit weight for all soils involved in the problem (fill, natural soil and foundation soil), friction angle for reinforcement-soil and fill-foundation interfaces, as well as factors of safety for global and internal stability. External factors of safety are calculated and presented at the final screen.

5. Calculations

5.1 Internal Stability

The program calculates the number (spacing) and length of reinforcement layers with basis on limit equilibrium. The spacing is considered as variable with height, in order to optimize the reinforcement distribution.

The active thrust is calculated at the wall or slope face as:

$$E=\frac{K\gamma}{2}\left(H'^2-h^2{}_0\right)\text{..} eq.(1)$$

Where:

γ = unit weight of fill

$H'=H+h_0$

H = wall or embankment

h_0 = equivalent height due to surcharge = q/γ

q = surcharge

The coefficient of active thrust is calculated as:

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$$K=\frac{Sin^2(\alpha+\phi'_d)}{Sin^2\alpha.Sin(\alpha-\delta)\left\{1+\left[\frac{Sin\ (\phi'_d+\delta).Sin\ \phi'_d}{Sin(\alpha-\delta).Sin\alpha}\right]\right\}}\text{.............................}eq.(2)$$

The inclination of the front slope with the horizontal is given by θ =180-α.
In this expression the design friction angle for the fill material is calculated as:

$$\phi'_d=\arctan\left(\frac{\tan\phi'_p}{FS}\right)\text{...}eq.(3)$$

Where:
$Ø'_d$ = Fill design friction angle
FS = Global factor of safety
$Ø'_p$ = fill peak friction angle
In this expression, δ is fill-wall face friction, varying from 0 to φ'_d. The program assumes δ = 0 to be on the safe side.
The cohesion can be taken into account using the following expression:

$$E=2H_C.\sqrt{K}\text{..}eq.(4)$$

The formulation considers a dry crack due to cohesion.
For slopes with face inclination θ=180-α with horizontal, the active thrust coefficient can be calculated as:

$$K'=\frac{Sin^2(\alpha+\phi'_d)}{Sin^3.\alpha\left[1+\frac{Sin\phi'_d}{Sin\alpha}\right]^2}\text{...}eq.(5)$$

The program includes a simplified seismic analysis, in which the additional thrust due to a horizontal acceleration is calculated as:

$$E_{seism}=\frac{3}{8}\gamma H^2.k_h\text{...}eq.(6)$$

Where:
k_h is the horizontal seismic coefficient.
The spacing between reinforcement layers is given by:

$$S=\frac{T_d}{\sigma'_h}\text{..}eq.(7)$$

where:
σ'_h = horizontal stress along slope height, calculated from the expression above
T_d = design tensile load of reinforcement, considering reduction factors for creep,installation damage, chemical and biological degradation.

The reinforcement length is calculated with basis on the tensile loads acting for each layer, considering the soil-reinforcement interface friction angle and the vertical stress acting on each layer.

$$L_a=\frac{T.FS}{2.\sigma_v\tan\delta_{st}}-(H-z)\left[\frac{1}{\tan\theta}-\frac{1}{\tan\rho}\right]\text{.......................................}eq.(8)$$

Where, for each reinforcement layer:

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T.FS = horizontal force times the pullout factor of safety.
σ_v = vertical stress.
δ_{sr} = soil-reinforcement friction angle.
H = wall height.
z= layer depth.
θ= face inclination.
$\rho = 0.5(\theta+\varphi'_d)$.

5.2 External Stability

The external stability is calculated according to the following equations:

5.2.1. Overturning

As shown in Fig.3,

$$FS_{t.} = \frac{W.X_W + Q.X_Q + E.Sin(\delta+\theta-90^\circ).X_E}{E.Cos(\delta+\theta-90^\circ).Y_E} . \geq 2 .... eq.(9)$$

$$W.. = B.H.\gamma$$

$$Q = q.B$$

$$X_W = \frac{B}{2}\left(1+\frac{H}{B.\tan\theta}\right)$$

$$X_W = \frac{B}{2}\left(1+\frac{H}{\tan\theta}\right)$$

$$Y_Q = \frac{H}{3}\left[\frac{H'+2h_0}{H'+h_0}\right]$$

Where :

$$X_E = B + \frac{Y_E}{\tan\theta}$$

5.2.2 Sliding

$$FS_d = \frac{W+Q.+E.Sin(\delta+\theta-90^\circ)}{E.Cos(\delta+\theta-90^\circ)}.\tan\delta_B \geq 2 .... eq.(10)$$

5.2.3. Bearing Capacity

As shown in Fig.4.Where, according to Meyerhoff:

$$X_R = \frac{W.X_W + Q.X_Q + E.[X_{E.}Cos(\delta+\theta) + Y_E.Sin(\delta+\theta)]}{W+Q-E.Cos(\delta+\theta).} .... eq.(11)$$

The load eccentricity at the base is given by:

$$e = \left|\frac{B}{2} + X_R\right| .... eq.(12)$$

The normal stresses at the base are given by:

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$$\sigma_{va} = \frac{2.N}{B} . \left(2 - \frac{3.X_R}{B} \right) \geq 0 .... eq.(13)$$

$$\sigma_{vb} = \frac{2.N}{B} . \left(\frac{3.X_R}{B} - 1 \right) \geq 0 .... eq.(14)$$

Where N is the normal force:

$$N = W + Q - E.Cos(\delta + \theta) .... eq.(15)$$

The bearing capacity is obtained from Terzaghi's general formulation:

$$q_{max} = c.N_C + q_s..Nq + 0.5.\gamma_f .B.N .... eq.(16)$$

6. The Examples

This section deals with many chosen examples Pre-design numerically by the present computer program TERRAM.

6.1 Example No.1

This example deals with design of the wall and slopes as variable face inclination and constant other data (q=0 kPa, H=5m) shown in Figs.(5), (8), (11), (14)**.** The reinforcement distribution and the factors of safety as shown in Figs.(6), (7), (9), (10), (12), (13), (15), and (16). The final report for internal stability each case are explain in tables (1), (2), (3), and (4).

6.2 Example No.2

This example deals with Pre-design of the wall and slopes as variable face inclination and constant other data (q=20 kPa, H=5m) shown in Figs. (17), (20), (23), (26)**.**
The reinforcement distribution and the factors of safety as shown in Figs. (18), (19), (21), (22), (24), (25), (27), (28). The final report for internal stability each case is explained in tables (5), (6), (7), (8).

The relationships of the angle of slope (β) versus the number of reinforcing layers for q = (0, 10, 20, 30, 40, 50) kPa are shown in Fig.(29). These figures indicate clearly that the number of reinforcement layers increases with the angles of slope at the same loading condition, also these figures indicate that at the same angle of slope the number of reinforcement layers increases with the loading condition. For the case that H=5 and the surcharge load is more than 50 kPa can not design because surcharge must be numerically lower than 10 times the slope height.

7. Conclusions

According to the results which are obtained by this research, the following points are concluded:

1. The program used in this research gives three types of results:
   a) A drawing for the reinforced wall, showing reinforcement spacing and length. At this stage it is possible to alter the reinforcement, and the calculation is redone automatically.
   b) A brief report containing information for each reinforcement layer (position, length, and load).
   c) Factors of safety for external stability (sliding, overturning and bearing capacity for foundation soil). These safety factors are presented in the last screen, where the user may

alter the reinforcement length and the program recalculates the final report as well as the internal and external safety factors.

2. Reinforcement can allow more steep slopes to be formed with an ample factor of safety. This fact can save the required space as well as cost and time of construction of the slope.
3. The results of numerical analyses have shown that the number of reinforcement layers increases with the angles of slope at the same loading condition, also these figures indicate that at the same angle of slope the number of reinforcement layers increases with the loading condition.

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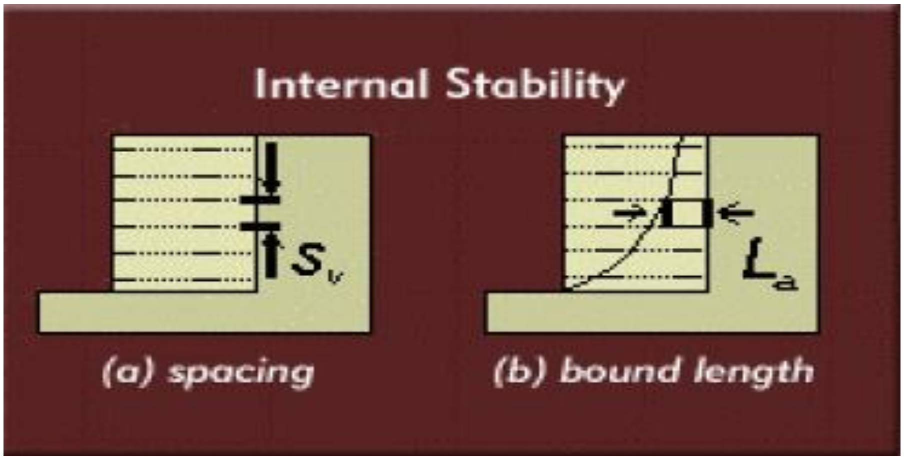

Fig.1 Internal Stability of the Wall.

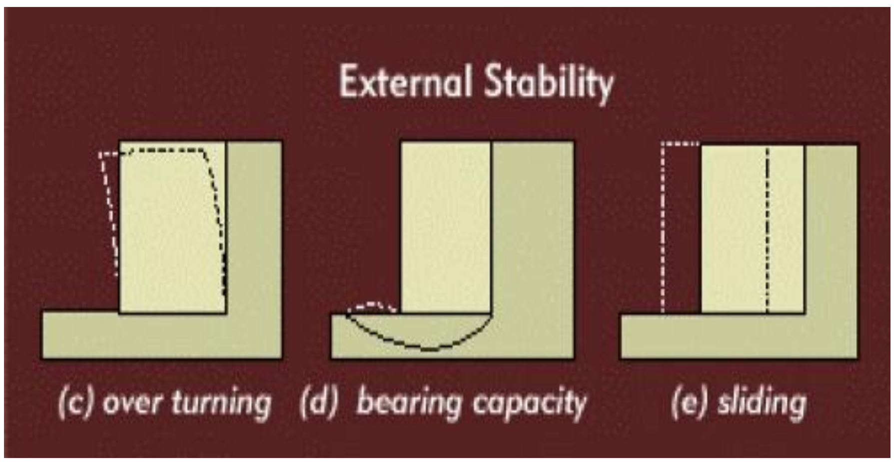

Fig.2 External Stability of the Wall.

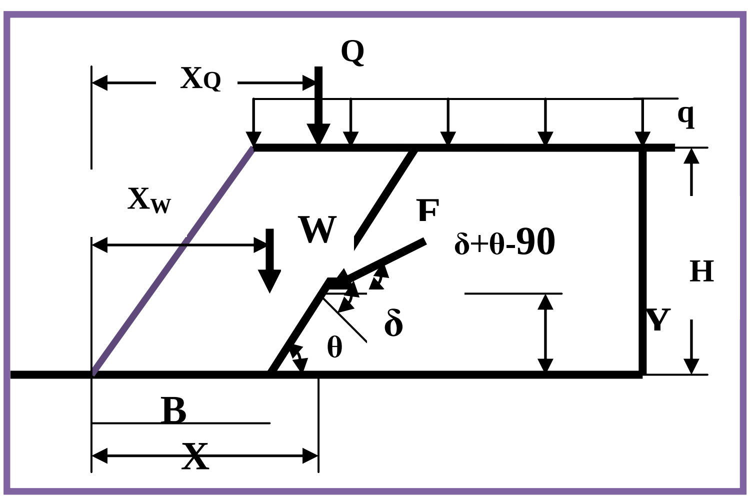

Fig.3 The **Overturning Stability.**

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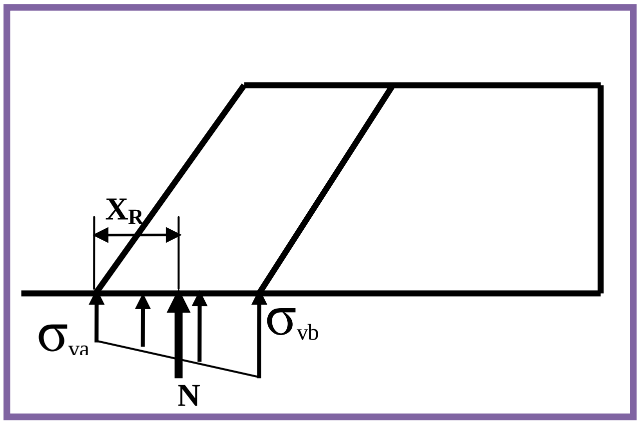

Fig.4 The Bearing Capacity.

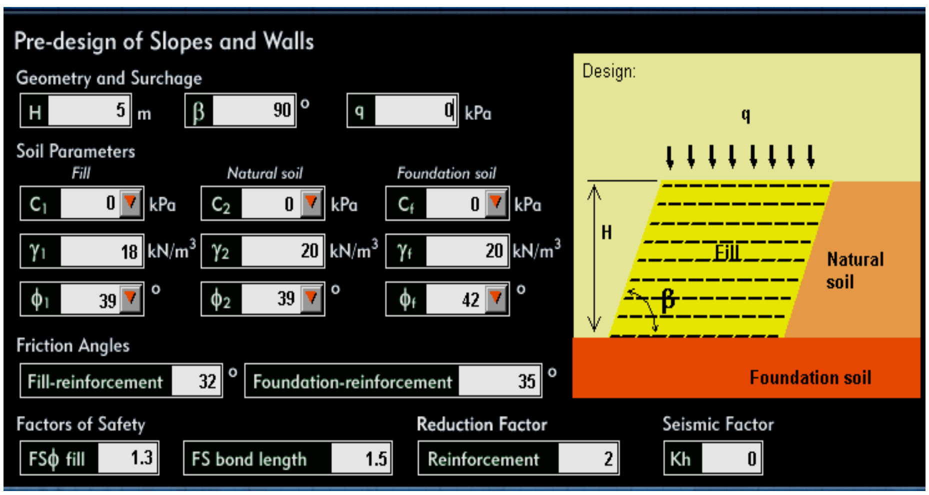

Fig.5 The Wall with Geometric Properties (β= 90^o).

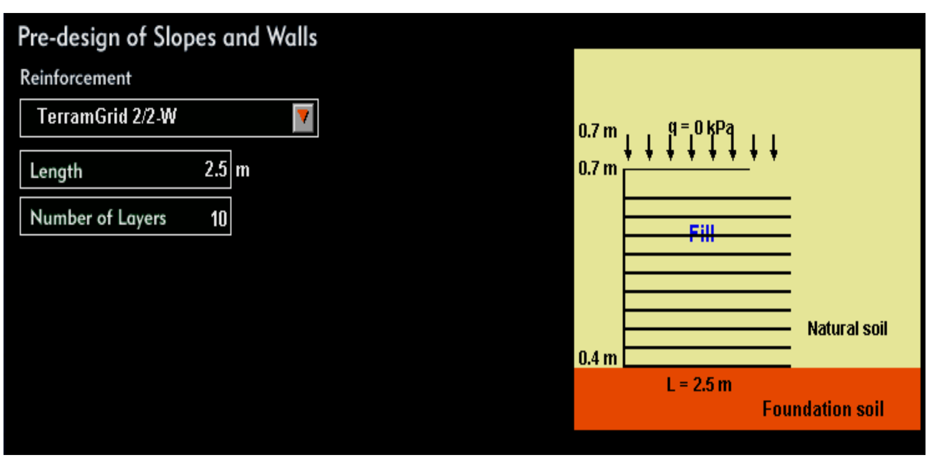

Fig.6 The Wall after Reinforcement.

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Table 1 The Final Report Internal Stability with β=90°.

INTERNAL STABILITY

Layer	Depth(m)	Spacing(m)	Tension in Reinforcement(kN/m)
1	1.2	0.7	6.3
2	1.9	0.7	7.2
3	2.6	0.4	7.1
4	2.9	0.4	5.6
5	3.3	0.4	6.3
6	3.6	0.4	7.0
7	4.0	0.4	7.7
8	4.3	0.4	8.4
9	4.7	0.4	9.0
10	5.0	0.4	9.7

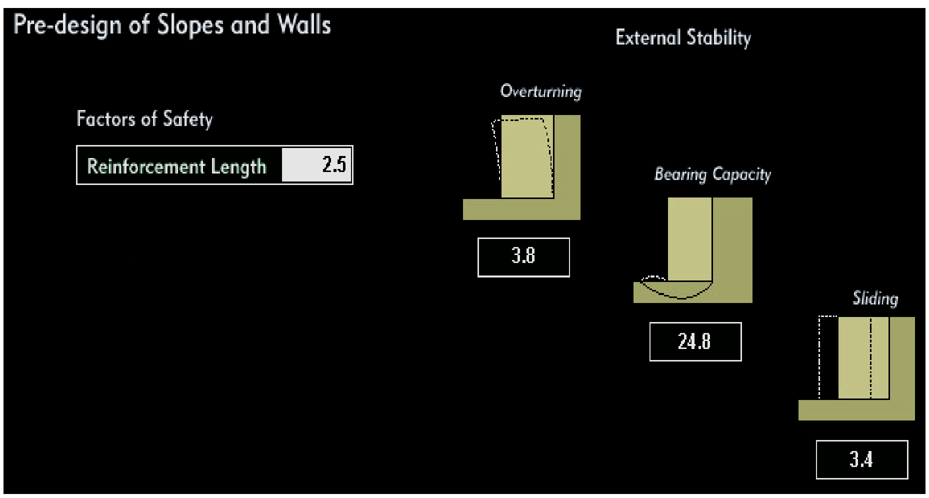

Fig.7 The Wall Factors of Safety.

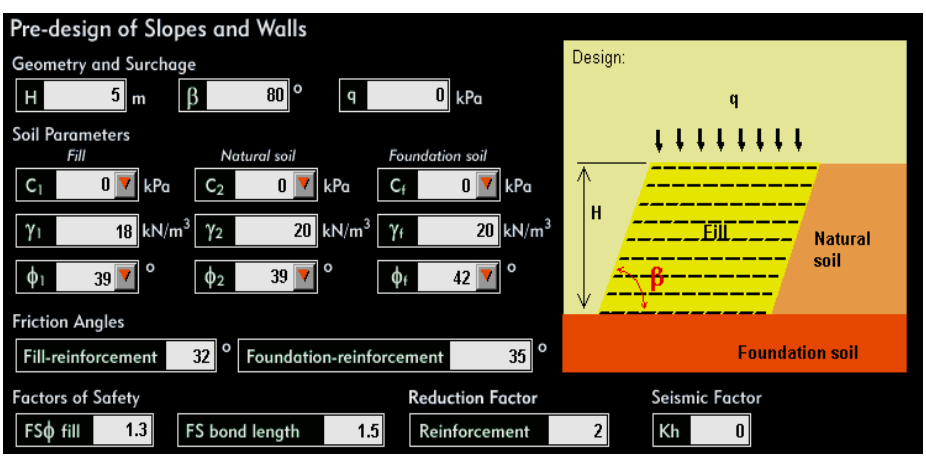

Fig.8 The Slope with Geometric Properties (β= 80°).

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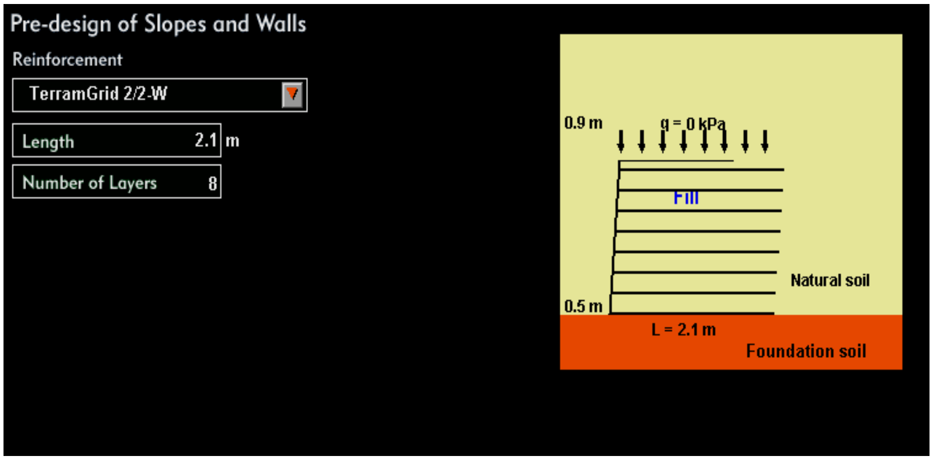

Table 2 The Final Report Internal Stability to the Slope with β=80^o.

INTERNAL STABILITY

Layer	Depth(m)	Spacing(m)	Tension in Reinforcement(kN/m)
1	1.4	0.9	5.6
2	2.3	0.5	6.4
3	2.8	0.5	5.5
4	3.2	0.5	6.4
5	3.7	0.5	7.3
6	4.1	0.5	8.2
7	4.6	0.5	9.0
8	5.0	0.5	9.9

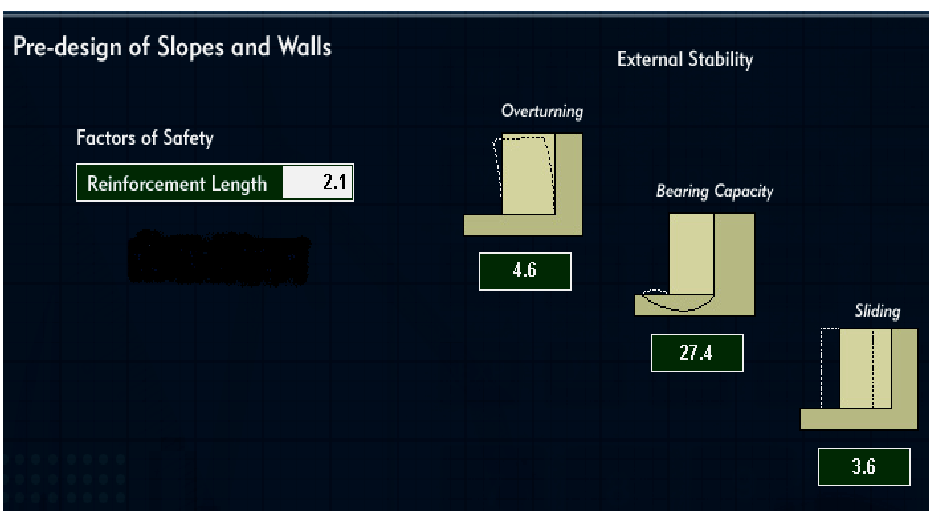

Fig.10 The Slope Factors of Safety.

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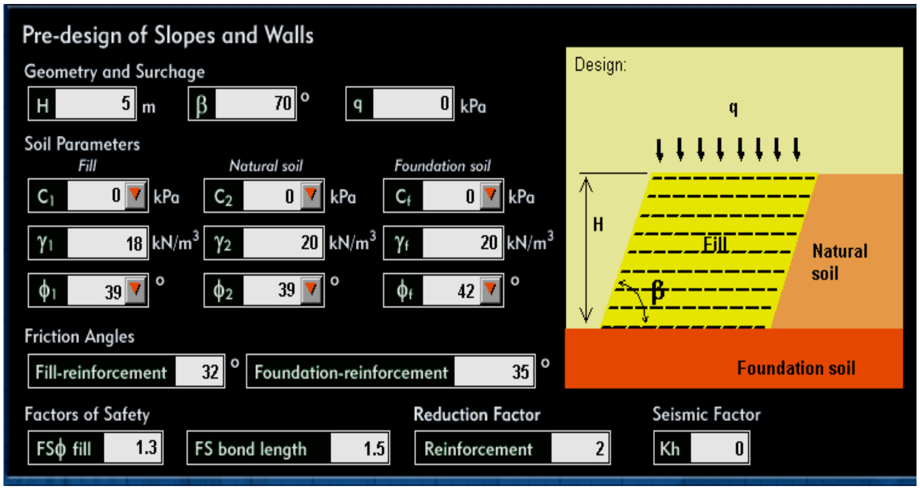

Fig.11 The Slope with Geometric Properties (β= 70°).

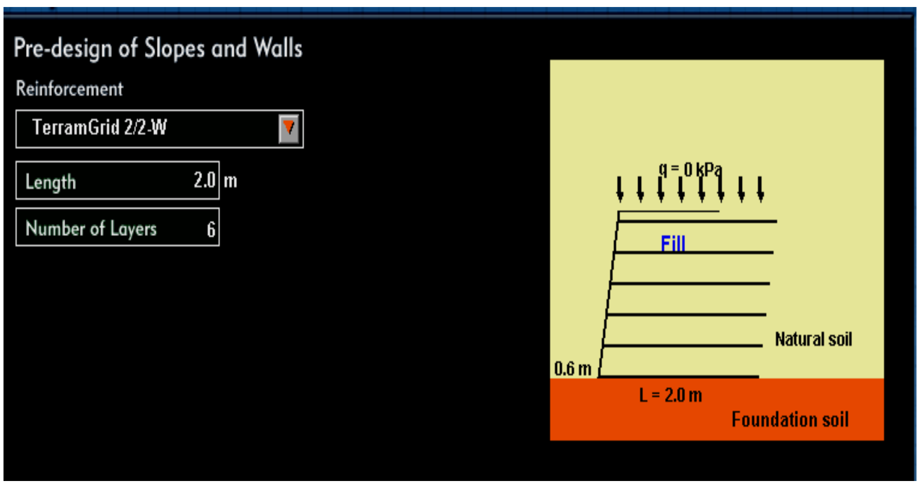

Fig.12 The Slope after Reinforcement.

Table 3 The Final Report Internal Stability to the Slope with β=70°.

INTERNAL STABILITY

Layer	Depth(m)	Spacing(m)	Tension in Reinforcement(kN/m)
1	2.0	0.6	5.5
2	2.6	0.6	5.3
3	3.2	0.6	6.5
4	3.8	0.6	7.7
5	4.4	0.6	8.9
6	5.0	0.6	10.1

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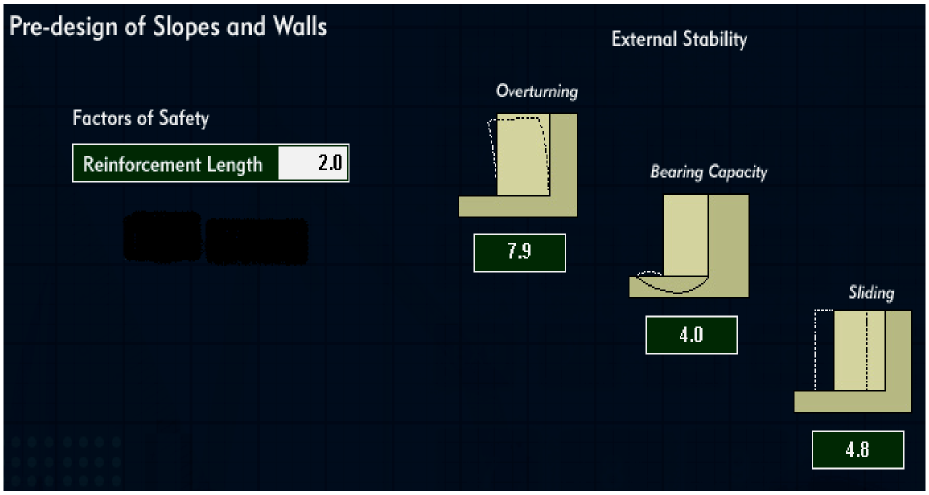

Fig.13 The Slope Factors of Safety.

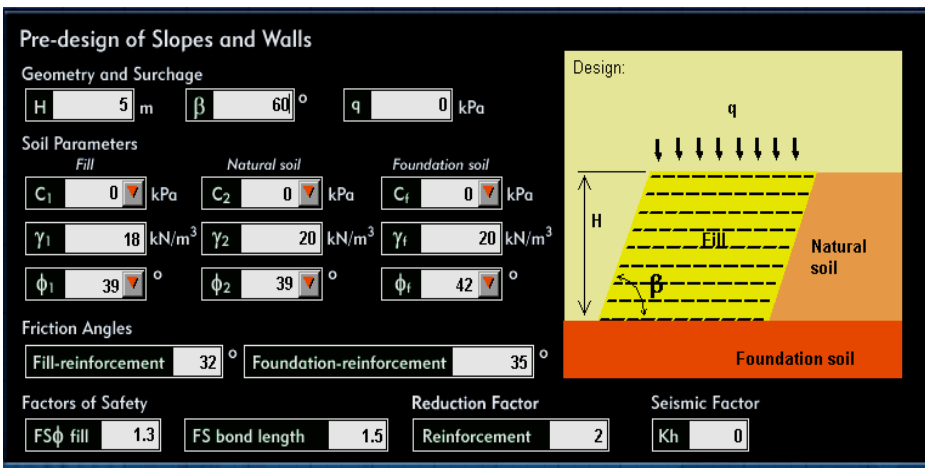

Fig.14 The Slope with Geometric Properties (β= 60^{o}).

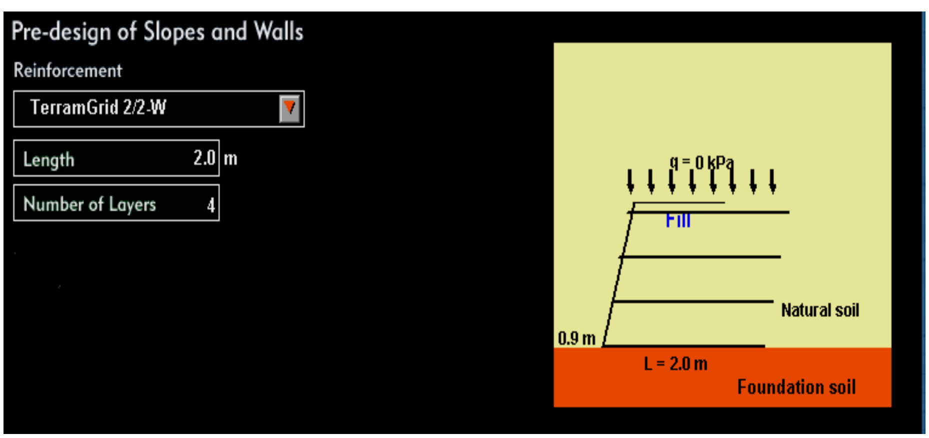

Fig.15 The Slope after Reinforcement.

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Table 4 The Final Report Internal Stability to the Slope with β=60°.

INTERNAL STABILITY

Layer	Depth(m)	Spacing(m)	Tension in Reinforcement(kN/m)
1	2.5	0.9	6.5
2	3.3	0.9	6.6
3	4.2	0.9	8.4
4	5.0	0.9	10.1

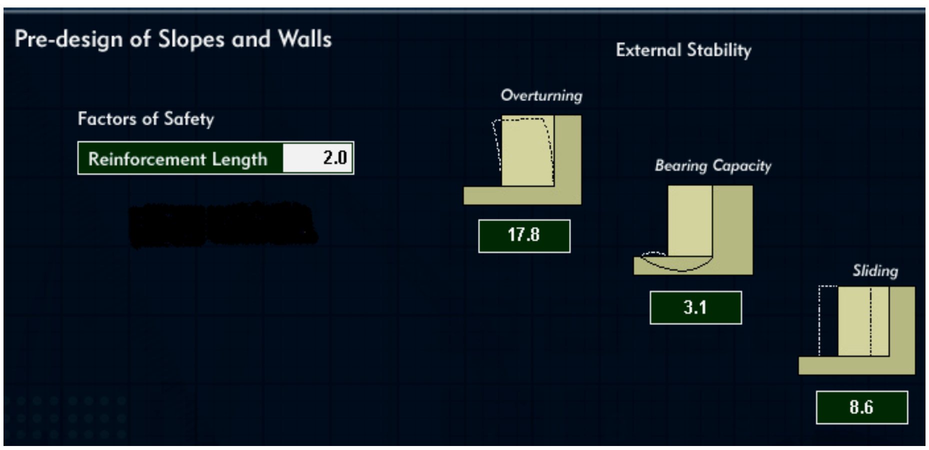

Fig.16 The Slope Factors of Safety.

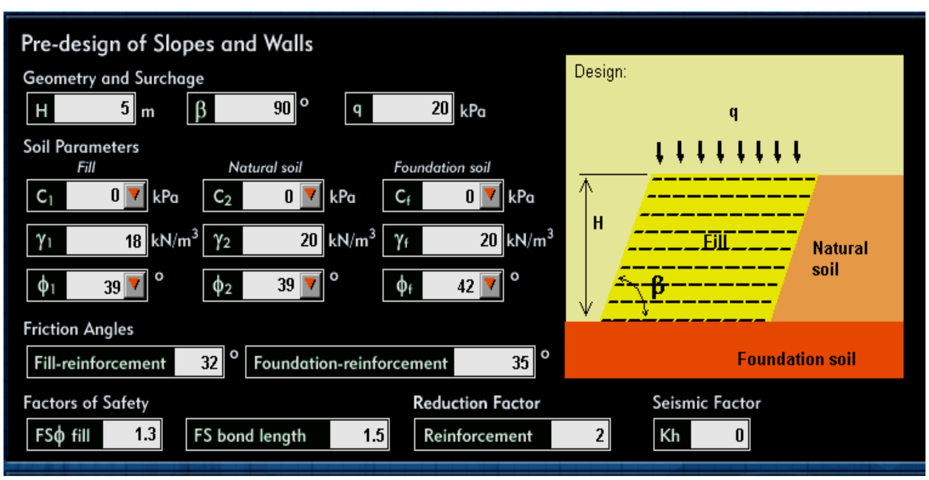

Fig.17 The Slope with Geometric Properties (β= 90°).

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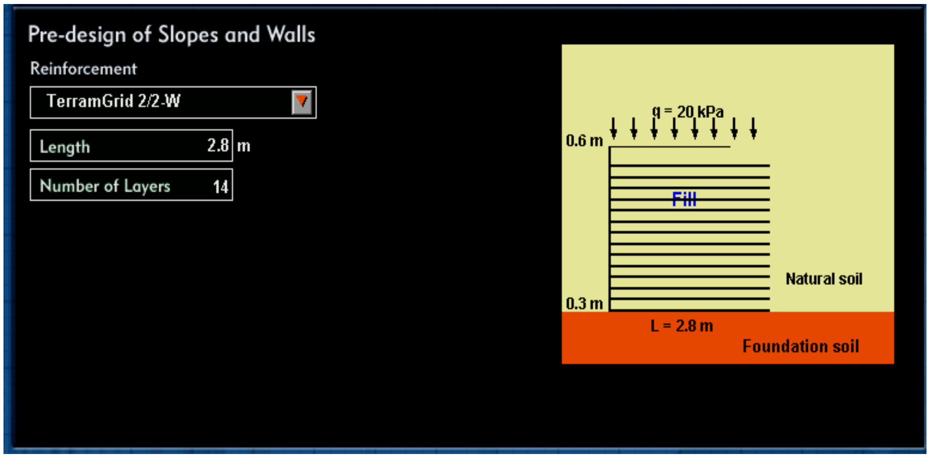

Fig.18 The Slope after Reinforcement.

Table 5 The Final Report Internal Stability to the Slope with β=90^{o}.

INTERNAL STABILITY

Layer	Depth(m)	Spacing(m)	Tension in Reinforcement(kN/m)
1	0.5	0.6	6.5
2	1.1	0.6	7.4
3	1.7	0.3	6.8
4	2.0	0.3	5.2
5	2.3	0.3	5.7
6	2.6	0.3	6.2
7	2.9	0.3	6.7
8	3.2	0.3	7.2
9	3.5	0.3	7.7
10	3.8	0.3	8.2
11	4.1	0.3	8.7
12	4.4	0.3	9.2
13	4.7	0.3	9.7
14	5.0	0.3	10.2

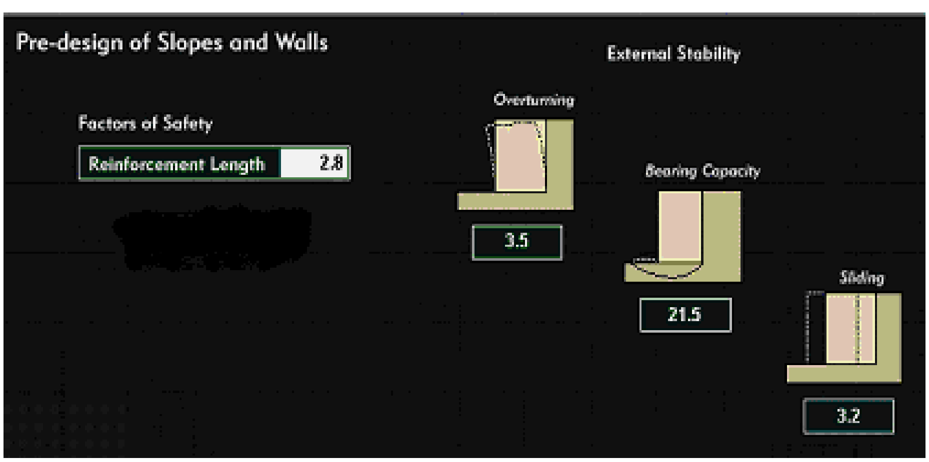

Fig.19 The Slope Factors of Safety.

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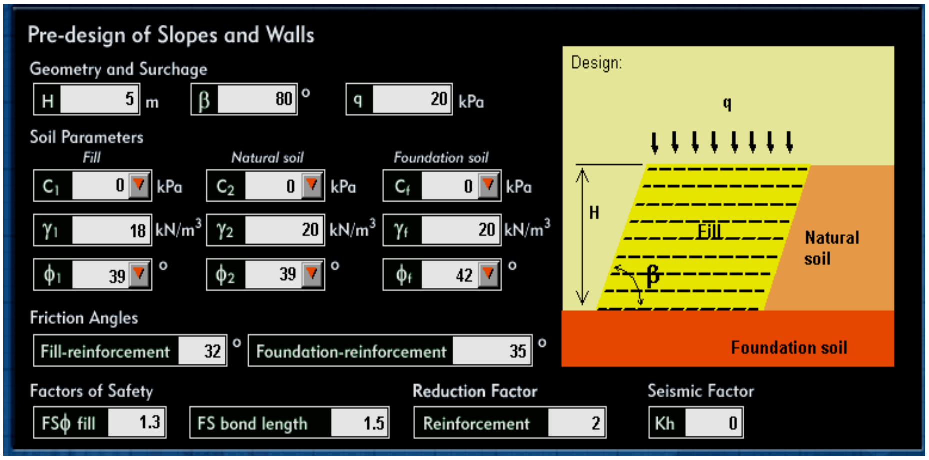

Fig.20 The Slope with Geometric Properties (β= 80°).

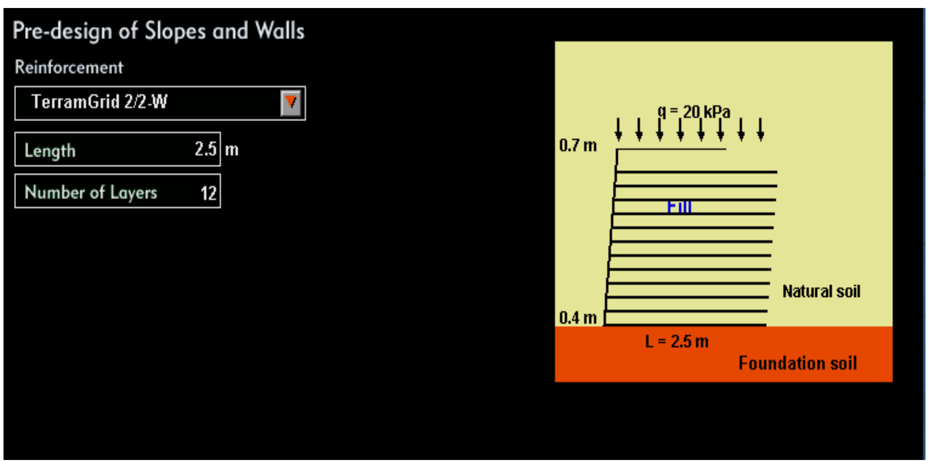

Fig.21: The Slope after Reinforcement.

Table 6 The Final Report Internal Stability to the Slope with β=80°.

INTERNAL STABILITY

Layer	Depth(m)	Spacing(m)	Tension in Reinforcement(kN/m)
1	0.4	0.7	5.8
2	1.2	0.7	7.0
3	1.9	0.4	6.6
4	2.2	0.4	5.1
5	2.6	0.4	5.7
6	2.9	0.4	6.2
7	3.3	0.4	6.7
8	3.6	0.4	7.3
9	4.0	0.4	7.8
10	4.3	0.4	8.4
11	4.7	0.4	8.9
12	5.0	0.4	9.4

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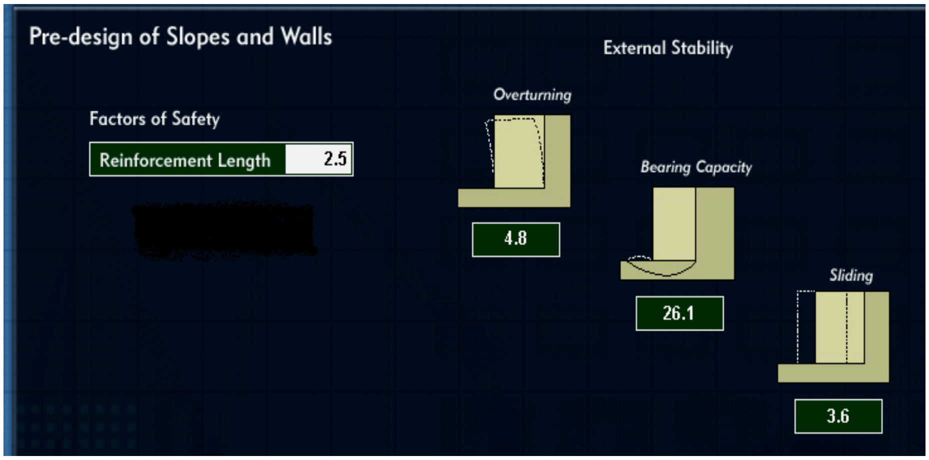

Fig.22 The Slope Factors of Safety.

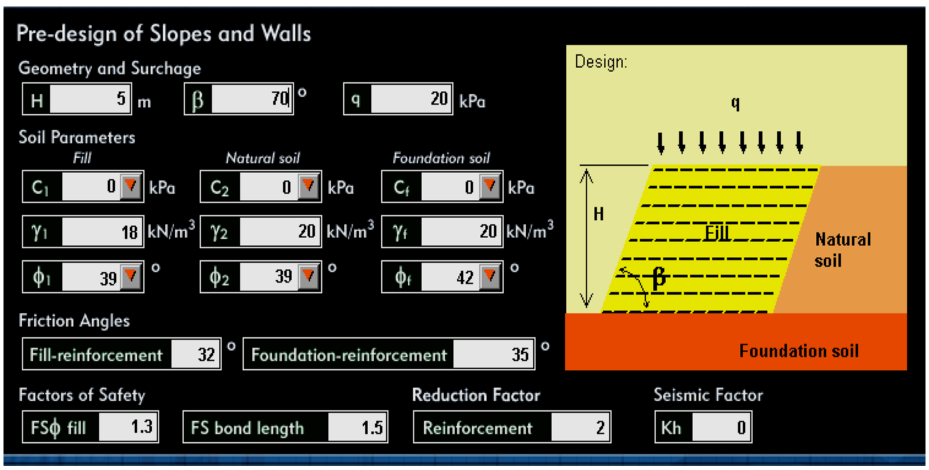

Fig.23 The Slope with Geometric Properties (β= 70^{o}).

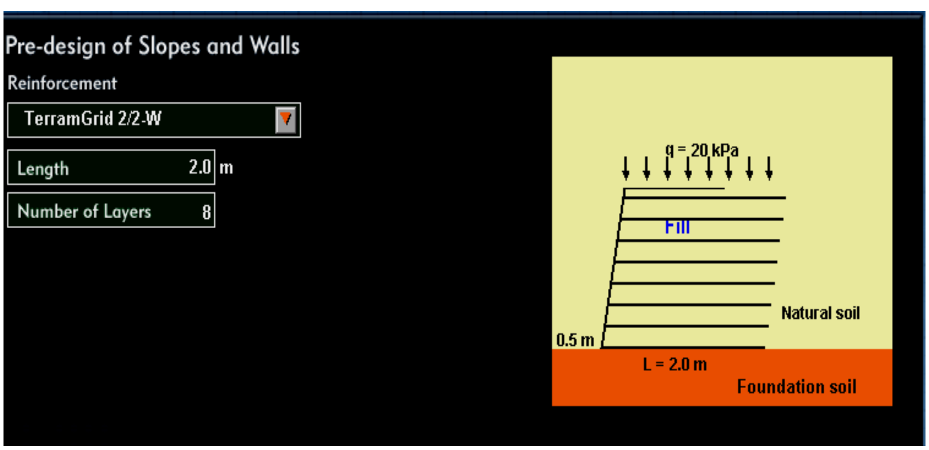

Fig.24 The Slope after Reinforcement.

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Table 7 The Final Report Internal Stability to the Slope with β=70^{o}.

INTERNAL STABILITY

Layer	Depth(m)	Spacing(m)	Tension in Reinforcement(kN/m)
1	1.5	0.5	6.2
2	2.0	0.5	5.3
3	2.5	0.5	6.1
4	3.0	0.5	6.9
5	3.5	0.5	7.8
6	4.0	0.5	8.6
7	4.5	0.5	9.5
8	5.0	0.5	10.3

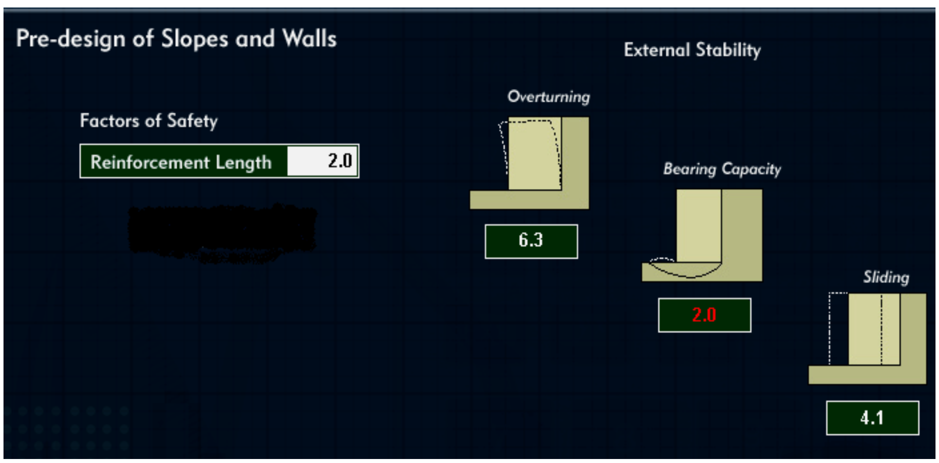

Fig.25 The Slope Factors of Safety.

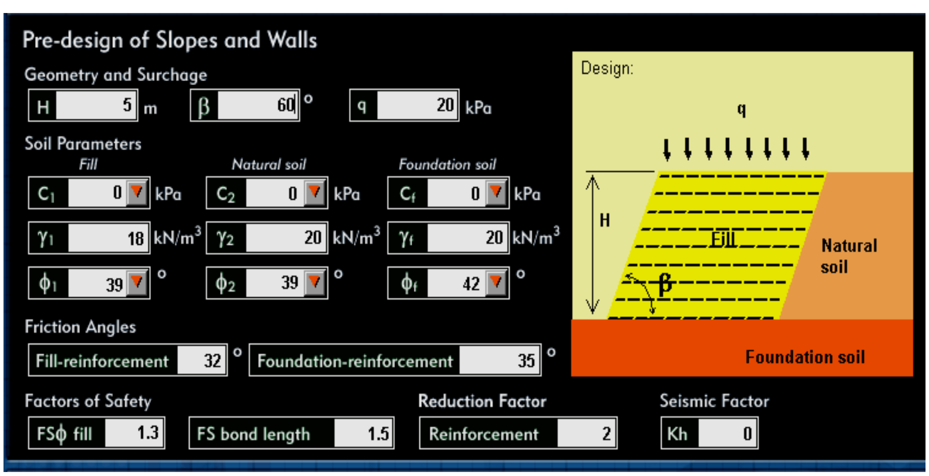

Fig.26 The Slope with Geometric Properties (β= 60^{o}).

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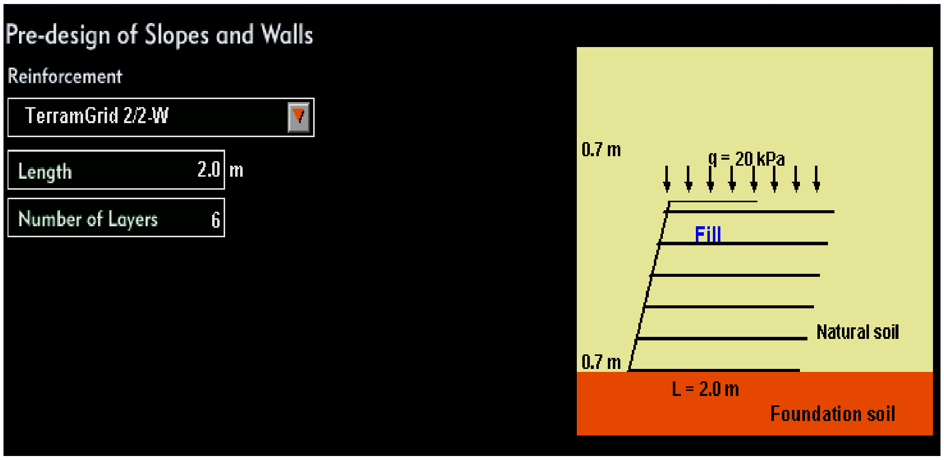

Fig.27 The Slope after Reinforcement.

Table 8 The Final Report Internal Stability to the Slope with β=60°.

INTERNAL STABILITY

Depth(m)	Spacing(m)	Tension in Reinforcement(kN/m)
1.5	0.7	5.9
2.2	0.7	5.5
2.9	0.7	6.6
3.6	0.7	7.8
4.3	0.7	9.0
5.0	0.7	10.1

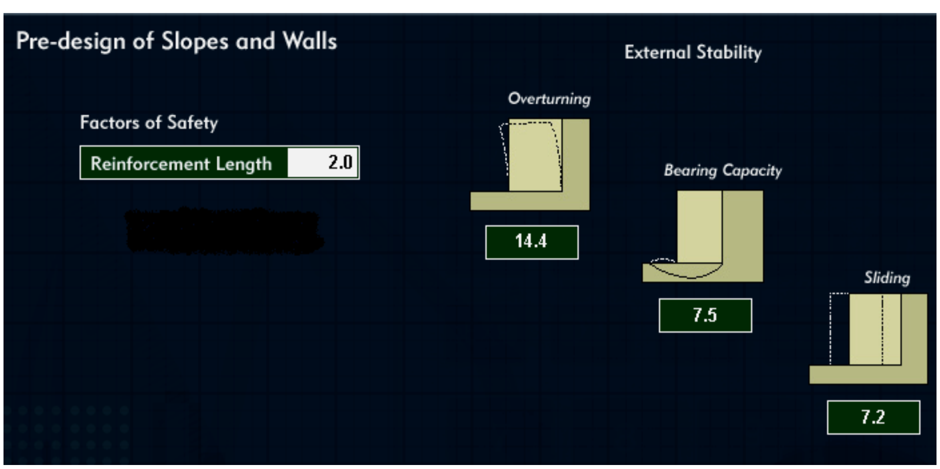

Fig.28 The Slope Factors of Safety.

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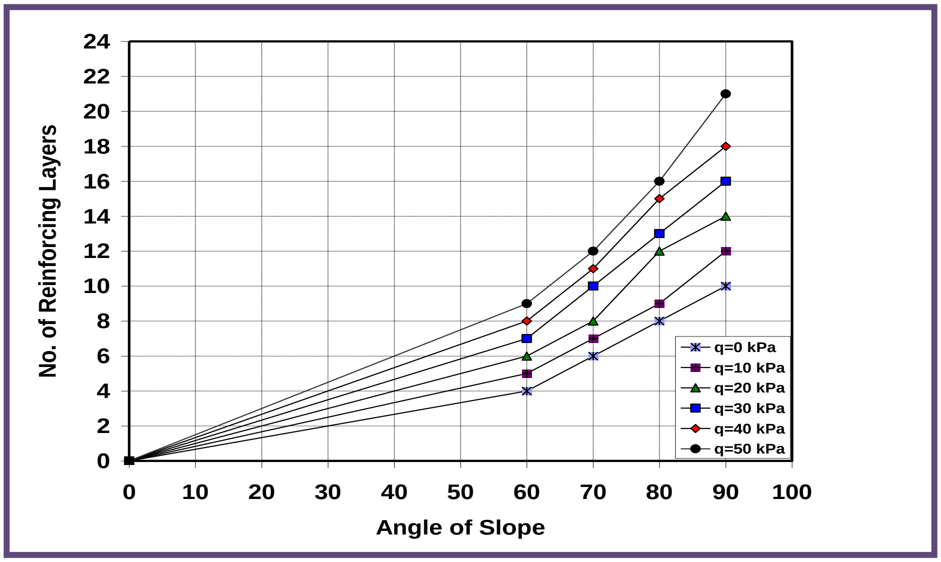

Fig.29 No. of Reinforcing Layers versus Angle of Slope for different q with H= 5m.