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FACTORS AFFECTING THE STABILITY OF HIGHWAY SIDE SLOPES
" Case Study: Roads Adjacent Water Ways In Upper Egypt "

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The present study is concerned with the stability of side slope for the highways lying between two canals, eastern Nag Hamady canal and western side canal at Km(70.8).The canals and highway are located on the right bank of the Nile, and pass through the governorates of Assiut and Sohag. The side slope cracks as well as cracks in the asphalt road usually happen after winter closing period in the left side slope of the road. This is attributed to the difference in water levels between the two neighboring canals and soil weakness. The present study deals with this problem and can be divided into two main parts:

- *The first part is an experimental work using triaxial test, shear box test, and consolidation test, which are carried out on undisturbed samples to determine physical and mechanical soil properties.*
- *The second part is the numerical investigation using the obtained soil properties from the experimental work. Two computer programs are used from GEOSTUDIO 2004 library. First (SLOPE/W) is used for slope stability analysis by limit equilibrium method. This program deals with slope stability methods such as Ordinary, Bishop, Janbu and Morgenstern- price methods. The second is the stress analysis program (SIGMA/W).This program is based on finite element technique. The Mohr-Coulomb yield criteria is used to represent soil layers. Study results showed that slopes at the investigated seating sites are unsafe.*

The numerical simulation with GEOSTUDIO 2004 is powerful to determine the location of the cracks for highway side slope of eastern Nag Hamadey canal, and is in good agreement with the actual observation in the field. Also, proposed practical methods are suggested to improve stability properties for the highway side slope using piles, cut- off wall to obtain factor of safety, greater than 1.5

KEYWORDS: *Stability of highway side slopes, triaxial test, shear box test, and finite element method.*

1. INTRODUCTION

Analyzing the stability of earth structures is the oldest type of numerical analysis in geotechnical engineering. The idea of discretizing a potential sliding mass into slices was introduced early in the 20^{th} Century. The stability analysis of the Stigberg Quay in Gothenberg was presented, Sweden where the slip surface was taken to be circular and the sliding mass was divided into slices. Fellenius introduced the Ordinary or Swedish method of slices [4]. In the mid-1950 Janbu [9], and Bishop developed advances in the method [1]. The advent of electronic computers in the developed made it possible to more readily handle the iterative procedures inherent in the method which led to mathematically more rigorous formulations such as those developed by Morgenstern and Price[10]. One of the reasons the limit equilibrium method was adopted so readily, is that solutions could be obtained by hand-calculations. Simplifying assumption had to be adopted to obtain solutions, but the concept of numerically dividing a larger body into smaller pieces for analysis purposes was rather novel at the time.

Modern limit equilibrium software is making it possible to handle ever-increasing complexity within an analysis. It is now possible to deal with complex structures, highly irregular pore-water pressure conditions, various linear and nonlinear shear strength models, almost any kind of slip surface shape, concentrated loads. Limit equilibrium formulations based on the method of slices are also being applied more and more to the stability analysis of structures such as cut-off walls.

Many different solution techniques for the method of slices have been developed over the years. Basically, all are very similar. The differences between the methods are what equations of static are included and satisfied, which inter slice forces are included and what is the assumed relationship between the inter slice shear and normal forces. **Figure 1** illustrates a typical sliding mass discretized into slices and the possible forces on the slice. Normal and shear forces act on the slice base and on the slice sides.

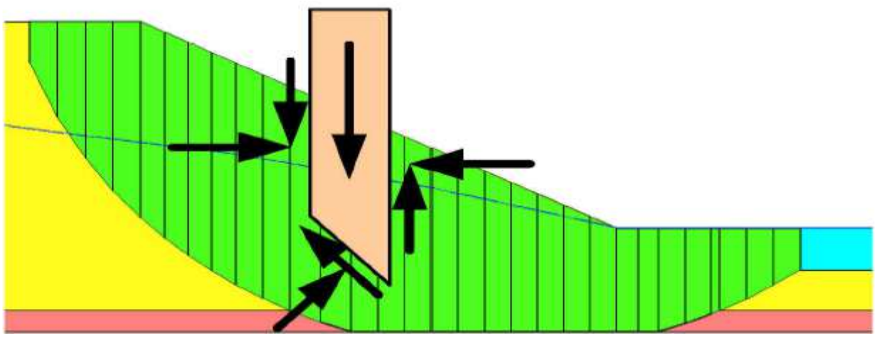


Fig. 1. Slice discretization and slice forces in a sliding mass.

The Ordinary, or Fellenius method was the first method developed. The method ignored all inters slice forces and satisfied only moment equilibrium. Adopting these simplified assumptions made it possible to compute a factor of safety using hand calculations, which was important since there were no computers available. Later Bishop [1], devised a scheme that included inter slice normal forces, but ignored the inter slice shear forces. Again, Bishop's Simplified method satisfies only moment equilibrium. Of interest and significance with this method is the fact that by including the normal inter slice forces, the factor of safety equation became nonlinear and an iterative procedure was required to calculate the factor of safety. The Janbu's Simplified method is similar to the Bishop's Simplified method in that it includes the normal inter slice forces and ignores the inter slice shear forces. The difference between the Bishop's Simplified and Janbu's Simplified methods is that the Janbu's Simplified method satisfies only horizontal force equilibrium, as opposed to moment equilibrium as shown in **Table 1**.

Table 1: Summary of different limit equilibrium methods of slices.

Method	Force equilibrium		Moment equilibrium	Inter slice	
	1st Direction vertical	2nd Direction horizontal		Normal	Shear
Ordinary or Fellenius	Yes	No	Yes	No	No
Bishop's Simplified	Yes	No	Yes	Yes	No
Janbu's Simplified	Yes	Yes	No	Yes	No
Morgenstern and Price	Yes	Yes	Yes	Yes	Yes

Later, computers made it possible to more readily handle the iterative procedures inherent in the limit equilibrium method, and this lead to mathematically more rigorous formulations which include all inter slice forces and satisfy all equations of static such as the Morgenstern-Price methods.

The problem of slope failure happens every year, ten years ago after winter closing period in the left side slope of the road as well as cracks in the asphalt road. This is attributed to the difference in water levels between two neighboring canals and weakness of road soil. The location of highway side slope failure happened in Salmona village of Akhmim city, Sohag governorate at Km (70.8) for head regrator of Nag Hamady canal. Therefore, previous strengthening to this problem such as lining of the western side canal by box culvert and pitching with mortar for the failure side slope in eastern Nag Hamady canal are uneconomic and unstable for pitching so searching for new strengthening methods are necessary. The shape of failure and its location is shown in **Fig. 2**.

2. THEORETICAL APPROACH

2.1 Slope/w Computer Program

SLOPE/W is a program of the package ***GEOSTUDIO2004*** [4]. One of the powerful features of this integrated approach is that it opens the door to types of analyses of a much wider and more complex spectrum of problems, including the use of finite element computed pore-water pressures and stresses in a stability analysis. Not only does an integrated approach widen the analysis possibilities, it can help overcome some limitations of the purely limit equilibrium formulations. The very large number of options in ***SLOPE/W*** can be summarized in terms of three components:

- Geometry - description of the stratigraphy and shapes of potential slip surfaces.

- Soil strength parameters used to describe the soil properties.
- Pore-water pressure means of defining the pore-water pressure conditions.

Fig. 2. Failure example of the highway.

SLOPE/W is used for slope stability using, limit equilibrium analysis and finite element simulation. Different methods were used, each has different limits but generally they are unlimited soil layers and elements. In define input the Ordinary or Fellenius, Bishop's simplified, Janbu's simplified and Morgenstern-Price methods are used for calculating the factors of safety.

2.2 SIGMA/W Computer Program

SIGMA/W is a finite element software product that can be used to perform stress and deformation analyses of earth structures. Its comprehensive formulation makes it possible to analyze both simple and highly complex problems. For example, you can perform a simple linear elastic deformation analysis or a highly sophisticated nonlinear elastic-plastic effective stress analysis. When coupled with other ***GEOSTUDIO2004*** software products, it can also model the pore-water pressure generation and dissipation in a soil structure in response to external loads using either a fully coupled or un-coupled formulation. ***SIGMA/W*** has application in the analysis and design for geotechnical, civil engineering projects.

2.3 Factor of Safety Methods

Over the past years, many different methods have been developed for computing factors of safety. This part describes each of the methods available in ***SLOPE/W***. All the methods are based on limit equilibrium formulations except for one method, the finite element method, which uses finite element computed stresses.

2.3.1 Ordinary or Fellenius Method

This method is also sometimes referred to as the Swedish method of slices. This is the first method of slices developed and presented in the literature. The simplicity of the method made it possible to compute factors of safety using hand calculations. In this method, all inter slice forces are ignored. The slice weight is resolved into forces parallel and perpendicular to the slice base. The force perpendicular to the slice base is the base normal force, which is used to compute the available shear strength. The weight component parallel to the slice base is the gravitational driving force. Summation of moments about a point used to describe the trial slip surface is also used to compute the factor of safety. The factor of safety is the total available shear strength along the slip surface divided by the summation of the gravitational driving forces (mobilized shear).

The simplest form of the Ordinary factor of safety equation in the absence of any pore-water pressures for a circular slip surface [4] and [7] is:

$$FS=\frac{\sum\left[C\beta+N\tan\phi\right]}{\sum W\sin\alpha}=\frac{\sum S_{resistance}}{\sum S_{mobilized}} \tag{1}$$

Where:

c = cohesion,

β = slice base length,

N = base normal force *(Wcos α)*,

ϕ = friction angle,

W = slice weight, and

α = slice base inclination.

2.3.2 Bishop's simplified method

In the (1950) Professor Bishop [1] at Imperial College in London devised a method which included inter slice normal forces, but ignored the inter slice shear forces. Bishop developed an equation for the normal at the slice base by summing slice forces in the vertical direction. The consequence of this is that the base normal becomes a function of the factor of safety. This in turn makes the factor of safety equation nonlinear and an iterative procedure is consequently required to compute the factor of safety. A simple form of the Bishop's Simplified factor of safety equation in the absence of any pore-water pressure is:

$$FS=\frac{\sum\left[\left(C\beta+W\tan\phi\right)\left\{\cos\alpha+\frac{\sin\alpha\tan\phi}{FS}\right\}\right]}{\sum W\sin\alpha} \tag{2}$$

FS is on both side of the equation as noted above. The equation is not unlike the Ordinary factor of safety equation except for the m_α term, which is defined as:

$$m_\alpha = \cos\alpha + \frac{\sin\alpha\tan\phi}{FS} \tag{3}$$

To solve for the Bishop's Simplified factor of safety, it is necessary to start with agues for *FS*. In *SLOPE/W*, the initial guess is taken as the Ordinary factor of safety. The initial guess for *FS* is used to compute m_α and then a new *FS* is computed. Next the new *FS* is used to compute m_α and then another new *FS* are computed. The procedure is repeated until the last computed *FS* is within a specified tolerance of the previous *FS.* Fortunately, usually it only takes a few iterations to reach a converged solution.

2.3.3 Janbu's simplified method

The Janbu's Simplified method is similar to the Bishop's Simplified method except that the Janbu's Simplified method satisfies only overall horizontal force equilibrium, but not overall moment equilibrium. Failure is assumed to occur by the sliding of a block of soil on a non-circular slip surface, as shown in **Fig. 3**, [6]. In this method the assumption is made that the inter slice shear force is zero. Assuming $X_R = X_L = 0$ i.e. Inter slice forces are horizontal.

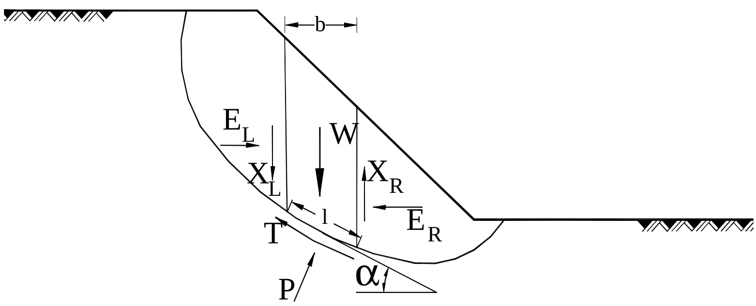


Fig. 3. Janbu's simplified method.

The equilibrium parallel to base of slice:

$$T + \left(E_R - E_L\right)\cos\alpha = \left[W - \left(X_R - X_L\right)\right]\sin\alpha \tag{4}$$

Again assume $X_L = X_R = 0$; rearrange, and substitute for T, so:

$$E_R - E_L = W\tan\alpha - \frac{1}{F}\left[Cl + (P - ul)\tan\phi\right]\sec\alpha \tag{5}$$

Overall forces equilibrium if there is no surface load is:

$$\sum\left(E_R - E_L\right) = 0 \tag{6}$$

So:

$$\sum(E_R - E_L) = \sum W\tan\alpha - \frac{1}{F}\sum\left[Cl + (P - ul)\tan\phi\right]\sec\alpha = 0 \tag{7}$$

Whence

$$F = \frac{\sum\left[Cl + (P - ul)\tan\phi\right]\sec\alpha}{\sum W\sin\alpha} \tag{8}$$

Where u is the pore water pressure.To take account of the inter slice shear forces, the correction factor f_o was applied, which was dependent on the geometry of the problem as well as the soil condition, where:

$$F_f = f_\circ .F \tag{9}$$

In original formulation, P was eliminated and the expression obtained:

$$F = \frac{\sum\left[Cb + (W - ub)\tan\phi\right]/\,n_\alpha}{\sum W\tan\alpha} \tag{10}$$

In which $n_\alpha = m_{\alpha.}\cos\alpha$

In this method, the body mass contained within the assumed slip surface and free ground surface is divided into *n* slices. Then for *n* slices, we have the following: n of the P forces and (n – 1) numbers for the magnitude of the X forces (X = 0). Since one additional assumption is made, technically it cannot be a rigorous solution. This method is suitable for total and effective stress analyses [7] and [8].

2.3.4 Morgenstern and price method

Morgenstern and Price were describe of a method of analysis which may be applied to circular and non-circular slip surfaces, as shown in **Fig. 4**, the essence of the method is to divide the sliding mass into a relatively small number of linear sections or wedges which are vertical sided in the conventional way [10]. Within each of these sections, which may be many times wider than the slice considered in most other methods, an element (in the calculus sense) can be considered. The conditions of force equilibrium can be considered, taking directions normal and parallel to the slip surface. In the normal direction the equilibrium equation yields:

$$dN + dP_b = dW\cos\alpha - dX\cos\alpha - dE\sin\alpha - dP_w\sin\alpha \tag{11}$$

And in the shear direction,

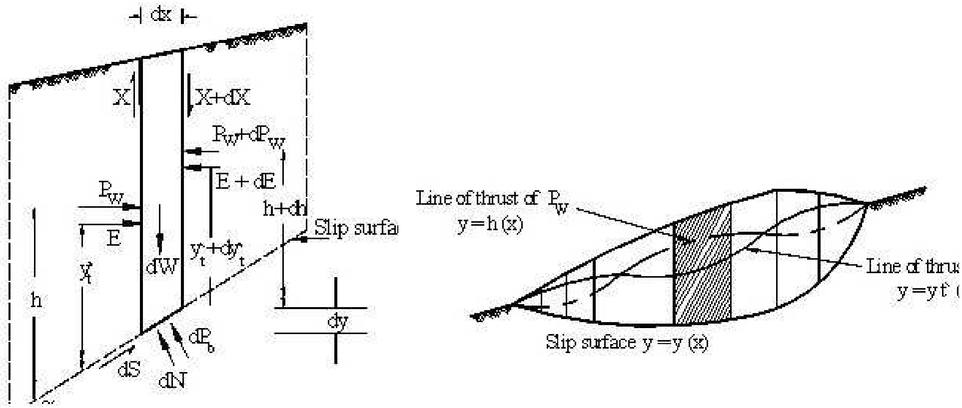
$$dS = dE\cos\alpha + dP_w\cos\alpha - dX\sin\alpha + dW\sin\alpha \tag{12}$$

Suppose that the errors in *E* and *R* at the end of the slip surface are δE and δR. A fresh estimate for the values of *F* and λ can be obtained by adding δF and $\delta\lambda$ respectively to the starting estimates, where δF and $\delta\lambda$ are evaluated by two-variable Newton approximation method:

$$\delta F = \frac{\delta R\dfrac{\partial E}{\partial\lambda} - \delta E\dfrac{\partial R}{\partial\lambda}}{\dfrac{\partial E}{\partial F}\dfrac{\partial R}{\partial\lambda} + \dfrac{\partial E}{\partial\lambda}\dfrac{\partial R}{\partial F}} \tag{13}$$

And

$$\delta\lambda = \frac{\delta E\dfrac{\partial R}{\partial F} - \delta R\dfrac{\partial E}{\partial F}}{\dfrac{\partial E}{\partial F}\dfrac{\partial R}{\partial\lambda} + \dfrac{\partial E}{\partial\lambda}\dfrac{\partial R}{\partial F}} \tag{14}$$



(a) An element of infinitesimal width (b) Sliding mass subdivided into small slices.

Fig. 4. A typical element in the Morgenstern.

In this method, the body mass contained within the assumed slip surface and free ground surface is divided into n slices. Then, for n slices, we have the following: n of the P forces and (n – 1) numbers for the magnitude of the X forces (X = 0). Since one additional assumption is made. This method therefore satisfies static equilibrium conditions rigorously. It is useful for soil and rock slopes, with effective and total stress analyses. It is applicable to failure surface of arbitrary shape and arbitrary boundary conditions but the use of computer is essential. The factor of safety can be determined using numerical methods, and the acceptability of solution must be checked as in Janbu method [9] and [11].

3. EXPERIMENTAL WORK PROGRAM

To study the factors affecting on the stability of the asphalt road between two canals, site investigation was carried out through excavation of 9 bore holes at eastern side of the road as shown in **Fig. 5**. The undisturbed samples are extracted to carry out experimental investigation for the soil profile. Tests are performed on undisturbed samples to determine the water content, bulk, dry densities, shear strength parameters, and initial modulus of elasticity.

3.1 Triaxial Test Results

Undrained quick triaxial tests are carried out under cell pressure $\boldsymbol{б_3}$ equal to (5, 10, and 15) *kN/m*^{2} on different samples to determine the shear strength of the soil samples. Undisturbed samples with inner diameter 3.81 cm and height 7.62 cm are used. The failure envelope is determined from triaxial tests as shown in **Figs. 6**, **7** and the soil parameters are presented in terms of half-Mohr circles; hence the failure envelope is referred to as the Mohr-Coulomb failure envelope.

The results between devotric stress ($\boldsymbol{б_1}$- $\boldsymbol{б_3}$) and axial strain were drowning. The slope of initial tangency was obtained for determinate of Young’s modules **Table 2,** and such as show in **Figs. 8** and **9**, respectively.

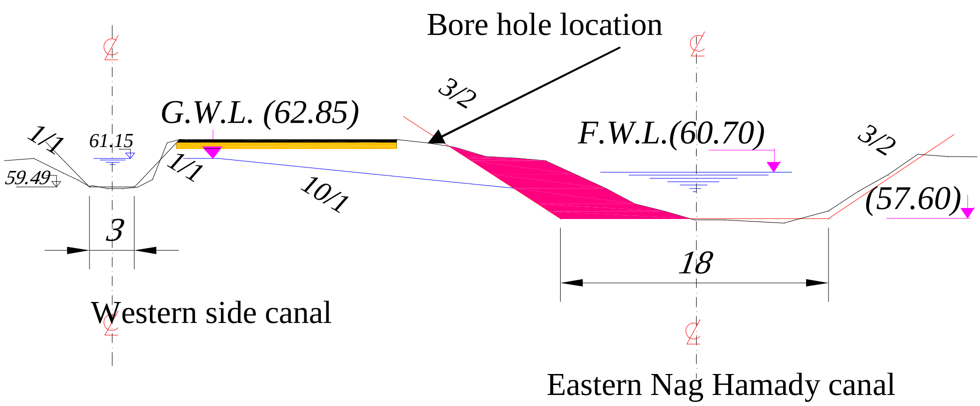


Fig .5. Bore holes location at km (70.8).

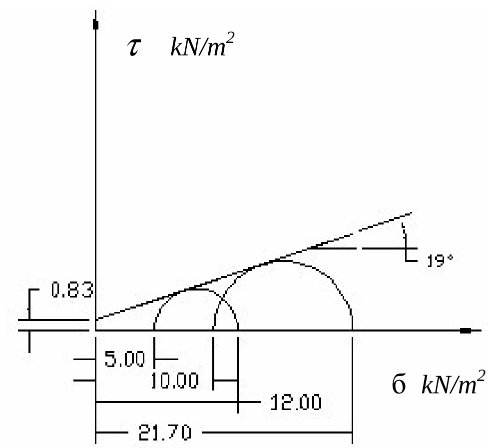


Fig. 6. Triaxial Undrained quick test for specimen No(1).

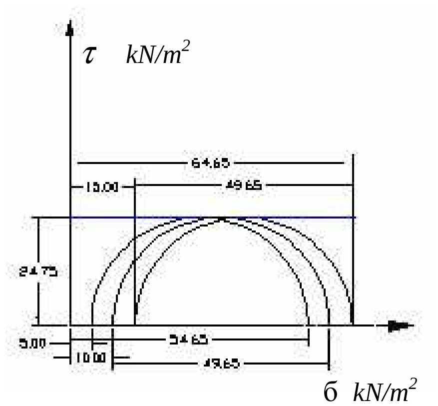
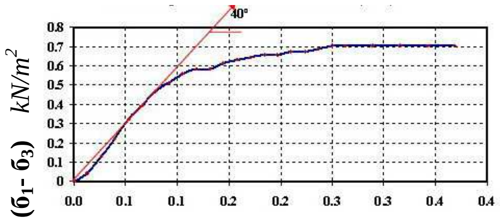


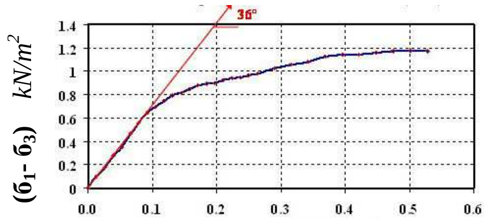
Fig. 7. Triaxial Undrained quick test for specimen No (2).

Table 2: Triaxial test results for specimens at location (70.8) Km.

Spec. No.	TEST No.	Depth m	σ_3 kN/m^2	σ_1 kN/m^2	E Young's modulus kN/m^2	γ Unit weight kN/m^3	c Cohesion kN/m^2	ϕ Friction angle Degree
1	1----1	2.0	5	12	40000	17.5	0. 8	19
	1----2		10	21.7	36000	18.2		
2	2----1	3.0	5	54.65	31000	17.4	24.8	0
	2----2		10	59.85	38000	17.7		
	2---3		15	64.65	34000	17.6		



Axial strain ε %
Fig. 8. Stress strain relationship for specimen No (1-1).



Axial strain ε %
Fig. 9. Stress strain relationship for specimen No (1-2).

3.2 Shear Test Results

The most common way of describing the shear strength of geotechnical materials is by Coulomb's equation, which is:

$$\tau = c + \sigma \tan \phi \qquad (15)$$

τ = Shear stress.
c = Cohesion.
σ = Normal stress on shear plane.
ϕ = Angle of internal friction (phi).

The relationship can be represents by straight line .The shear strength versus normal stress relationship are plotted in **Figs. 10**, and **11**. The intercept on the shear strength axis is the cohesion (c) and the slope of the line is the angle of internal friction (ϕ).

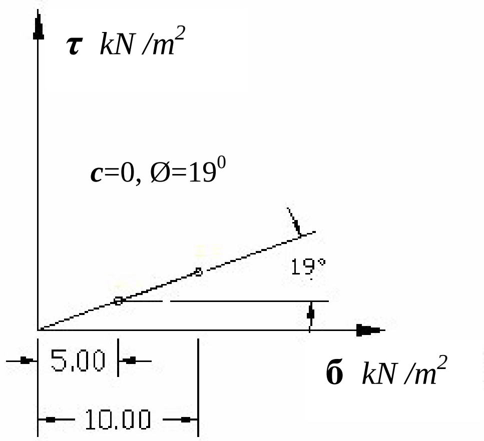


Fig.10. graphical representation of coulomb shear strength equation test No.1.

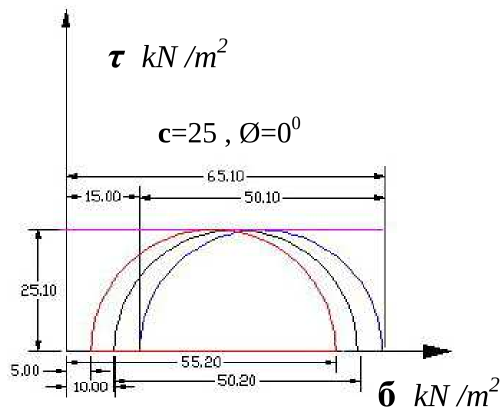


Fig.11. graphical representation of coulomb shear strength equation test No.2.

4. RESULTS AND DISCUSSIONS

4.1 Shape of Failure Before Strengthening

The input data which are required for *SLOPE/W*, *SIGMA/W* are shown in **Table 3**, [3] and [4].

$k_\circ$ =Coefficient of earth pressure at rest,

$k_\circ = б_h / б_v$ or $= б_3 / б_1$ (16)

where $k_\circ = 1 - \sin\phi$

From *GEOSTUDIO 2004* software products (*SLOPE/W*, *SIGMA/W*) computer programs can obtain the critical slip surface by analyzing a wide range of potential slip surfaces and used dual axle loads as shown **Fig. 12**.

Table 3: Input data and the values of description layers and soil.

Section K.M	No. of Soil specimen	Thickness of specimen	Description of Soil	*E* kN/m^2	γ kN/m^3	*c* kN/m^2	ϕ In Dg.	υ	$k_\circ$
70.8	1	10 cm	Asphalt	12500000	23.5	10	30	0.35	0.5
	2	15 cm	Base	11200000	21	8	45	0.35	0.3
	3	25 cm	Sub base	1040000	21	5	38.5	0.35	0.38
	4	2.0 m	Sub grade Soil	38000	17.9	0.8	19	0.45	0.67
	5	3.0 m	Soil	31000	17.4	24.8	0	0.45	1
			Concrete	25000000	25	1000	45	0.2	0.3

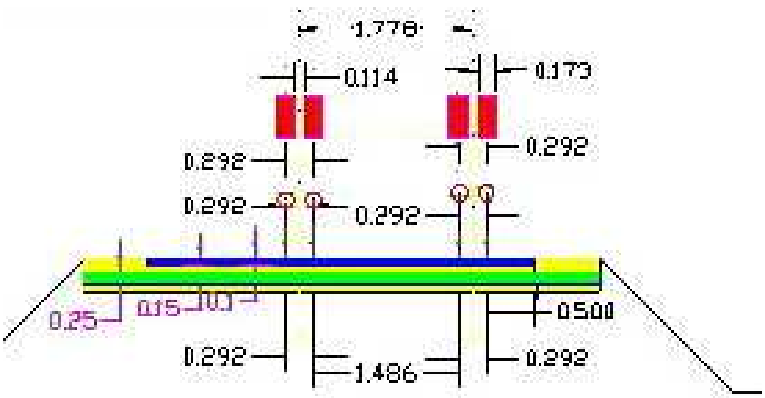


Fig .12. Dual axle loads =22.5*4=90 kN.

The factor of safety of Slope stability own weight only at section km (70.8) results were obtained in **Fig. 13**.

The results which were obtained from *SIGMA/W* without load (own weight) pressure section at km (70.8) are show in **Fig. 14**.

The factors of safety of Slope stability loading section at km (70.8) results were obtained in **Fig. 15**.

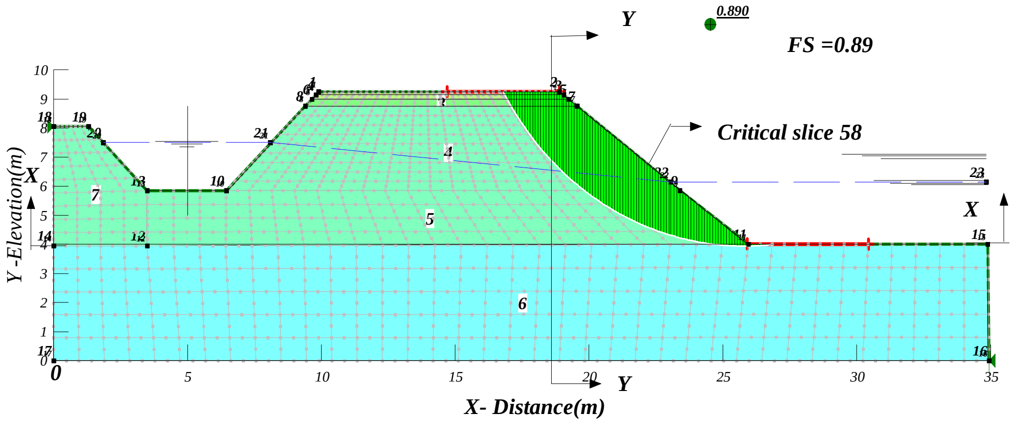


Fig. 13. Slope stability factor of safety for own weight only.

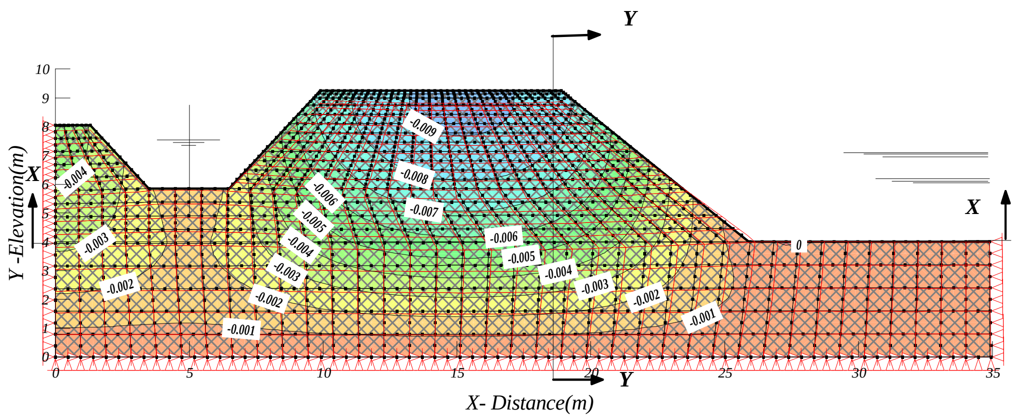


Fig. 14. Contours X- Displacement due to own weights

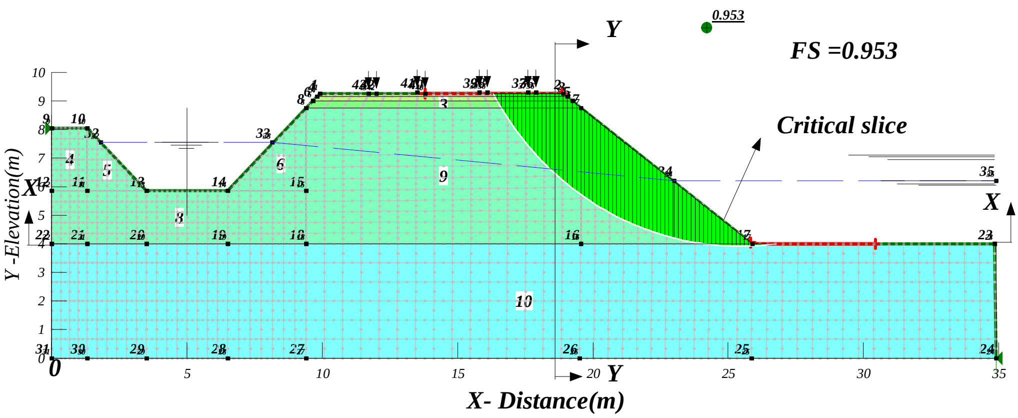


Fig. 15. Slope stability factor of safety for loading.

The results which were obtained from SIGMA/W load pressure section at km (70.8) is show in **Fig. 16**.

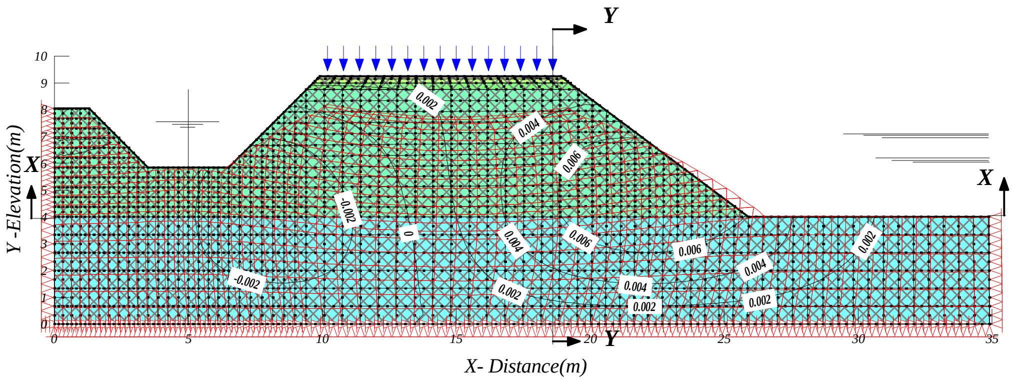


Fig.16. Contours X- Displacement due to load pressure.

The factors of safety values from different methods are Compared and reported in **Table 4**.

Table 4: results output data from computer before strengthening.

Method	Ordinary or Fellenius	Bishop.	Janbu.	Morgenstern and Price
FS Slope stability for own weight only	0.843	0.936	0.846	0.89
FS Slope stability for loading	0.907	1.005	0.907	0.953

The results show that the factor of safety is less than (1.0), This mean the cross section is not safe at km (70.8). Therefore same trials were used to solve this problem.

5. METHODS OF STRENGTHENING WORKS

The methods for slope strengthening can be summarized as follows:

1) Soil reinforcement:

Soil reinforcement is commonly accomplished with geosynthetics such as woven geotextiles, geogrids, or steel strips. The reinforcement should extend beyond the failure surface that has a minimum factor of safety of 1.5.

The presence of water in a slope can reduce the shear strength of the soil, reduce the shear resistance through buoyancy effects, and impose seepage forces. Those effects reduce the factor of safety of the slope and can cause failure of the slope. Both passive and active dewatering/subsurface-water-control systems can be used. Reinforcement of soil and of ground has become extensive and very commonly preferred alternative to enhance the performance of the earth structures. The reinforcement in all the above instances is in the form of strips, bars, grids or sheets fabricated or manufactured from metals or geosynthetics. The reinforcement is presumed to restrain tensile deformations of the soil and thus increases the over all resistance of the composite soil through interfacial bond resistance but limited by its own tensile strength. The Soil reinforcement consists of:

- Geotextile
- Geomembrane
- Geogrid

2) Vertical cut off wall:
A retaining wall can be constructed through an unstable slope to provide additional resistance and raise the factor of safety for material behind the wall to an acceptable level. Retaining structures should be founded in stable earth materials. The retaining structure should be evaluated for possible sliding, overturning, and bearing failures using standard techniques. Consideration must be given to whether material in front of the wall that is assumed to provide passive resistance could be removed or excavated in the future.

3) Vertical piles:
The factor of safety of a slope, can be increased by installing soldier piles/drilled shafts through the unstable soil into competent underlying materials. The piles/drilled shafts are sized and spaced so as to provide the required additional resisting force to achieve adequate slope stability. The piles drilled shafts typically provide resistance through the bending capacity of the shaft anchored by passive resistance in stable earth materials underlying the slide mass.

4) soil replacement:
Resistance to failure is provided by passive earth pressure within the "stable earth materials." In this context, stable earth materials are defined as those materials located beneath the potential failure surface having a static F.S ≥ 1.5.Generally is calculated assuming no lateral support from the same material down slope of the soil replacement.

5) Soil stabilitation:
- Cement
- Lime
- Some other methods

6) Lining of the side canals.

5.1 Numerical Idealization For Piles

GEOSTUDIO 2004 program studies two dimensional problems .Piles used to reinforce the slope are installed at regular distances in the longitudinal directions (s), to idealize the piles to resist axial and lateral loads they are transformed to equivalent material is the axial and lateral direction.
For axial stiffness for any layer (**Fig. 17**):

$$E_s A_s + E_P A_P = E_{eq} A_{eq} \Rightarrow E_{eq} = \frac{E_S A_S + E_p A_p}{A_{eq}} \tag{17}$$

Where: $A_{eq} = S d_a$

Equivalent lateral stiffness of piles as wall can be calculated as follows:

If bending stiffness was neglected for soil and road layers between the piles. The following equation can be given:

$$E_p I_p = E_{eq} I_{eq} \Rightarrow E_p \frac{\pi d^4}{64} = E_{eq} \frac{S d^3}{12} \qquad (18)$$

Assume d_{pile}= 0.4, S =1.0 *m* and E_P =25*10^6 kN/m^2 ⟶ E_{eq} =5890486 kN/m^2
By substituted for above equation gets $d_a = 0.36\ m$ take $d_a = 0.4\ m$ for safe.

$$A_s \gamma_s + A_p \gamma_p = A_{eq} \gamma_{eq} \Rightarrow \gamma_{eq} \qquad (19)$$

The factors of safety of slope stability with equivalent cut off wall 40 cm section at km (70.8) results were obtained in **Fig. 18**.

The results which were obtained from *SIGMA/W* with equivalent cut off wall 40 cm section at km (70.8) is show in **Fig. 19**.

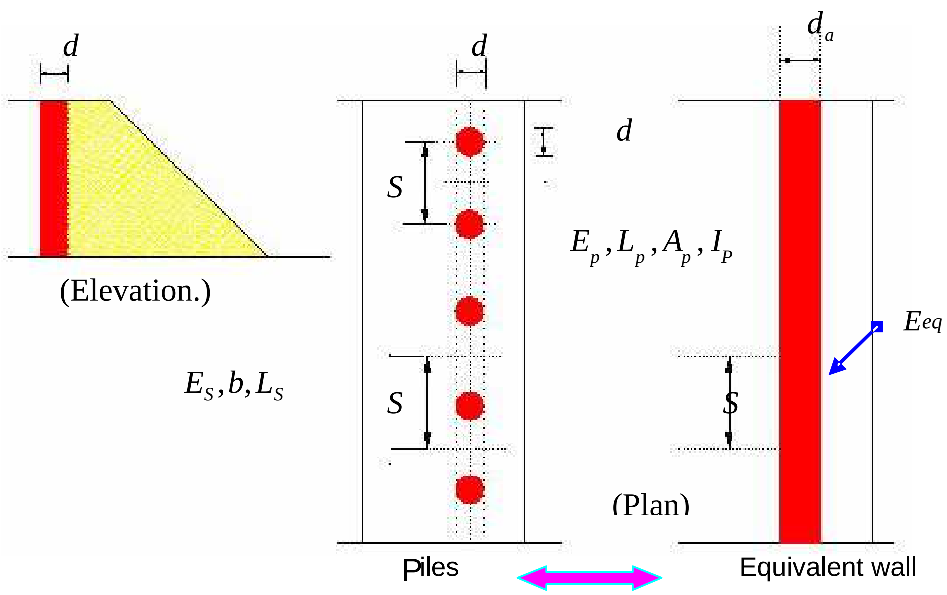


Fig .17. Piles equivalent wall.

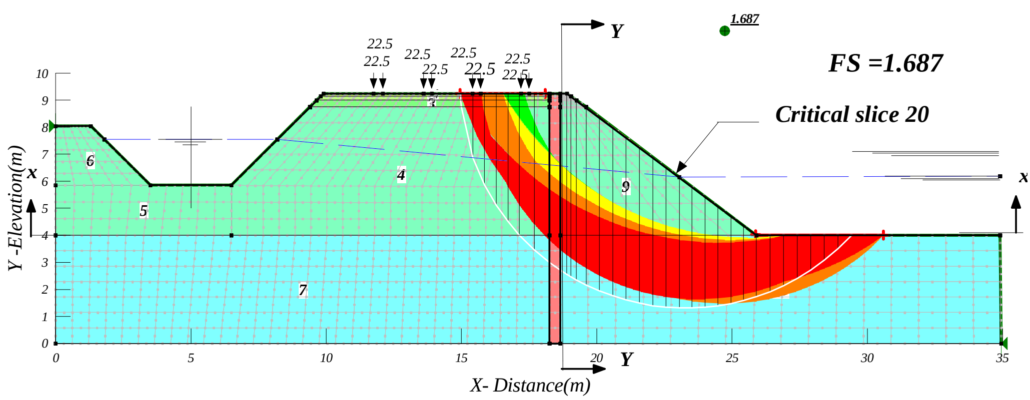


Fig. 18. Slope stability factor of safety with equivalent cut off wall 40 cm.

The factor of safety values after using piles equivalent cut-off wall are shown in the following **Table 5**.

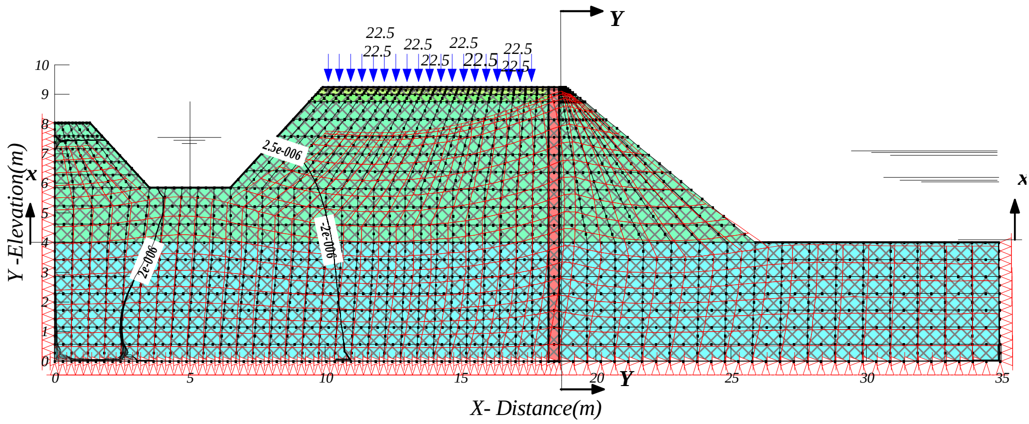


Fig. 19. Contours X- Displacement due to equivalent cut off wall 40 cm

Table 5: Slope stability factor of safety with equivalent cut off wall 40 cm.

Method	Ordinary or Fellenius	Bishop.	Janbu.	Morgenstern-Price
FS	**1.16**	**1.7**	**1.279**	**1.687**

5.2 Factor of Safety after Using Retaining Wall with Thickness 25cm

The factors of safety of slope stability with using retaining wall 25 cm section at km (70.8) results were obtained in **Fig. 20**, [2]and [5].

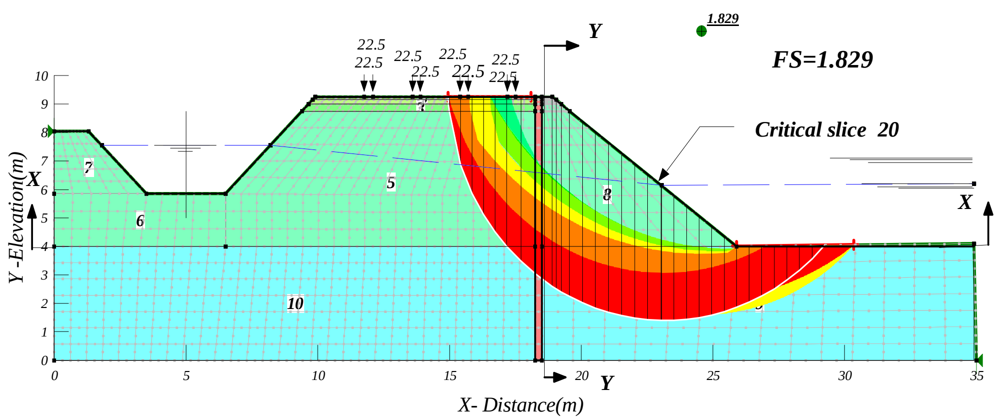


Fig. 20. Slope stability factor of safety with using retaining wall 25 cm

The results which were obtained from SIGMA/W with using retaining wall 25 cm section at km (70.8) is show in **Fig. 21**.

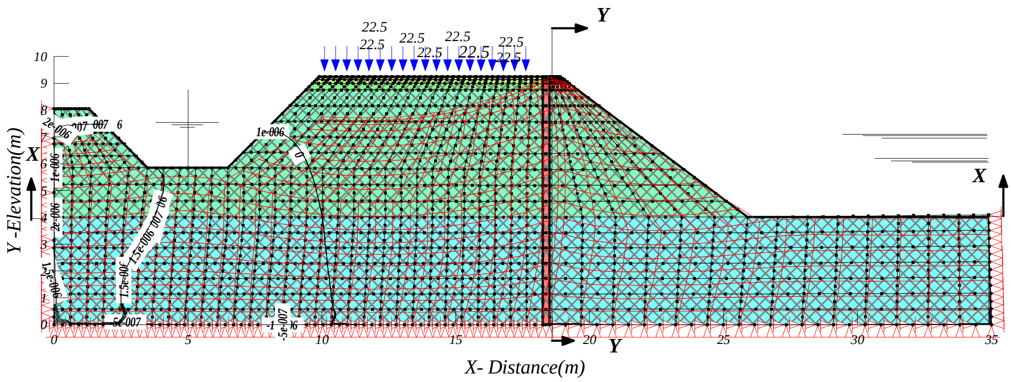


Fig. 21. Contours X- Displacement due to retaining wall *25 cm* loaded case

The horizontal effective stress (б3) distribution with different cases for vertical cross section Y-Y at failure location At (X=18.6m) (own weight, loading with vehicle, equivalent wall 40cm and cut off wall 25cm left ,right wall) show in **Fig. 22**.

The vertical effective stress (б1) results distribution with different cases for cross section X-X at 4.0m level (own weight, loading with vehicle ,equivalent wall 40cm and cut off wall 25cm left ,right wall) show in **Fig. 23**.

The X-Displacement at (X=18.6m) for different cases (own weight, loading with vehicle ,equivalent wall 40cm and cut off wall 25cm left ,right wall) show in **Figure 24**.

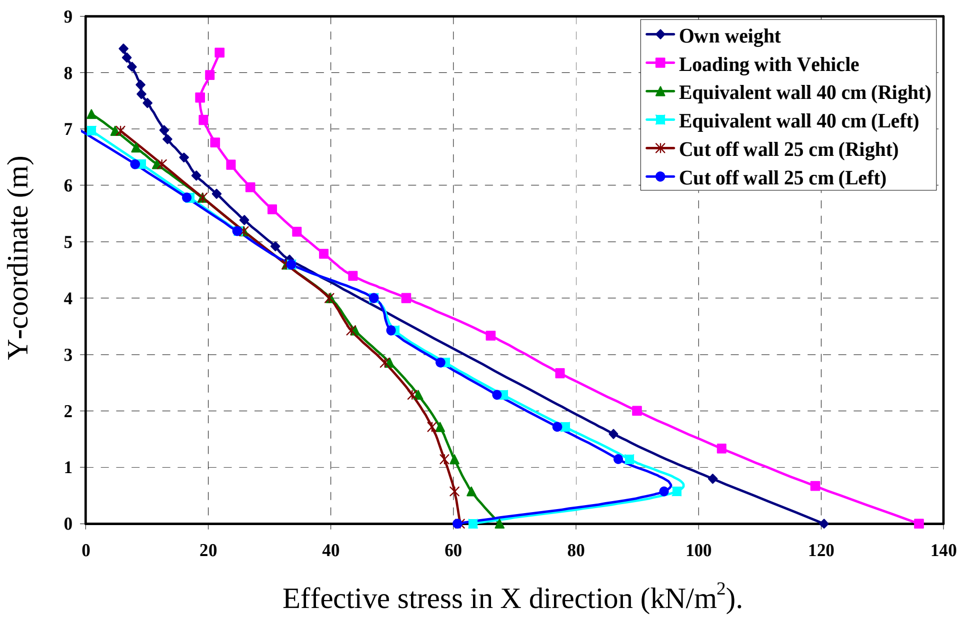


Fig. 22. Effective stress $б_3$ distribution with different cases.

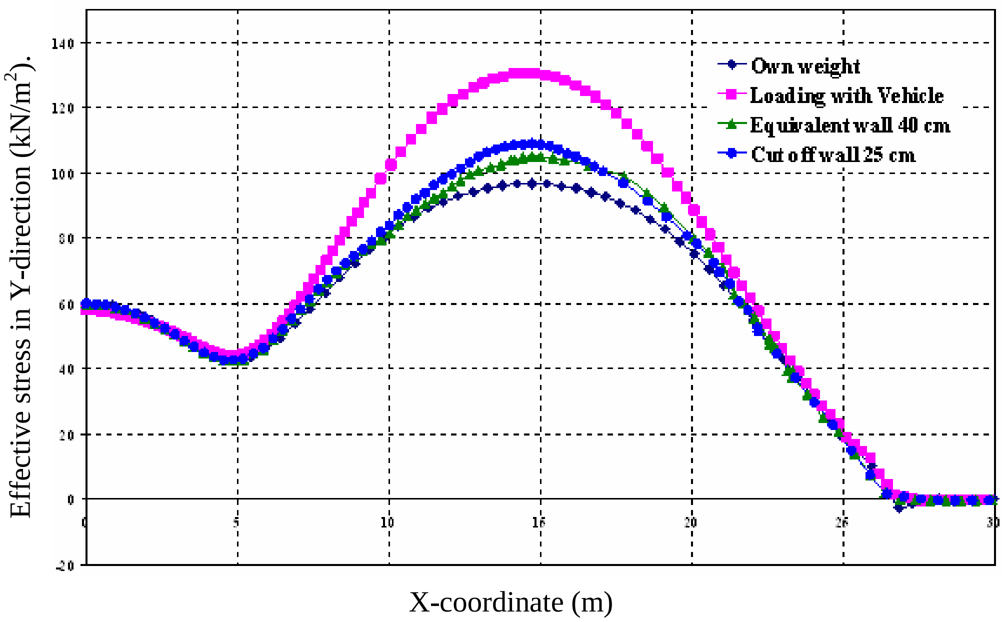


Fig. 23. Effective stress distribution with different cases.

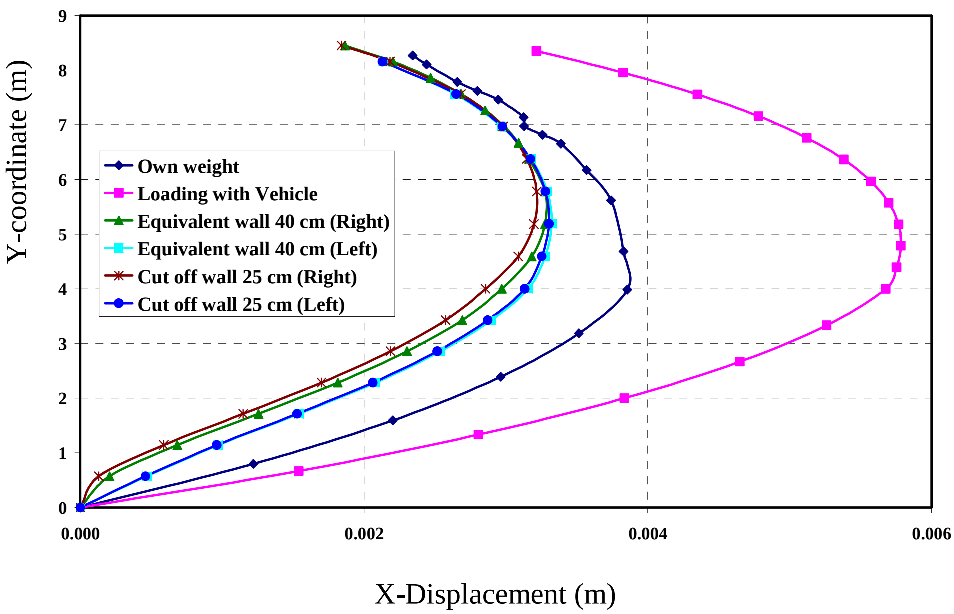


Fig. 24. X-Displacement for different cases.

The effective stress distribution in the side slope cross section:

The following discussions on the effective stress distribution in the clay soil in side slope can be made from ***GEOSTUDIO 2004*** program. The effective in X-direction, and Y- direction were plotted for own weight, loading with vehicle, equivalent wall 40 cm and cut-off wall 25cm.

The effective stress in X-direction:

The effective stress in X-direction is shown in **Fig. 22**. It can be notice that the effective stress in the case of loading with vehicle is higher than that of the own weight. The values of effective stress in X-direction for equivalent wall 40cm and cut off wall 25cm were approximately the same and less than that of own weight case.

The effective stress in Y-direction:

The effective stress in Y-direction in case of Loading with vehicle is also higher than the own weight case, but the effective stress in two cases of equivalent wall 40 cm and cut off wall 25 cm lies between own weight, loading with vehicle.

Horizontal displacement in X-direction:

The Horizontal displacement approximately equal zero at depth 4 m below the failure location for various cases, and the maximum horizontal displacement at failure location, but the horizontal displacement are smaller value than with cut-off wall and equivalent wall.

The factor of safety values after using cut off wall 0.25cm are shown in the following **Table 6**.

Table 6: Slope stability factor of safety using cut off wall 0.25cm.

Method	Ordinary or Fellenius	Bishop.	Janbu.	Morgenstern and Price
FS	1.807	1.788	1.525	1.829

The final factors of safety results from computer program for three methods are shown in the following **Table 7**, and from these results can be noticed that the factor of safety more than 1.5, therefore section is safe.

Table 7: Final results from computer for three methods by Morgenstern and Price.

Sections (70.8) Km	without load	loading	equivalent soil cut -off wall 40 cm	Retaining wall 25 cm
FS	0.89	0.953	**1.687**	1.829

6. CONCLUSIONS

- Experimental determination of the physical and mechanical soil properties is essential to obtain good numerical results.
- The proposed strengthening methods have great effect on reducing the lateral displacement of the road section with a factor of safety greater than 1.5.
- The Horizontal effective stresses at the critical section decreased at the location of the strengthening walls or piles by about 30 %.
- The results of the numerical model at the examined sections before strengthening give the same insite observation.

REFERENCES

[1] A.W. Bishop, ‘The use of the slip circle in the stability analysis of slopes’, Geotechnique 5, pages 7-17, (1955).

[2] Ernest Hinton and Roger Owen, ‘Computational modelling of reinforced concrete structures ’,book chapter 2, pages 44,62-64 Swansea, June (1986).

[3] Fwat.F.Tan S.A.and Zhu Ly. ‘Reexamining [C, Ø] concept for asphalt paving mix design‘ Journal of Transpirtation Engineering, pages 67-73, Feb. (2001).

[4] John Krahn, ‘*Geostudio 2004* software products (*SLOPE/W, SIGMA/W*) computer program, tutorial first edition, revision, pages 7-203, August (2004).

[5] K.Thiel , ‘Rock mechanics in hydro engineering ’, book chapter 2, general characteristics of rock physical properties, pages5,46-48 Elsevier Amsterdam-Oxford-New York-Tokyo (1989).

[6] M. Doležalová, I. Hladík. and v. Zemanová, ‘Stability analysis of a motorway embankment on soft subsoil using FEM, FLAC and limit equilibrium models’, proceedings of the 2nd international FLAC conference in FLAC and numerical modeling in geomechanics, d. Billaux et al. (eds.), pages 125-132, Lyon, France, Swets & Zeitlinger, (2001).

[7] M. Enieb, G. Swoboda and H. Tiefenthaler, ‘Effect of critical state hardening model on stability of embankment’, proceedings of the 1st international conference of civil engineering science (ICCES1), pages 345-355, Assiut, Egypt, (2003).

[8] M. Enieb,’Elasto-plastic critical state model with strain localization in soil structures‘ Ph.D,Thesis, university of Innsbruck,Austria, (2004).

[9] N. Janbu, ‘Earth pressures and bearing capacity calculations by generalized procedure of slices’, proceedings of the fourth international conference on soil mechanics and foundation engineering, pages 207-212, (1957).

[10] N.R. Morgenstern, and V.E. price, ‘The analysis of stability of general slip surfaces’, Geotechnique, 15, pages 79-93, (1965).

[11] R.N. Choudhury, ‘Developments in geotechnical engineering vol. 22, slope analysis’, Elsevier Scientific publishing company, 1978.

العوامل المؤثرة فى إتزان الميول الجانبية لجسور الطرق السريعة
" حالة الدراسة: طريق مجاور لمجرى مائى فى مصر العليا"

تعتبر دراسة إتزان الميول والعوامل المسببة للإنهيارات التى تحدث على الميل الجانبى لجسور الطرق السريعة والمجاورة للمجارى المائية الممتدة فى مصر العليا من أهم الدراسات الهندسية التى تشغل بال كثير من الباحثين فى هذا المجال.

ولذا فقد تناولنا فى هذا البحث دراسة تطبيقية على الجسر المشترك بين ترعتى نجع حمادى الشرقية والجنابية الغربية الموازية لها عند الكيلومتر (70.8) من فم ترعة نجع حمادى الشرقية والذى يمثل الطريق السريع القاهرة أسوان على الجانب الشرقى لنهر النيل بين محافظتى أسيوط وسوهاج.

تم رصد بعض الأنهيارات والشروخ الموجودة بهذا الجسر وقد وجد أن الأنهيارات والشروخ فى أسفلت الطريق ناحية الميل الجانبى لجسور الترع تبدأ فى الظهور عقب السدة الشتوية كل عام ويعزى ذلك إلى ضعف قوة تحمل التربة وأيضا إختلاف مناسيب المياه بالترعتين المتجاورتين.

تم عمل الدراسات النظرية لهذه الشروخ والانهيارات بأستخدام بعض البرامج التى تخدم هذا المجال مثل ***GEOSTUDIO 2004*** ومنه امكن إيجاد معامل الأمان لأكثر من طريقة فى أتزان الميول بأستخدام ***SLOPE/W*** وكذلك تم تقسيم العناصر الإنشائية للقطاع الى عدد من العناصر اللإنهائية ذات التقنية العالية والحديثة بأستخدام ***SIGMA/W*** مع أمداده بخواص وعناصر طبقات التربة المستنتجة معملياً وتم تمثيل شكل القطاع الحقيقى على الطبيعة، وقد أفادت المحاكاة الرقمية المستخرجة من البرنامج فى تحديد مكان الأنهيار وإتجاهة للطريق السريع.

ولهذه الدراسة فقد تم إجراء بعض التجارب المعلية بأستخدام الضغط المحورى وصندوق القص والأنضغاط الحر والتى أجريت على عينات غير مقلقلة من الطبيعة على أعماق مختلفة من موقع القطاع وذلك لتحديد الخواص الطبيعية للتربة بمنطقة الأنهيارات.

ثم أمكن إستنتاج بعض النتائج الهامة فى هذا البحث مثل معامل الأمان أقل من واحد، وكذلك تم مقارنة شكل الأنهيار الناتج من الدراسة النظرية بما هو فى الطبيعة وكانت نتائج موفقة حيث تطابق شكل الأنهيار الناتج من البرنامج مع الشكل الطبيعى للقطاع الحقيقى.

وقد وجد أيضا فى هذا البحث أن دق خوازيق بقطر 40 سم وعلى مسافات متساوية كل 1.0 متر أو أستخدام حائط ساند خرسانى بسمك 25 سم يؤدى الى تقليل الأجهادات الأفقية بنسبة حوالى 30% وأيضا الى تخفيض الاجهادات الراسية والازاحة الافقية الناتجة عن مختلف انواع الاحمال والمركبات على الطريق السريع وبالتالى زيادة معامل الأمان ليتجاوز 1.5.
أيضا أشتمل البحث على عديد من النتائج الهامة الأخرى التى تخدم المهندسين فى موقع التنفيذ فى هذا المجال.