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Slope Stability Analysis of Vertical Unsupported Slopes near West Approaches of Al-Alam Bridge

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ABSTRACT

There are vertical slopes on the western banks of Tigris near Al-Alam Bridge in Tikrit, Iraq. These slopes are not supported and are located near an important road at Tikrit University. This study aims to find a safety factor (FOS) of the slope to prevent failure, besides its effect on human and financial losses. The study consists of two parts: the first part studied the layers of the slope and found the soil resistance coefficients. The second part analyzed the stability of the natural slope itself under the impact of the water level change of the Tigris River and the external loading. The analysis was done by a program called (PLAXIS 3D), which depends on the finite element method. The finite element method is a numerical approach that searches for approximate solutions and solves problems by dividing the problem into several triangular elements linked to each other by points called (nodes). The results showed that the vertical slope stability at the natural state with no influences indicated was in a semi-stable state with a factor of safety equal to (1.04865). The factor of safety decreased by (0.423%) with rising the river level until it reached (1.04074) at (93 m a.s.l.). As for the applied external loads condition, the factor of safety for imposed (50,150 and 250 kN/m2) decreased by (4.738%), then the soil body failed when the factor of safety was (0.9902). In the critical state, the soil body failure at this stage and the factor of safety became equal to (0.98769) with decreasing by (5.812%).

تحليل استقرارية المنحدرات العمودية غير المسندة عند المقتربات الغربية لجسر العلم

فاطمة عبدالله كامل خطاب قسم الهندسة المدنية / كلية الهندسة / جامعة تكريت / تكريت - العراق.
فاروق مجيد مهوس قسم الهندسة المدنية / كلية الهندسة / جامعة تكريت / تكريت - العراق.

الخلاصة

تهدف الدراسة إلى إيجاد قيمة معامل الأمان (FOS) لتحديد استقرار المنحدر من اجل منع الانهيار وما يترتب عليه من خسائر بشرية ومادية، المنحدر الواقع على الضفاف الغربية لنهر دجلة بالقرب من جسر العلم. تتكون الدراسة من جزئين: الأول عملي ويتضمن دراسة طبقات المنحدر قيد الدراسة وإيجاد معاملات مقاومة التربة عن طريق إجراء تجارب مختبرية على عينات تربة مأخوذة من الموقع. الجزء الثاني يدرس استقرار وثبات المنحدر الطبيعي نفسه وتأثير العديد من المتغيرات التي تؤثر على (FOS) باستخدام برنامج يسمى (PLAXIS 3D). المتغيرات التي تمت دراستها مثل التغير في منسوب مياه نهر دجلة، والاحمال الخارجية. أظهرت النتائج أن ثبات القطع العمودي في الحالة الطبيعية مع عدم وجود تأثيرات خارجية تشير إلى أنه في حالة شبه مستقرة مع معامل أمان يساوي (1.04865). انخفض معامل الأمان هذا بنسبة (0.423٪) مع ارتفاع منسوب النهر حتى وصل إلى (1.04074) عند (93 م فوق مستوى سطح البحر). أما بالنسبة لتغير حالة الأحمال الخارجية فعند فرض (50 كيلو نيوتن / م2) اعلى القطع العمودي أصبح معامل الأمان يساوي (1.04804). عندما يصل الحمل إلى (250 كيلو نيوتن / م2) كان القطع العمودي غير آمن وبنسبة تناقص (4.738٪)، عندها ينهار جسم التربة عند معامل امان يساوي (0.9902). أما بالنسبة للحالة الحرجة، فإن معامل الأمان يساوي (0.98769) حيث ينهار جسم التربة في هذه المرحلة وبإنخفاض (5.812٪) في معامل الأمان.

الكلمات الدالة: استقرارية المنحدرات، المنحدرات العمودية، نهر دجلة، معامل الامان، العناصر المحددة، استقرار المنحدر.

1.INTRODUCTION

In civil engineering, slope stability analysis is extremely important. It is employed in the construction of highways, railroads, airports, and canals; in the development of natural resources such as surface mining and earth dams; and in many other human activities, including building construction and excavation [1]. A slope failure can result in the loss of human lives and property. A safe and economical slope design is now available due to the development of current soil testing and stability analysis techniques. So as geotechnical engineers have developed a variety of slope stability analysis methods to detect and avoid slope failure during the last few decades, such as (limit equilibrium methods, finite element method, rockfall simulation, and stereo net analysis) [2, 3]. On another side, the crucial factors that cause instability in a slope and lead to failure are erosion, rainfall, gravitational force, earthquakes, external loading, and rapid drawdown [4, 5]. There are many dangerous vertical unsupported slopes on the west bank of the Tigris River Fig. 1. These slopes are exposed to erosion by weather factors, as well as the presence of some cracks, cavities, and river water. These reasons previously led to some collapses and slips near the study area. The vertical slopes lie near an important road at Tikrit university, and many people may be exposed to danger from sudden slope failure when using this road. Since there is no study examining the stability of these slopes, this paper aims to study the stability of the slope and find the FOS in the natural condition, the river flood condition, and the applied external loads. The reason behind choosing these situations is that many previous studies have shown the extent of these situations' impact on slope stability. For example, the study conducted by (Rouaiguia and Dahim) [6] on a slope showed the effect of changing the shear parameters values, saturated unit weight, and pore water pressure of the upper layer of a slope consisting of two layers with different properties, the values of (c, ϕ, γ, and W.T.) were alternately increased for the upper layer with fixed lower layer properties. It was found that the relationship between the shear parameters and the saturated unit weight with the factor of safety was semi-linear, and its value increased with the shear parameters values, while its value decreased with the rise in the water level as well as the saturated unit weight.

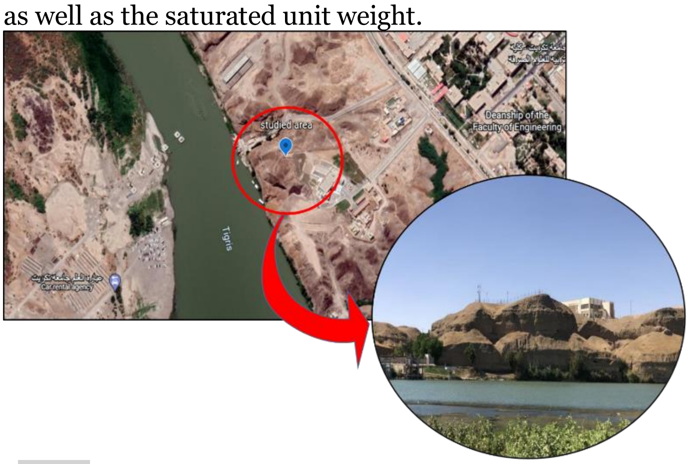

Fig. 1 Study site in Tikrit University (Google map).

As for the river level effect, a study was performed by [7], who analyzed the stability of a slope with clay soil using the finite element method (FEM), where the effect of the water height adjacent to the slope and the effect of its infiltration into the slope on accelerating the failure of the slope were. It was concluded that the water imposed an additional load on the slope, which in turn accelerated the slippage of the soil. The infiltration of water into the slope and its movement led to erosion and soft soil erosion, as the fine material in the soil was considered a cementitious substance that strengthens the cohesion of the soil, and its erosion weakens its strength. Another study on the river level effect in southwest China, specifically in the deposit slope on the left bank of the Gushui Reservoir was conducted by (Meng et al.) [8]. The stability of the slope was calculated, and the variance of the FOS under the influence of different reservoir water levels was analyzed. The combined FEM-LEM method was used in the analysis. The results indicated that the overall safety factor for failure falls under the fast impoundment and rapid drawdown conditions. The minimum safety factor occurred in the rapid drawdown condition. When the water level of the reservoir rose, the most dangerous slip surface had a safety factor of (1.073), which means a small overflow. The study also showed that the proposed combined FEM-LEM method reflected the mechanism of the effect of the water level on the stability of the slope, taking into account the pore pressure, the seepage force, and the change of strength parameters. As for the external loads' effect, (Feng et al.)[9] took a municipal road as a case study and adopted the strength reduction method. The finite element method was used to calculate the stability of the slope. The uniform distributed load of (150kN/m) was applied on the slope top of the original model. The results of the analysis showed that when the loading was applied from the top of the slope, the safety factor decreased by (16%~21%). The study showed that the maximum shear strain of the slope was significantly affected by the top loading of the slope, and the effect of the slope loading on the maximum horizontal displacement of the slope was insignificant. (Chen et al.)[10] analyzed an artificial slope with homogeneous soil by changing the shear strength parameters' values and changing the external loads on the top of the slope using software (FLAC3D). The loads were (0kPa, 2kPa, 20kPa, and 200kPa) and internal friction angles of (17°, 27°, 37°, and 47°). The results showed that in the case of the slope without loading on the upper surface, the factor of safety was (1.1052) at the angle of internal friction of (17°), and the factor of safety was (2.1818) at the angle of internal friction of (47°). As the value of the external loads' increased, the factor of safety gradually decreased until it reached (0.7583) at the angle of internal friction of (17°) at a load of (200.0kPa). In contrast, the factor of safety was (1.6647) at the angle of internal friction of (47). A comparative study between the methods of the analysis showed that the 3D method and strength reduction method (SSR) agreed well for normal situations, and the factors of safety obtained by the SSR were slightly higher than those from the LEM, which was similar to the corresponding 2D analysis [11].

2. EXPERIMENTAL PROGRAM

2.1. *Site description*

This paper deals with the slopes located on the western side of the Tigris River banks near the Al-Alam Bridge in Salahaldin Governorate in Iraq at (Latitude= 34.6798°), (Longitude= 43.6641°) and (Altitude= 91.3368m a.s.l.). The portion of these slopes was taken with length (150 m) and width (100 m) for stability analysis study. The elevations and topography of the studied area were obtained from the GIS program*. Fig. 2 represents the side view of the vertical slope.

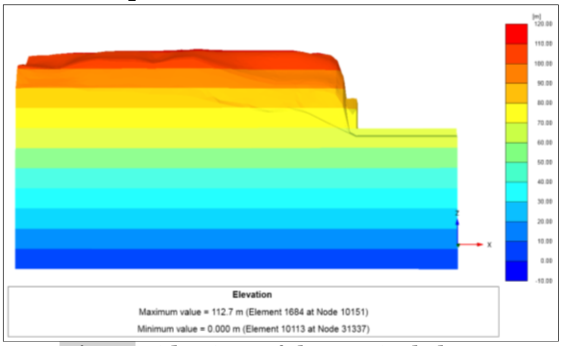

Fig. 2 Side view of the vertical slope.

2.2. *Laboratory Tests*

After visiting the site and conducting preliminary investigations, it was found that the slope is composed mostly of soil (Poorly graded gravel with sand) interspersed with layers of a thickness (0.7 m) of soil (Poorly graded sand). Laboratory tests carried out on samples taken from the studied area were:

1. Moisture Content and Field Density. (ASTM D2216).
2. Specific Gravity Test. (ASTM D 854, 2014).
3. Grain Size Distribution Test. (ASTM D422, 2007).
4. Liquid and Plastic Limit Tests. (ASTM D4318, 2017).
5. Direct Shear Test. (ASTM D3080, 2011).

The necessary parameters for the study were obtained through previous tests and information available in some references. Two types of soil samples are taken to represent the necessary parameters in the program, as shown

* A geographic information system (GIS) is a database containing geographic data and descriptions of phenomena for location.

in Table 1. Fig. 3 represents the location and depth of the samples.

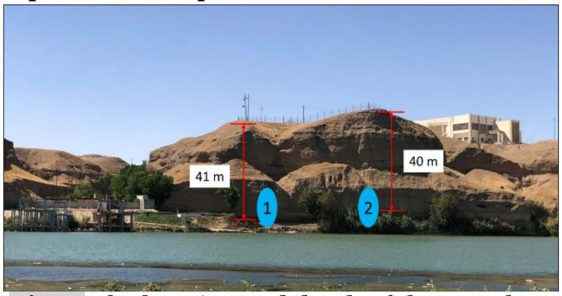

Fig. 3 The location and depth of the samples.

Table 1 Summary of Laboratory Tests results

Properties		Soil 1	Soil 2	Reference
Specific gravity		2.7	2.66	Lab. Test
Atterberg limits	Liquid limit (LL)%	-	25.73	Lab. Test
	Plastic limit (PL)%	-	3.15	Lab. Test
Coefficient of uniformity (C_u)		11.45	7.07	Lab. Test
Coefficient of curvature (C_c)		4.28	0.71	Lab. Test
Unified Soil Classification		GP	SP-SC	USCS
Field unit weight (γ_f) kN/m³		19.61	15.21	Lab. Test
Dry density (γ_d) kN/m³		17.46	15	Calculations
Saturated density (γ_{sat}) kN/m³		20.85	18.69	Calculations
Cohesion (kPa)		36	46	Lab. Test
Cohesion after soaking (c) (kPa)		-	20	Lab. Test
Friction angle (ϕ) (degree)		41°	28°	[12] / Lab. Test
Friction angle after soaking (ϕ) (degree)		34°	10.90°	Lab. Test
Void ratio (*e*)		0.51	0.59	Calculations
Poisson's ratio (μ)		0.25	0.375	[12]
Modulus of elasticity (E) (MN/m²)		120	45	[12]
Permeability (k) (m/s)		4×10^{-4}	4×10^{-5}	[13]

2.3.Finite Element Procedure

The finite element method in soil mechanics is a complex and difficult multi-geometric. It results from the great change in the properties of the soil and the assumptions of extensive loading and computer programs. This method can be summarized by dividing the problem into several elements, either triangular or quadrilateral, linked to each other by points called (nodes). The finite element method is used to solve two- and three-dimensional problems. PLAXIS 3D program has been used to analyze the vertical slopes. It is a full-featured 3D geotechnical finite element program. The use of the FEM method in PLAXIS 3D requires no prior assumptions regarding the shape or location of the failure surface, and this is the reason behind choosing PLAXIS 3D. Failure naturally occurs through areas within the soil mass where the soil shear strength is unable to withstand the applied shear stresses. Since there are no slices in this way, assumptions about the lateral forces of the slice are unnecessary. FEM maintains global equilibrium until failure is reached. The FEM is capable of monitoring progressive failure, including total shear failure [14, 15]. The simple graphical input procedures enable a quick generation of complex finite element models, and the enhanced output facilities provide a detailed presentation of computational results. The calculation itself is fully automated and based on numerical procedures. PLAXIS 3D consists of five separate interfaces used sequentially to represent the problem and perform the required calculations, as follows, **Soil:** In order to define the underlying properties of the soils that form all the layers of the problem, the properties were entered through (Add) command in (Material set) in the soil interface. **Structure:** In this interface, the geometry of the studied problem was formed. The terrain data was taken by satellite visualization and geographical programs (GIS and Surfer), then drawn using the (AutoCAD 3D) program, and after that, exported to PLAXIS 3D. **Mesh:** Since the analysis depends on the finite element method, it is natural that there is a stage in which the distribution of the finite element mesh is chosen (medium distribution was adopted in this study). PLAXIS 3D program relies on the triangular element in dividing the problem. The advantage of using triangular elements is the ability to develop meshing algorithms that can fast and easily mesh any irregular domain with triangular elements Fig.4.

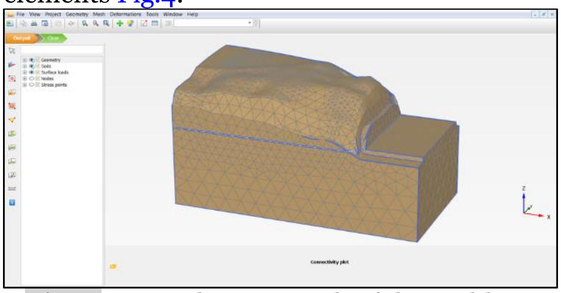

Fig. 4 Finite element Mesh of the problem.

Water level: At this stage, the river water level was represented in three phases, the first being the lowest previously recorded river level (83.55m a.s.l.)[†](as low level), the second being the highest previously recorded level (90.245m a.s.l.) (as medium level), and the third being a critical condition with a higher level than the previous ones (93m a.s.l.) (as high level). **Staged Construction:** At this stage, the studied phases were separately built, starting with the initial phase (Gravity Calculations), and the rest of the phases were built on this basis as the Initial phase, External loads phase, River level phase, and Critical phase. Three types of calculations [16] were used in the

[†] Data were obtained from the Water Resources Department in Salah al-Din.

previous phases to calculate the stability of the slope due to gravity, and then to calculate the factor of safety and the deformation occurring in the slope, and calculations were then started. **(1) Gravity loading Calculations:** Gravity loading is a type of Plastic calculation in which initial stresses are generated based on the volumetric weight of the soil. If Gravity loading were adopted, then the initial stresses would be set up by applying the soil self-weight in the first calculation phase. **(2) Safety Calculations:** The Safety calculation type is an option available in PLAXIS to compute global safety factors. This option can be selected as a separate Calculation type in the General tab sheet. The safety analysis was performed by reducing the soil and interface strength parameters until a target value of the total multiplier ΣMsf was reached. The program first tried to find a safe value (Phase ΣMsf), then recalculated the last step before passing the target and performed the last step to reach the target. The total multiplier ΣMsf is used to define the value of the soil strength parameters at a given stage in the analysis:

$$\Sigma \text{Msf} = \frac{\tan \phi_{input}}{\tan \phi_{reduced}} = \frac{c_{input}}{c_{reduced}} = \frac{S_{u,input}}{S_{u,reduced}}$$

The factor of safety is given by:

$$\text{FOS} = \frac{Available\ strength}{strength\ at\ failure} = \text{Value of } \Sigma\text{Msf at failure}$$

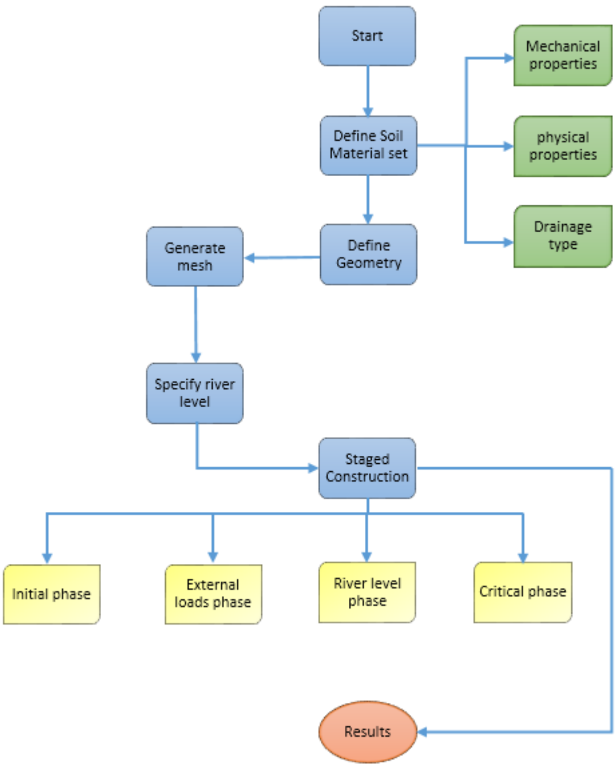

Fig. 5 Flow chart of the Programing.

(3) Plastic calculation: A Plastic calculation is used to carry out an elastic-plastic deformation analysis in which it is unnecessary to take the change of pore pressure with time into account. If the Updated mesh parameter had not been selected, the calculation was performed according to the small deformation theory. The stiffness matrix in a normal plastic calculation was based on the original un-deformed geometry. This type of calculation is appropriate in most practical geotechnical applications. A plastic calculation don't take time effects into account. Considering the quick loading of saturated clay-type soils, a Plastic calculation performing a fully drained analysis can assess the settlements in the long term, which gives a reasonably accurate prediction of the final situation. Fig.5 represents the flowchart of the site modeling process in (Plaxis 3D) and the representation and analysis of loading states.

3.RESULTS AND DISCUSSIONS

After conducting laboratory experiments for samples taken from the vertical slope and modeling the soil layers and the rest of the parameters in (PLAXIS 3D), the most significant results found are reported below.

3.1.Overall Vertical Slope Stability Analysis (natural condition)

The vertical slope was studied in its natural condition, in which the river level was low (83.55m a.s.l.) and with no external loads. The results of the natural condition analysis showed that the vertical slope was in a semi-stable state, as the factor of safety found was (1.04865). The maximum total displacement obtained from the plastic calculations was (1.00533 m). The highest deformation due to gravity calculations was (1.005 m) Fig. 6. The failure mechanism of the initial phase was indicated by incremental displacement results Fig. 7, where Fig. 8 shows the slip surfaces.

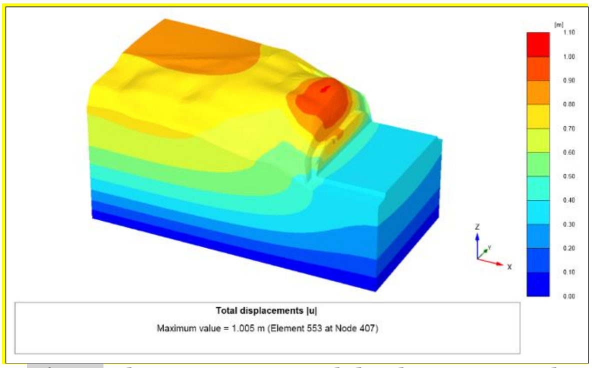

Fig. 6 The maximum total displacement in the initial phase.

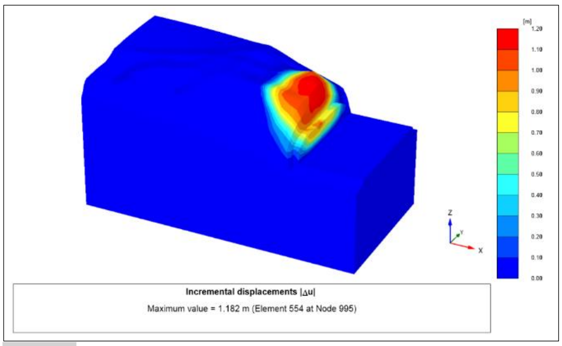

Fig. 7 Plot of failure mechanism of the natural phase.

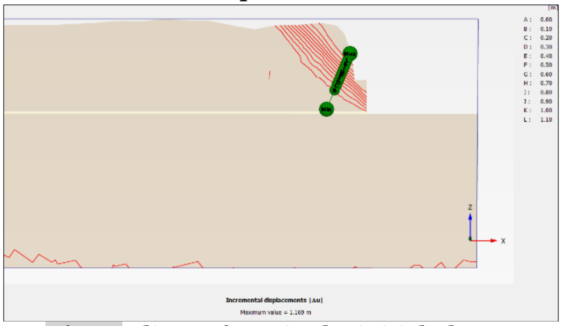

Fig. 8 Slip surfaces in the initial phase.

3.2. Effect of Changing in Water Level of the River

For the phase change analysis of the river level, the vertical slope was studied at three different river levels (83.55m, 90.245m, and 93m a.s.l.) with no external loads. The factor of safety appears in Figs. (9, 10) shows the highest deformation obtained in gravity calculations was (1.029 m). The highest deformation obtained from the plastic calculations was (1.0292 m). Fig. 11 shows slip surfaces in the river level condition to predict where the failure may happen.

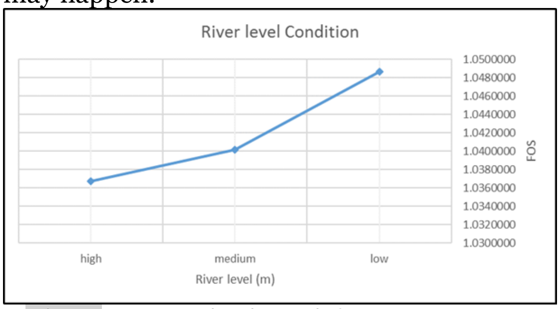

Fig. 9 Factor of safety of changing in water level.

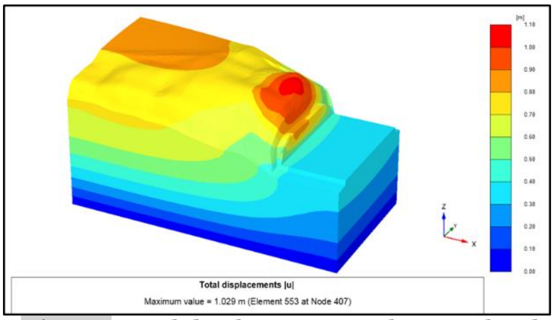

Fig. 10 Total displacement in the river level condition in (gravity calc.).

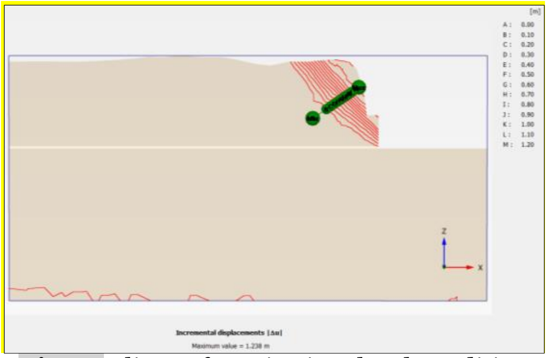

Fig. 11 Slip surfaces in river level condition.

3.3. External Loads Condition

For the external load condition analysis, the vertical slope was studied assuming external loads represented by a rectangular foundation (5m x 10m) and at a distance of (5m) from the edge of the vertical slope, where three different loads were exposed (50kN/m2, 150kN/m2 and 250kN/m2). The factor of safety is shown in Fig. 12. It is clear that the vertical slope was unsafe when the load reached (150 kN/m2), while the soil body collapsed when the load reached (250 kN/m2). Fig. 13 shows that the highest deformation obtained in gravity calculations was (1.15 m). Fig. 14 shows slip surfaces in external loads condition to predict where the failure may happen.

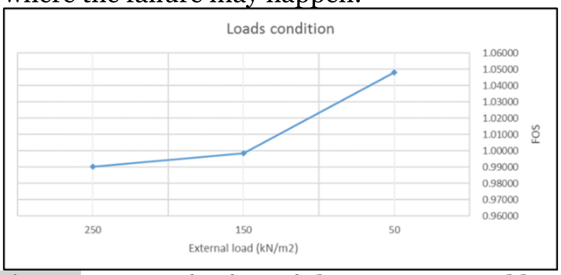

Fig. 12 Factor of safety of changing external load.

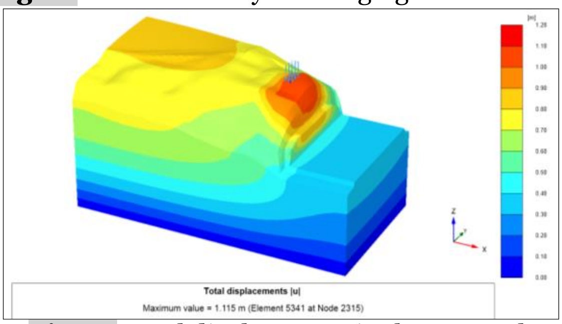

Fig. 13 Total displacement in the external Loads condition in (gravity calc.).

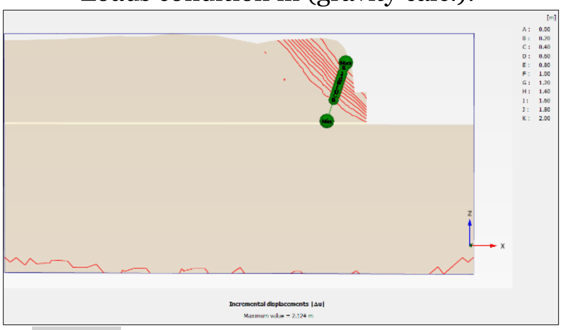

Fig. 14 Slip surfaces in the external loads condition.

3.4.River Level Change with Loads Condition

In this condition, the study was carried out by changing the river level (low, medium, and high level) with (50 kN/m2, 150 kN/m2, and 250 kN/m2) cases of external loads, as shown in Table 2 and Fig. 15. The results of the river level change with loads condition analysis showed that the vertical slope was in a semi-stable state when the load was (50 kN/m2). The vertical slope was unsafe when the load reached (150 kN/m2) at any level of the river, while the soil body collapsed when the load reached (250 kN/m2). Fig.16 shows that the maximum total displacement obtained from gravity calculations was (1.114 m). The maximum total displacement obtained from the plastic calculations was (1.1273 m). Fig. 17 shows the slip surfaces in river level change with the loads condition to predict where the failure may happen.

Table. 2 Factor of safety of river level change with load.

Loads (kN/m²)	water level	FOS
50	low	1.04804
50	medium	1.04204
50	high	1.03912
150	low	0.99837
150	medium	0.99603
150	high	0.99288
250	low	0.99028
250	medium	0.98388
250	high	0.98090

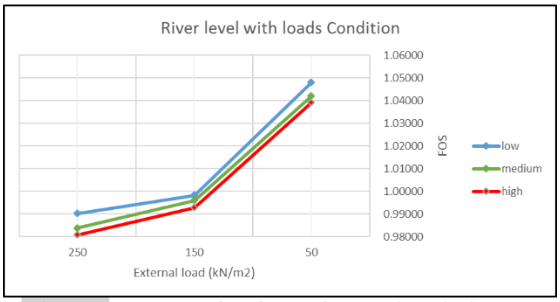

Fig. 15 Factor of safety of river level change with load.

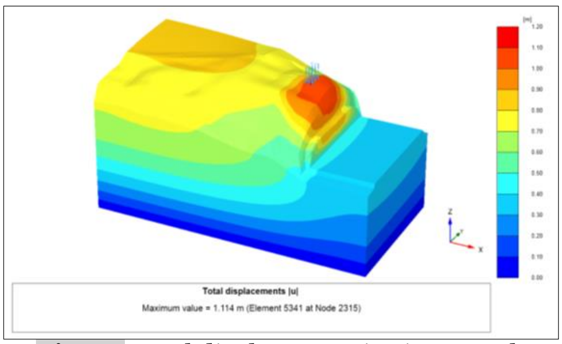

Fig. 16 Total displacement in river Level Change with Loads Condition in (gravity calc.).

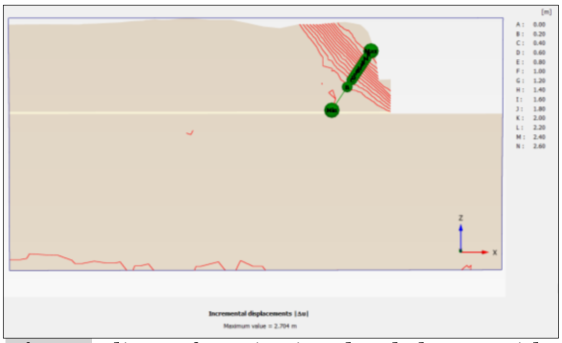

Fig. 17 Slip surfaces in river level change with loads condition.

3.5.Critical Condition

The vertical slope was subjected to the highest external load (250kN/m2) and with the river rising to its highest level (93m a.s.l.). The results of the critical condition analysis showed that the vertical slope was in an unstable state, and the soil body collapsed in the plastic calculations stage. Also, it was found that the factor of safety was (0.9809). Fig. 18 shows the maximum total displacement obtained from gravity calculations was (1.109 m). The maximum total displacement obtained from the plastic calculations was (1.11 m). The failure mechanism of the critical phase was indicated by incremental displacement results in safety calculations. Fig. 19 shows slip surfaces in critical condition to predict where the failure may happen.

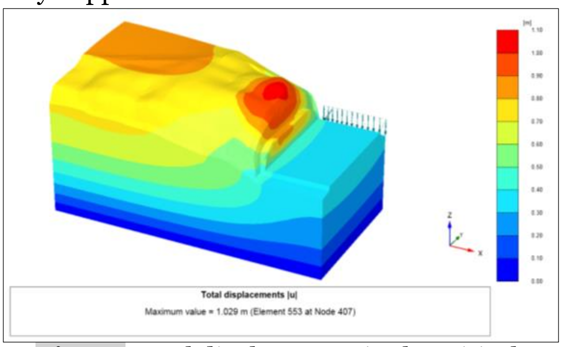

Fig. 18 Total displacement in the critical condition in (gravity calc.).

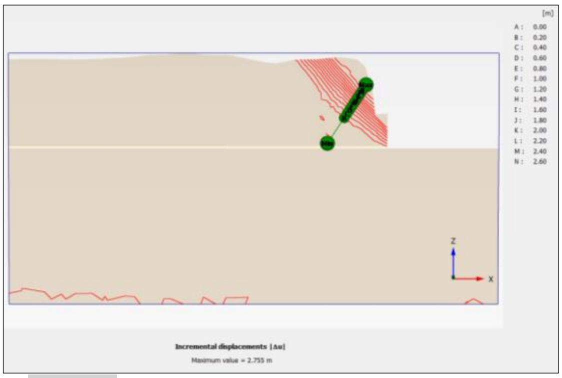

Fig. 19 Slip surfaces in Critical Condition.

4.CONCLUSIONS

According to the objectives of the research, the following conclusions were reached: Site inspection and laboratory tests were performed to examine the soil properties. Generally, gravel soils with sand interspersed with layers of soft, hard sandy soils were found in the study area at the river bank slope. This material was relatively loose and easy to scour due to river flooding. The initial vertical slope stability at a natural state with no influences indicates showed that the vertical slope was in a semi-stable state with a factor of safety of (1.04865). This factor of safety decreased by (0.423%) with rising the river level until it reached (1.04074) at (93 m a.s.l.). As for the change in external load condition, the factor of safety for imposed (50 kN/m2) at (5 m) from the crest became (1.04804). When the load reached (150 kN/m2), the vertical slope was unsafe, with a reduction of (4.738%) in the factor of safety. While the soil body collapsed when the load reached (250 kN/m2) with a factor of safety of (0.9902). An external load imposed by the amount of (250 kN/m2) at (93 m a.s.l.) river level, the vertical slope became in critical condition with a factor of safety of (0.9809). The soil body collapsed at this stage with a reduction of (5.812%) in the factor of safety. As a recommendation, studying and investigating a suitable method for slope reinforcement should be performed, as well as checking the stability of the slopes in the neighboring areas.

REFERENCES

[1] Huang YH. Slope Stability Analysis by the Limit Equilibrium Method: Fundamentals and Methods. 1 ed: ASCE Press; 2014.

[2] Ogeli Z. Analysis of Slope Stability Using Shear Strength Reduction SSR. Aleppo University; 2011.

[3] Arora KR. Soil Mechanics & Foundation Engineering In Si Units. 6 ed: Standard Publishers Distributors; 2004.

[4] Budhu. Soil mechanics and foundations. 3 ed: John Wiley & Sons; 1999.

[5] Murthy V. Principles and practices of soil mechanics and foundation engineering. *New York: Marcek Decker INC* 2002.

[6] Rouaiguia A, Dahim MA. Numerical modeling of slope stability analysis. *International Journal of Engineering Science and Innovative Technology* 2013;**2**(3):533-542.

[7] Johansson J. Impact of water-level variations on slope stability. Luleå tekniska universitet; 2014.

[8] Meng Q, et al. Numerical analysis of slope stability under reservoir water level fluctuations using a FEM-LEM-combined method. *Geofluids* 2020;**2020**.

[9] Feng X, Li M, Ma P, Li Y. Factorial experiment of slope stability under slope-top loading and heavy rainfall. *IOP Conference Series: Earth and Environmental Science*: IOP Publishing; 2019. pp. 032065.

[10] Chen KP, Liu JY, Yuan BX. Environmental safety analysis for slope under the situation with and without load on top surface. *Advanced Materials Research*: Trans Tech Publ; 2012. pp. 2114-2117.

[11] Wei W. Three dimensional slope stability analysis and failure mechanism. 2008.

[12] B. Das, "Fundamentals of Geotechnical Engineering, Thomson," USA, 2005.

[13] Carter M, Bentley SP. Correlations of soil properties: Pentech press publishers; 1991.

[14] BR V, Shivananda P, Swathivarma R, Bhaskar M. Some of Limit Equilibrium Method and Finite Element Method based Software are used in Slope Stability Analysis. *International Journal of Application or Innovation in Engineering & Management (IJAIEM)* 2017;**6**(9):5.

[15] Griffiths D, Lane P. Slope stability analysis by finite elements. *Geotechnique* 1999;**49**(3):387-403.

[16] Plaxis B. PLAXIS 3D 2013 reference manual. *PLAXIS BV, Delft* 2013.