Slope Stability Study of Residential Area in Hay AL-Araby / Mosul with Suggested Remedial Application

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ABSTRACT

Slope stability analysis is a common analytical tool to assess the factor of safety (FOS) of natural and man-made slopes i.e. embankment. In geotechnical engineering, different methods were used to determine the factor of safety (FOS) of slopes such as traditional or programming methods. Numerical methods using Geo-Studio software (Slope/W) is suitable one, in assessing the stability of slopes under different conditions.

The aim of this study is to analyze the slope stability for the suggested residential project in Hay-AL-Araby / Mosul, with the application of some suggested remedial solutions. GeoStudio2007 software program was used to compute the minimum FOS values, also probabilistic and reliability indexes were studied. The FOS for both natural and corrective with and without seismic cases has been determined using Morganstern-Price, Bishop, Janbu, and ordinary methods. Several methods for remedial of the slopes to increase the FOS have been proposed in the analysis were studied.

The results showed that there are significant differences in the values of minimum FOS of natural slope between dry and wet conditions which varied between (3.348-3.68) and (1.838-2.326) respectively. Also, nailing and pile remedial methods were found to be effective for the dry and wet conditions respectively with minimum FOS=1.111 and 1.137. As well, the application of seismic loading showed that the natural slope would be at risk with minimum FOS equal to 1.826, and 1.006 respectively for both dry and wet cases. Finally, the deterministic and probabilistic analysis of natural and remedial slopes is in the ranges (8.443 to 1.428) for dry and (9.688 to 0.570) for wet conditions.

Keywords: Slope stability, Factor of safety, Remedial, Probability, Reliability index.

دراسة استقرار المنحدر لمشروع سكني مقترح إقامته على منحدر في منطقة حي العربي / الموصل مع تطبيق بعض الحلول العلاجية المقترحة

الخلاصة

يُعد تحليل الاستقرارية للمنحدر من الطرق العامة لتقييم وإيجاد معامل الأمان (FOS) للمنحدرات سوء الطبيعية أو التي هي من صنع الإنسان. في الهندسة الجيوتكنيكية، هنالك طرق مختلفة لإيجاد قيم معامل الأمان

للمنحدرات مثل الطرق التقليدية أو البرمجة. تعد الطريق التحليلية باستخدام Slope/W من أحد انسب الطرق في تقييم استقرار المنحدرات تحت ظروف مختلفة.

الهدف من هذه الدراسة هو تحليل استقرار المنحدر لمشروع سكني مقترح إقامته في منطقة حي العربي / الموصل، مع تطبيق بعض الحلول العلاجية المقترحة. اعتمد في التحليل على برنامج حاسوبي Geo-Slope2007 software لحساب اقل قيمة لمعامل الأمان FOS، كما تمت دراسة probabilistic و reliability indexes. وقد تم تحديد قيمة لمعامل الأمان FOS لكلا الحالتين الطبيعية والمقترحة مع وبدون حدوث هزة أرضية باستخدام طرق الحل (Morganstern-Price, Bishop, Janbu, and Ordinary methods). وتمت دراسة استخدام عدة طرق علاجية تم اقتراحها في التحليل من اجل زيادة قابلية تحمل المنحدرات.

أظهرت النتائج أن هناك اختلافات في قيم FOS للمنحدر الطبيعي بين الظروف الجافة والرطبة والتي تراوحت بين (3.348 - 3.68) و (1.838- 2.26) على التوالي. أيضا، تم الاستنتاج إن استخدام طريقة المعالجة بطريقة (nailing) وكذلك استخدام طريقة المعالجة باستخدام (nailing and Pile) فعالة للظروف الجافة والرطبة على التوالي وبقيم تراوحت بين FOS = 1.111 و1.137. كذلك، أظهرت نتائج احتمال حدوث هزة أرضية إن المنحدر الطبيعي سيكون في خطر وبقيم لمعامل الأمان يساوي 1.826، 1.006 على التوالي للحالة الجافة والرطبة على التوالي. أخيرا، فإن التحليل probabilistic و reliability indexes للمنحدرات الطبيعية والمعالجة بمدى (443،8-428،1) للحالة الجافة، و(688،9-570،0) للحالة الرطبة.

INTRODUCTION

Stability of slopes and the determination of the critical slip surface with a minimum factor of safety are one of the important characteristics that need to be considered in designing of earth slopes, embankments, excavation, and landfills. The factor of safety may be defined as the ratio of the summation of the resisting shear force along a slip surface to the summation of the mobilized shear force along slip surface.

The slope stability analysis is performed to assess the safe and economic design of human made or natural slopes. In the assessment of slopes, engineers primarily use factor of safety values to determine how close or far slopes are from failure, if the factor of safety is less than one the slope should have already failed.[1]

Failures of slopes cause economic and a possible human loss to the community. When a slope is critical, remedial work is required, it is essential to carry out failure investigations to find out the possible causes. The suitable remedial design can only be carried out after knowing the causes of failure. [2]

Many methods can be used in the analysis and compute the factor of safety determination method used for example Bishop (1955), Morgenstern and Price (1965), Spencer (1967), Janbu (1968), and Sarma (1979). Many treatment methods may be used to decrease the possibility of the slope failure and to increase the factor of safety such as: anchors, micro-piles, nailing, geogrids, retaining walls, piles, geotextile, as well as other methods. Remediation of slope failures required stabilization of the slope. These methods used to increase the safety factor of slopes versus failure.

Abdalla et al. (2012) studied the prediction of minimum factor of safety against slope failure in clayey soil using Artificial Neural Network (ANN). They observed that the ANN prediction is very close to the factor of safety calculated by corresponding analytical method and concluded that such ANN model is reliable, simple and valid computational tool for predicting the factor of safety and for assessing the stability of slopes of clayey soil [3]. Clvien and Lim (2005) study some case histories of slope remedial works they discuss many methods to stabilize a failed slope and select the most feasible method, they conclude that, the cause of the failure should be identified the site condition and cost of construction should be taken in consideration.[3]

Totsev and Jellev (2009) analyzed slope stability using conventional methods and finite element methods to establish the slope stability. The results of applying conventional methods were compared with the calculations performed by the FEM analysis using shear resistance reduction (φ, c – reduction). The obtained results in determining the slope stability by using different computational methods vary within wide limits. The calculations from Plaxis incremental shear strains (φ, c – reduction) and computational model by the FEM assess more precisely the soil behavior. When studying the problems related to slope stability, especially concerning safety of buildings, they recommend that observations should be carried out on the structure during its construction. [4]

FOS for remedial slopes was calculated throughout literature, Ghazavi and Shuhmandi (2008) presented an analytical static stability analysis of slopes reinforced by stone columns. Further parametric studies have been carried out to determine the influencing factors such as stone column diameter, friction angle of stone column material, and distance between stone columns [5]. Ghosh and Biswas (2012) study the effect of reinforcement on the stability of slopes. Slope stability evaluation by limit equilibrium of slope method and computed with the results from the GEOSLOPE software [6]. Baghini and Toufigh (2012) study the reinforced slope stability analysis using Natural Element Method (NEM) as a result; a reinforced slope that is analyzed with NEM is compared with the result of Geo-Studio 2004 software which indicates good accuracy in analyzing and locating failure. [7]

With the development of computer, finite element methods has been increasingly used in slope stability analysis, the advantage of a finite element approach to the analysis of slope stability problems over traditional limit equilibrium methods is that no assumption needs to be made for the shape or location of the failure surface, slice force, the method can be applied to complex slope configurations and soil deposits in two or three dimensions. [8]

According to the literatures, finite element method could be considered a powerful technique for slope stability analysis. The capacity of analyzing slope with spatially random soil properties could be achieved when the finite element method combined with a random field generator is used. This is due to the nature of the finite element method where the entire slope domain is divided into many discrete elements and every element can be assigned a different random variable by the random field generator [9]. A finite element analysis process in Geotechnical engineering should not only sufficient knowledge about soil mechanics and finite element topics, but also able to deal easily with the software performance.

This work describes a numerical simulation study of slope stability of case study situated in Hay-AL-Arabe –Mosul-Iraq, with suggested remedial application using computer software code SLOPE/W (Geo-Studio 2007). Slope stability analyses of natural and remedial slopes were examined in both dry and wet conditions. Seismic analyses under these conditions have also been conducted. Probabilistic and reliability indexes studied for both dry and wet conditions for the suggested remedial method are also considered.

Numerical Slope Stability Factor and Computer Programming Used

Over the years, many different methods have been developed for computing factor of safety for the slope stability:

1. Ordinary methods: This method also sometimes referred to as Fellini's or Swedish method. In this method all inter slice force (normal and shear) are ignored. The factor of safety equation for the slip surface is: [10][11]

$$F.S = \frac{\sum[c\,\beta + N\tan\emptyset]}{\sum W\sin\alpha} = \frac{\sum S_{resistance}}{\sum S_{mobilized}} \quad ....(1)$$

   Where:
   c: cohesion, β: slice base length, N: normal force on the base of the slice, ϕ: friction angle, W: slice weight, α: slice bas inclination.

2. Bishop's method: A simple form of the Bishop's factor of safety which included inter slice normal forces, but ignored the inter slice shear force. Bishop's method satisfies only moment equilibrium. [10][11]

$$F.S = \frac{1}{\sum W\sin\alpha}\sum\left[\frac{c\,\beta + W\tan\emptyset - \frac{c\,\beta}{F.S}\sin\alpha\tan\emptyset}{m_\alpha}\right] \quad ......(2)$$

$$m_\alpha = \cos\alpha + \frac{\sin\alpha\tan\emptyset}{F.S} \quad .....(3)$$

   Where:
   W: slice weight, α: slice bas inclination, c: cohesion, β: slice base length, ϕ: friction angle.

3. Janbu's method: This method is similar to Bishop's method except that the Janbu's method satisfies only overall horizontal force equilibrium, but not overall moment equilibrium, also consider normal force but not shear force.[10]
4. Morgenstern – Price method: Morgenstern – Price method developed two factors of safety equation, one with respect to moment equilibrium and other with respect to horizontal force equilibrium. This method satisfies both force and moment equilibrium. [10]

   SLOPE/W is a software product that uses Limit Equilibrium theory to evaluate the FOS of the slope. It possible to analyzed both simple and complex (complex geometry, material anisotropy, ...etc) slope stability problems using a variety of methods (Morganstern-Price, Bishop, Janbu, and ordinary methods, and other methods) to calculate the FOS.

In SLOPE/W program, dynamic effects can be considered in several ways, one of theme is pseudo static type analysis which represents the effects of earthquake shaking by accelerations that create inertial force. These forces act in the horizontal and vertical directions at the centered of each slice. The force is defined as: [10]

$$F_h = \frac{a_{h\,W}}{g} = k_{h\,W} \quad .....(4)$$

$$F_v = \frac{a_v W}{g} = k_{v\,W} \qquad .....(5)$$

Where:

a_h and a_h are the horizontal and vertical pseudo tic accelerations. g is the gravity acceleration constant, and W=slice weight.

The SLOPE/W equilibrium equations are based on the shear mobilized at the base of each slice and the mobilized shear is the shear strength divided by the factor of safety. In equation form, the mobilized shear S_m is:

$$S_m = \frac{S_{soil}}{F.S} \qquad .....(6)$$

In SLOPE/W, reinforcement can be represented such as anchors, nails, and Geo-fabrics. If the reinforcement is to be included to increase the shear resistance, then the reinforcement forces must also be divided by the factor of safety, S_m then is:

$$S_m = \frac{S_{soil}}{F.S} + \frac{S_{Reinforcement}}{F.S} \qquad .....(7)$$

For deriving the moment equilibrium factor of safety equation, the summation of moments for all slices can be written as follows:

$$\sum W_x - \sum S_m R - \sum N_f + \sum k\, W_e \pm \sum D_d \pm \sum A_a = 0 \qquad ......(8)$$

$$F_m = \frac{\sum(\acute{c}\,\beta\, R + (N - U\,\beta) R \tan\acute{\phi})}{\sum W_x - \sum N_f + \sum k\, W_e \pm \sum D_d \pm \sum A_a} \qquad .....(9)$$

For deriving the force equilibrium factor of safety equation, the summation of force for all slices can be written as:

$$\sum(E_L - E_R) - \sum(N \sin\alpha) + \sum(S_m \cos\alpha) - \sum(k\, W) + \sum(D \cos\omega) \pm \sum A = 0 \qquad ....(10)$$

$$F_f = \frac{\sum(\acute{c}\,\beta\, R + (N - U\,\beta) \tan\acute{\phi} \cos\alpha)}{\sum N \sin\alpha + \sum k\, W - \sum D \cos\omega \pm \sum A_a} \qquad .....(11)$$

Slice normal force at the base: the normal force at the base of the slice is derived as:

$$(X_L - X_R) - W + N \cos\alpha + S_m \sin\alpha - D \sin\omega = 0 \qquad .....(12)$$

$$N = \frac{W + (X_L - X_R) - \frac{\acute{c}\,\beta\, R + (N - U\,\beta) R \tan\acute{\phi}}{F.S} + D \sin\omega}{\cos\alpha + \frac{\sin\alpha\,\tan\acute{\phi}}{F.S}} \qquad ....(13)$$

Where:
c': effective cohesion, β: slice base length, N: normal force on the base of the slice, ϕ': effective friction angle, W: slice weight, α: slice bas inclination, u: pore water pressure, D: line load, R, x, f, d, ω: geometry parameter, E_L and E_R: horizontal inter slice normal force, left and right sides.

In general, the factor of safety of slope represented the relative stability of a slope. It does not show the actual risk level of the slope. Slope stability analysis methods usually based on the search factor of safety which does not accurately describe for soil variability, so the true safety of a slope is unknown. Probability and reliability index calculation which taken into account the variability in soil strength is preferable to give a more realistic factor of safety calculation. The probability of failure study assists engineering decision for making a safe and economical slope design. Probability of failure and the reliability index quantify the stability risk level of a slope. The reliability index (ρ) is defined in term of mean (μ) and the standard deviation (σ) as shown in the following:[10][12]

$$\rho = \frac{\mu - 1}{\sigma} \quad ......(14)$$

Monte Carlo scheme used to compute the probability distribution for a factor of safety with normal probability density distribution functions, which is commonly used for probabilistic studies on geotechnical engineering. The number of required Monte Carlo trials is dependent on the desired level of confidence in the solution, as well as the number of variables being considered. Statistically, the following equation can be developed:[10][13]

$$N_{mc} = \left[\frac{d^2}{4\,(1-\varepsilon)^2}\right]^m \quad ......(15)$$

Where:

N_{mc} = number of Monte Carlo trials,
ε = the desired level of confidence (0 to 100%) expressed in decimal form,
d = the normal standard deviate corresponding to the level of confidence, and
m = number of variables.

The number of Monte Carlo trials increases geometrically with the level of confidence and the number of variables.

Problem Description and Studied Area

The studied area represented a natural slope located at Hay-AL-Araby, Mosul - Iraq between latitudes (36°24'57.42") N and longitudes (43° 6'45.18") E, as illustrated in Figure (1). The total area of the slope is 56,196,35 m^2, and the circumference is 1,010,05 m, with maximum 33 m in height and 215 m distance. This section represents a critical failure section due to its height and it's extend. Table (1) shows some of the indices and mechanical properties of soil, using the relevant tests based on the ASTM standard.

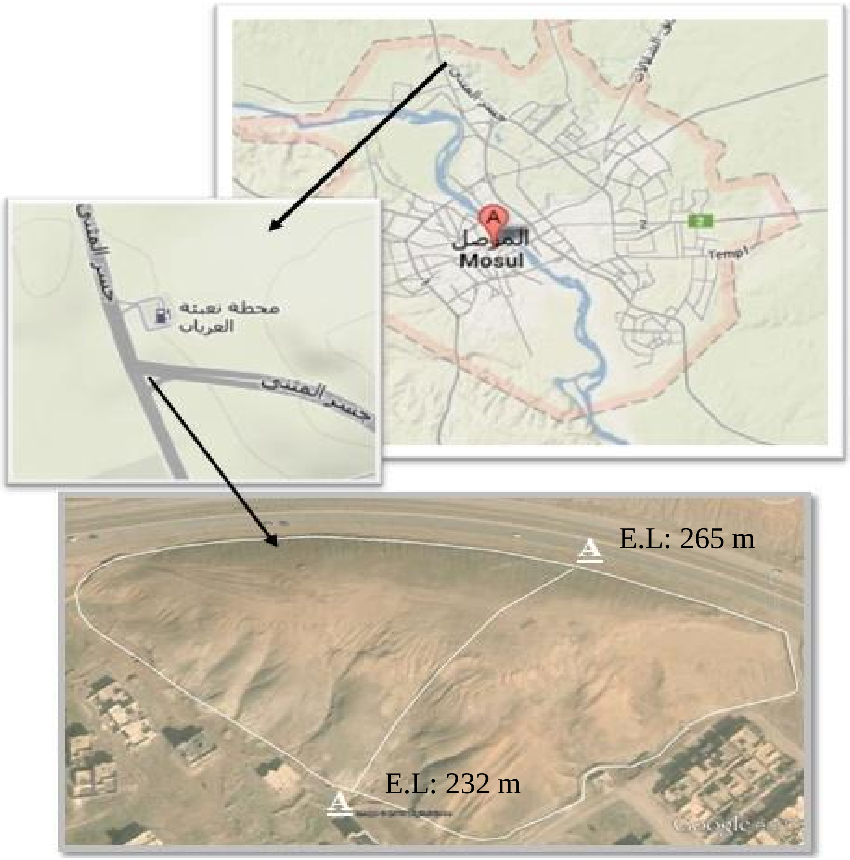

Figure. (1): Location of the studied area

Table (1): Physical and mechanical properties of slope soil

Description	Value
Liquid Limit (LL)	54 %
Plastic Limit (PL)	27 %
Plasticity Index (PI)	37 %
Unit Weight (γ)	15.3 kN/m^3
Specific gravity (Gs)	2.69
Cohesion (c') from direct shear test	58
Angle of friction (ϕ') from direct shear test	19 ^{o}
Unified Soil Classification System (USCS)	CH

Based on the index properties of the soil, and according to the Holtz and Gibbs (1956), and Chen (1975) classification, the soil can be classified as: a highly expansive soil.[14],[15] Expansive soils can induce damage to structures founded on them as: they exhibit volumetric changes with moisture content change. The damages in engineering structures range from minor cracking of pavements or interior finish deterioration in buildings to irreparable displacements of footings and Superstructure elements (Al-Shamrani and Dhowian, 2003) [16]. Thus, these soils can cause heavy economic losses, as well as being a source of risk to the population.

Table (2): Soil Expansively Prediction due to Index Properties [14],[15]

Degree of Expansion	**Classification based on liquid limit (%)**	**Classification based on plasticity index (%)**	
	Chen (1975)	Holtz and Gibbs (1956)	Chen (1975)
Low	< 30	< 20	0-15
Medium	30-40	12-34	10-35
High	40-60	23-45	20-55
Very High	> 60	> 32	> 35

For seismic analysis, the peak horizontal acceleration of seismic was taken as 0.15g as recommended by Cristiano and Sunil (2004) [17], while the effect of the vertical acceleration was neglected. The study involved eight working analysis conditions: natural dry slope, natural wet slope, natural dry slope with seismic, natural wet slope with seismic, remedial dry slope, remedial wet slap, remedial dry slope with seismic, remedial wet slope with seismic.

Remedial selected methods are:

1. Chang the geometry of the slope by removing part of slopes soil (cut).
2. Soil nails (N).
3. Ground anchors (A).
4. Geo-synthetics fabric (F).
5. Piles (P).

An anchor in Slope/W is reinforcement that consists of a bar that has a free length and abounded length, assumed to be tensioned or very rigid relative to the soil and the load is assumed to be active immediately. Nails and fabric be have similar to anchors, except that the bond length is equal to the reinforcement length, while pile is only provides shear resistance.

Coulomb sliding wedge method used to determine the magnitude of the total tensile strength (T_{max}) formed in all reinforcement amount used in the slope. All reinforcement's type lay every 1.75 m with 1.5 as bar factor of safety. Bar capacity and bond resistance used equal to 200 kN and 150 kPa respectively for anchors, nails, and fabric, while shear force used equal to 200 kN for pile. The slope was prepared in order to construct residential buildings as shown in Figure (2)

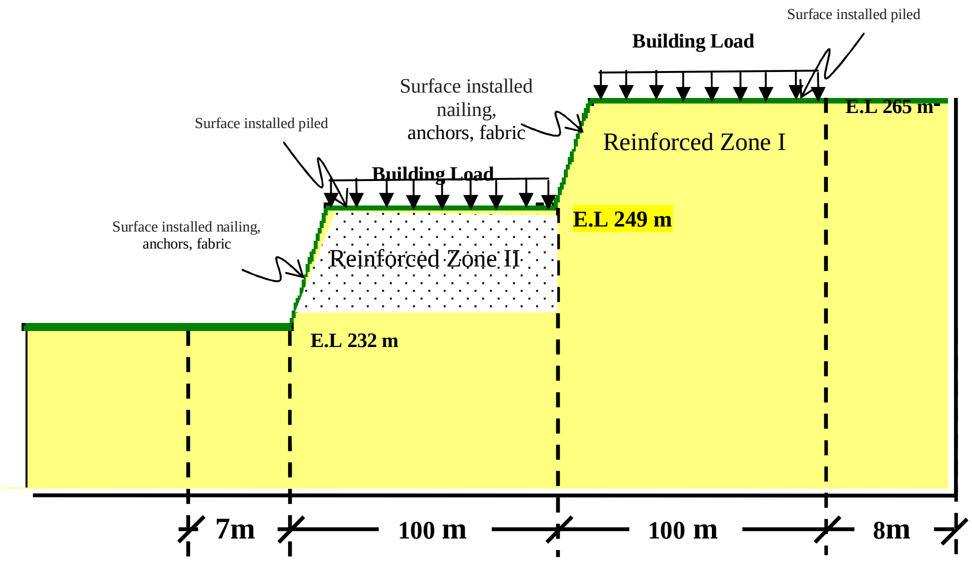

Figure. (2): Schematic Diagram of Suggested Geometry Slope

Results and Discussion

The stability of the slope in natural and remedial condition due to construction of residential building, with the possibility of increasing the number of floors for this building was studied. The initial applied load is 70 kN/m^2, followed by a regular rate of increase by 20 kN/m^2 till reaching a critical situation before the slope failure. This procedure was adopted to investigate the effect of increasing applied loads on the stability of slopes. The investigation showed that the values of applied load on the natural slope for residential building to achieve the minimum value of the factor is 110 kN/m^2 for the dry condition, and 30 kN/m^2 for wet conditions. So the slope should not carry more than these values in two cases, and this can be seen in figure (3).

The stability states of the natural slope in both dry and wet conditions with suggested remedial methods, and applied load were analyzed. Tables (3) and (4) summarizes the results of the minimum FOS for dry and wet conditions, respectively. The minimum factors of safety of natural slope varied between (3.348-3.68) and (1.838-2.326) for dry and wet conditions respectively for the used analyses methods (Morganstern-Price, Bishop, Janbu, and Ordinary). It is noted that there is a little difference in the values of the FOS between the selected methods (Morganstern-Price, Bishop, Janbu, and Ordinary) in the analysis. Noted that the Morganstern-Price and Bishop methods give the most closer values. This could be explained as, the Morgenstern-Price and Bishop methods satisfies moment equilibrium, while Janbu and Ordinary methods satisfy only equilibrium force, so this may give over or underestimations, but anyhow it is considered to be one of the easiest way using the traditional hand calculations.

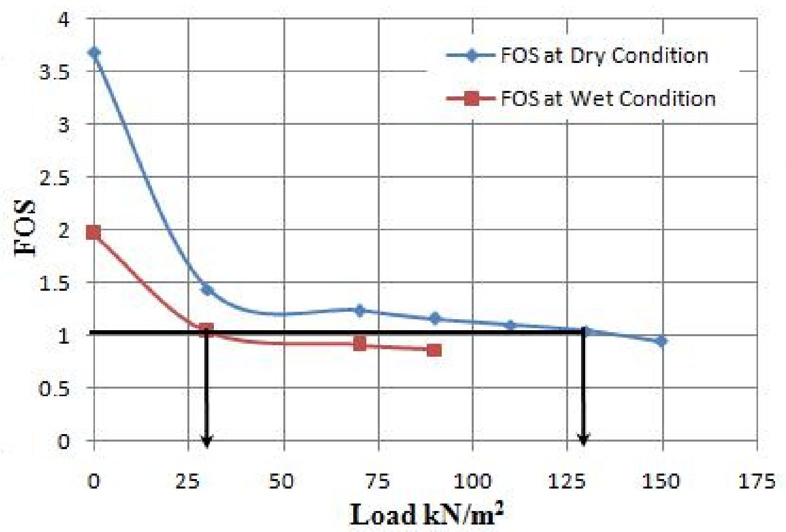

Figure. (3): relation between minimum FOS with the applied load

Tables (3) and (4) show also that the FOS values for the slope increase by the changing the slope geometry (supposed to be one of the remedial causes) as shown in figure (4). The values of FOS are in the ranges of (3.812-4.217) for the dry case and (2.095- 2.52) for wet. It`s worth noting that, the new geometry suggested by the building owner shown in figure (2) represents the actual state of slope, so it is considered as the initial case for the parametric study.

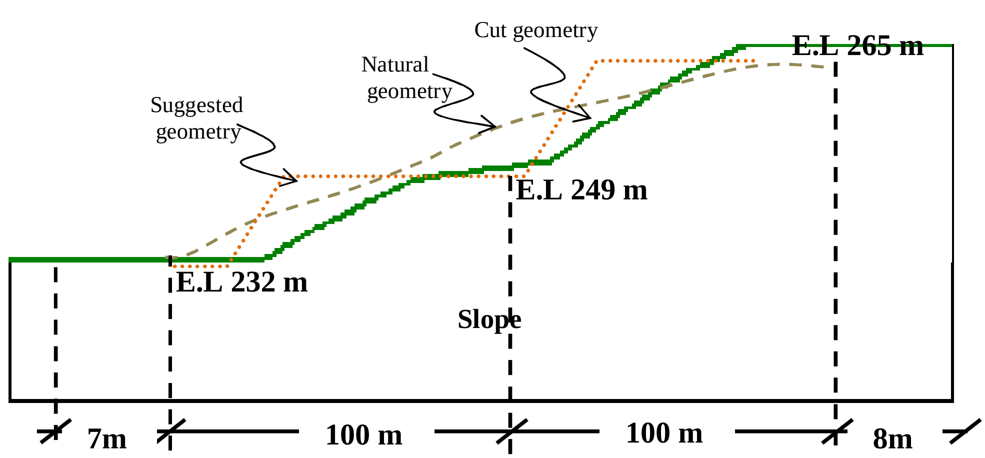

Figure. (4): Schematic Diagram of Natural, Cut, Suggested geometries

Table (3) Minimum Factor of Safety in Dry Condition

Method / Slope state	Morganstern-Price	Ordinary	Bishop	Janbu
Natural	3.678	3.438	3.680	3.348
Cut*	4.216	3.919	4.217	3.812
Load 70**	1.242	1.237	1.243	1.233
Load 110**	1.105	1.098	1.106	1.088
A* + Load 70**	1.810	1.814	1.809	1.824
A + Load 190**	1.182	1.176	1.184	1.169
F* + Load 70**	1.668	1.690	1.660	1.662
F +Load 210**	1.179	1.178	1.181	1.164
N* + Load 70**	2.554	2.541	2.556	2.509
N +Load 410**	1.106	1.084	1.111	1.065
P* + Load 70**	1.852	1.860	1.803	1.862
P + Load 210**	1.160	1.151	1.163	1.141

Load unit kN/m^2.

Chang the geometry of the slope by removing part of slopes soil (cut), Soil nails (N), Ground anchors (A), Geo-synthetics fabric (F), Piles (P).

Table (4) Minimum Factor of Safety in Wet Condition

Method / Slope state	Morganstern-Price	Ordinary	Bishop	Janbu
Natural	1.967	1.887	2.326	1.838
Cut	2.520	2.095	2.518	2.254
Load 70	0.916	0.913	0.916	0.915
Load 30	1.041	1.042	1.040	1.044
A + Load 70	1.453	1.456	1.452	1.468
A + Load 130	1.180	1.176	1.180	1.175
F + Load 70	1.370	1.386	1.369	1.376
F +Load 150	1.123	1.120	1.125	1.118
N + Load 70	1.507	1.51	1.505	1.520
N + Load 150	1.132	1.127	1.132	1.126
P + Load 70	1.748	1.750	1.748	1.757
P + Load 170	1.134	1.126	1.137	1.117

Four remedial methods were suggested to increase the stability of slope to carry the loads of suggested residential building. The bearing of the slope reaches 190 kN/m^2 when using anchor, 210 kN/m^2 when using fabric, 410 kN/m^2, 210 kN/m^2 when using nailing and pile respectively with the minimum FOS as illustrated in table (3) for dry condition. The bearing of the slope in wet case, in general was less than dry case and reached to 130 kN/m^2, 150 kN/m^2, 150 kN/m^2 and 170 kN/m^2 when using anchor, fabric, nailing, and for pile respectively as referred in table (4).

It can be seen from the results that the treatment using nail method was effective in the case of dry soil, although the other methods give a good result in the enhancement of the FOS values. While the treatment using piles gives a highest value of the safety factor in the wet case. The selection of suitable remedial method mainly governed by the site condition, implementation possibility, and economy bases.

Finally, the effect of seismic condition on the slope stability state studied considering dry and wet conditions for both natural and remedial slopes. The obtained values of minimum FOS have shown in the tables (5) and (6). Generally the value FOS of the slope reduces when the slope subjected to seismic load. Also, the minimum FOS in natural loaded case was less than that for the remedial conditions. Consequently, seismic stresses produce a real risk for both dry and wet loaded conditions for the natural slope.

Table (5) Minimum Factor of Safety in Dry Condition with Seismic Effects

Method / Slope state	Morganstern-Price	Ordinary	Bishop	Janbu
Natural + s*	2.033	1.887	2.030	1.826
Cut+ s	2.223	2.023	2.219	1.973
Load 70 + s	1.088	1.083	1.089	1.071
Load 110 + s	0.984	0.977	0.986	0.966
A + Load 70 + s	1.477	1.481	1.478	1.470
A + Load 190 + s	1.062	1.056	1.064	1.042
F + Load 70+ s	1.447	1.466	1.448	1.438
F +Load 210 + s	1.084	1.076	1.086	1.068
N + Load 70+ s	1.800	1.753	1.838	1.714
N + Load 410 + s	1.019	0.999	1.023	0.981
P + Load 70 + s	1.695	1.697	1.696	1.686
P + Load 210 + s	1.040	1.032	1.042	1.014

seismic condition

Table (6) Minimum Factor of Safety in Wet Condition with Seismic Effects

Method / Slope state	Morganstern-Price	Ordinary	Bishop	Janbu
Natural + s	1.194	1.006	1.184	1.056
Cut + s	1.286	1.062	1.276	1.143
Load 30 + s	0.880	0.879	0.880	0.875
Load 70 + s	0.795	0.791	0.795	0.786
A + Load 70 + s	1.176	1.181	1.178	1.170
A + Load 130 + s	1.011	1.010	1.013	1.001
F + Load 70 + s	1.179	1.180	1.180	1.173
F +Load 150 + s	1.010	1.000	1.011	0.999
N + Load 70 + s	1.232	1.234	1.232	1.228
N + Load 150 + s	0.982	0.977	0.982	0.969
P + Load 70 + s	1.409	1.410	1.410	1.401
P + Load 170 + s	0.991	0.982	0.993	0.967

The results of deterministic and probabilistic slope stability analysis of natural and remedial slope presented in table (7), and table (8). Probabilistic and reliability indices studied for both dry and wet conditions for the remedial suggested method using Morganstern-Price for determining the values of minimum

FOS. The results indicated nearly that the probability of failure decrease whiles the reliability index increases.

Table (7) Minimum Factor of Safety for Probabilistic Studied in Dry Condition

Slope state	F.O.S	Mean F of S	Reliability Index	P (Failure) %	Standard Dev.
Natural	3.678	3.702	8.024	0.000	0.337
Cut	4.216	4.253	8.443	0.000	0.385
Load 70	1.242	1.248	2.587	0.160	0.096
Load 110	1.105	1.108	1.446	6.540	0.075
A + Load 70	1.810	1.828	4.140	0.000	0.200
A + Load 190	1.182	1.186	2.123	1.200	0.088
F + Load 70	1.661	1.668	5.405	0.000	0.124
F +Load 210	1.179	1.180	2.776	0.180	0.065
N + Load 70	2.554	2.594	4.508	0.000	0.354
N + Load 410	1.106	1.107	1.428	7.200	0.075
P + Load 70	1.852	1.884	3.546	0.000	0.249
P + Load 210	1.160	1.163	1.922	2.020	0.085

Table (8) Minimum Factor of Safety for Probabilistic Studied in wet Condition

Slope state	F.O.S	Mean F of S	Reliability Index	P (Failure) %	Standard Dev.
Natural	1.967	1.965	8.057	0.081	0.120
Cut	2.520	2.518	9.688	0.000	0.157
Load 70	0.916	0.919	-1.385	92.06	0.058
Load 30	1.034	1.047	0.570	29.260	0.083
A + Load 70	1.453	1.465	3.445	0.020	0.135
A + Load 130	1.180	1.184	2.263	0.840	0.081
F + Load 70	1.370	1.375	4.270	0.000	0.088
F +Load 150	1.123	1.125	2.204	1.140	0.057
N + Load 70	1.507	1.494	3.117	0.000	0.159
N + Load 150	1.132	1.136	1.731	3.420	0.079
P + Load 70	1.748	1.780	3.112	0.000	0.251
P + Load 170	1.134	1.140	1.640	3.900	0.085

From the above tables, observed that the natural slope has more reliability index than the remedial slopes. The results also showed that the remedial using nailing loaded with 410 kN/m^3 gives a FOS=1.106 with a reliability index of 1.428 for dry condition, while the FOS for the remedial with pile gives a FOS=1.134, with corresponding reliability index of 1.640 for wet conditions. Consequently, it is concluded that the stability with pile in wet condition and nail in dry condition are more effective than other remedial methods.

CONCLUSIONS

From the calculations of the FOS for the slope by using different numerical methods the following conclusions could be pointed out:

1. The maximum load that can be carried with the slope was 110 kN/m^2 for dry condition, and not more than 30 kN/m^2 for wet conditions without remedial methods.
2. In the case of remedial methods, nailing treatment was effective in dry case for the slope while using piles was shown to be more effective and give a good stability of the slope in wet condition.
3. Considering the seismic stress effect, the loaded slope bearing without remedial methods would be at risk for both wet and dry conditions.
4. Probabilistic and reliability indexes studied for both dry and wet conditions indicated that the probability of failure decrease whiles the reliability index increases, studied give that the stability with pile and nail in wet and dry conditions respectively are more effective than other remedial methods.

REFERENCES

[1] Rouaiguia A., and Dahim M. A., " Numerical Modeling of Slope Stability Analysis ", International Journal of Engineering Science and Innovative Technology (IJESIT), Vol.2, Issue 3, PP 533-542, (2013).

[2] Chen C.S., and Lim C.S., " Some Case Histories of Slope Remedial Works ", 3rd International Conference on Geotechnical Engineering Combined with 9th Yearly Meeting of the Indonesian Society for Geotechnical Engineering Java, Indonesia, (2005).

[3] Abdalla J. A., Attom M., and Hawileh R., " Artificial neural network prediction of factor of safety of slope stability of soils ",14th International Conference on Computing in Civil Engineering, Moscow, Russia, (2012).

[4] Totsev A. , and Jellev J., " Slope stability analysis using conventional methods and FEM ", Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering, Egypt, PP 1503-1505, (2009).

[5] Ghazavi M., Shahmandi A., " Analytical Static Stability Analysis of Slopes Reinforced by Stone Columns ", International Association for Computer Methods & Advances in Geomechanics (IACMAG), PP 3530-3537, (2008).

[6] Ghosh P., Biswas A., "Effect of Reinforcement on stability of Slopes", International Conference on Benchmarks in Engineering Science and Technology ICBEST " Proceedings published by International Journal of Computer Applications® (IJCA), PP 29-32, (2012).

[7] Baghini E. G. , Toufigh M.M., " Reinforced Slope Stability Analysis Using Natural Element Method (NEM) ", International Journal of Computer Applications in Engineering Sciences, VOL II, ISSUE IV, PP410-414, (2012).

[8] Rocscience Inc, Toronto, " Application of the Finite Element Method to Slope Stability", 1-75, (2001-2004).

[9] Chok Y. H., "Modeling the Effects of Soil Variability and Vegetation on the Stability of Natural Slope ", Ph.D. thesis, School of Civil, Environmental, and Mining Engineering, University of Adelaide, (2008).

[10] Geo-Studio User's Guide, "Geo-Studio for Finite Element Analysis", (2007).

[11] Duncan, J. M., and Wright, S. G., "Soil Strength and Slope Stability", John Willey & Sons, Inc., United States, (2005).

[12] Christian, J. T., Ladd, C. C., and Baecher, G. B., " Reliability Applied to Slope Stability Analysis", Journal of Geotechnical Engineering, Vol. 120, No. 12, PP 2180-2207, (1994).

[13] Harr, M. E., " Reliability Based Design in Civil Engineering", Mc Graw-Hill Book Company, PP 290, (1987).

[14] Holtz, W.G. and Gibbs, H.J., " Engineering properties of expansive clays", Transactions of ASCE, Vol.121, PP 641-663, (1956).

[15] Chen, F.H., "Foundation on Expansive Soils", Developments in Geotechnical Engineering, Elsevier Scientific Publication Company, New York, (1975).

[16] Al-Shamrani, M. A. and Dhowian, A. W.,"Experimental Study of Lateral Restraint Effects on the Potential Heave of Expansive Soils" Engineering Geology, Vol. 69, PP. 63-81, (2003).

[17] Cristiano M. and Sunil S., "Seismic Coefficients for Pseudo static Slope Analysis", 13th World Conference on Earthquake Engineering Vancouver, Canada, No. 369, (2004).