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Investigation of Slope Stability in Gravel Soils in Unsaturated State

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***Abstract*—**In this paper, we consider the stability of a slope of 10 meters in silty gravel soils with modeling in the Geostudio Software. we intend to use the parameters of the volumetric water content and suction dependent permeability and provides relationships and graphs using the parameters obtained from gradation tests and Atterberg's limits. Also, different conditions of the soil will be investigated, including: checking the factor of safety and deformation rates and pore water pressure in drained, non-drained and unsaturated conditions, as well as the effect of reducing the water level on other parameters. For this purpose, it is assumed that the groundwater level is at a depth of 2 meters from the ground. Then, with decreasing water level, the safety factor of slope stability was investigated and it was observed that with decreasing water level, the safety factor increased.

***Keywords*—**Slope stability analysis, factor of safety, matric suction, unsaturated silty gravel soil.

I. INTRODUCTION

GRAVEL soils are the major materials found on natural slopes and are important engineering materials for filling slopes. These soils are often widely graded with large variations in grain size distribution [1]. For gravel soils, water content changes at very low suctions (e.g., smaller than 1 kPa) are significant, and such changes affect the permeability and shear strength of the soils significantly [2]. For example, the suction difference due to different hydrostatic pore water pressures at the top and bottom of a 50 mm height sample is 0.5 kPa. Such a suction difference is unacceptable for measuring a SWCC at very low suctions. An interpretation procedure that can reduce the inaccuracy associated with sample size at very low suctions is needed [2]. Fredlund et al. [3] model can be applied to predict the unsaturated shear strength of tested gravel soils except the case of partial dry ‘‘GC’’ soil. The model overpredicts the unsaturated shear strength of ‘‘GC’’ soil as it does not consider the presence of random disconnected cracks and also due to error in either measuring or in real estimation of high suction values of SWCC at relatively low degrees of saturation [4].

Soil-water characteristic curves (SWCCs) are widely used in geotechnical, geoenvironmental and agricultural engineering. A SWCC relates the gravimetric water content, w, the volumetric water content, θ_w, or the degree of saturation, S_r, to soil suction [5].

A SWCC describing the desaturation process of soil is termed as a drying curve, and a SWCC describing the saturation process of soil is termed as a wetting curve [6]. The measurement of SWCC for gravel soils at low suctions is valuable not only in the evaluation of water storage ability of gravel soils but also in seepage analysis, in which the results are highly dependent on the accuracy of the SWCC and the hydraulic conductivity curve used [2].

Subsequent parametric studies provided a rough guide regarding the influence of matric suction on the stability of a slope [7]-[9] and illustrated that matric suction maintained relatively consistent with time under certain boundary conditions [10].

In this paper, we have tried to observe the variation in the factor of safety in the earth's slop by mentioning a slop sample and applying the parameters of volumetric water content and suction-dependent permeability using the Geostudio software, slope/w. Geostudio software is a finite element based geotechnical program, through which different analyzes can be made. In the following, we will analyze the Geostudio software in modeling a slope stability. The main objective of this paper is to investigate: (1) Perform modeling using software Geostudio 2012 V15 and (2) Investigate results in non-drainage state and unsaturated behavioral model. Several articles have been investigated for this research and how the formation of volumetric water content against matric suction has been investigated and one of these papers [4] has been used as a guide and purpose article for one type of soil, silty gravel soils.

II. PROPERTIES OF STUDIED GRAVEL

In paper [4], the effect of fine particles with low plasticity in compressed gravel soils on their undrained shear strength has been investigated. In the following, five different types of soils with different fine grains have been studied and compared. In this study, we have used this article to use the characteristics of one of the studied soils. Thus, using the Fig. 1 and Table I, the specifications required for matric suction functions are obtained in the software.

III. MODELING USING GEOSTUDIO 2012 V15 SOFTWARE

Fredlund and Rahardjo [5] defined the volumetric water content (θ_w) as the ratio of volume of water, V_w, to the total volume, V, of the soil. The volumetric water content can also be expressed in terms of specific gravity, Gs, void ratio, e, and water content.

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$$\theta_w = \frac{w(h)\ Gs}{1+e} \tag{1}$$

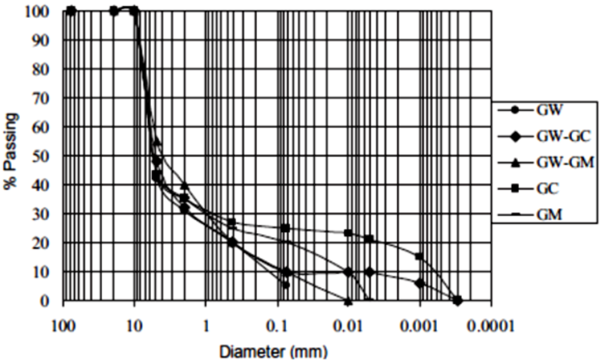

Fig. 1 The grain-size distribution curve [1] the GM layer has been used

The ratio of volumetric water content to be calculated according to (1) for saturated and unsaturated soil conditions whose values are calculated and presented in Table II for different layers of soil.

In order to perform flow analysis in Sigma/w software, it is suggested to introduce soil permeability functions and volumetric water content functions by matric suction and pore pressure variations. Several methods for introducing these functions are provided in the Geostudio 2012 software, the most notable one is to use of triaxial testing results with pore water pressure readings during test and introducing different points in the software to form a function. Considering that such results are not available in this project, we will use a different method to show the functions mentioned below by introducing the values of D10 and D60 as well as the soil psychological limitations and selecting 25 points for matric suction and selecting the minimum range pore water pressure, these functions are formed automatically by the software. Also, to form a permeable function against pore pressure, it is necessary to determine a suitable value for soil permeability in saturation, which is used for this estimation from the experimental value. The saturation capability of each soil layer with regard to its depth and soil name is considered in the Unified classification by engineering judgment. Also, to determine the suction range, the default values for the software manual are assisted.

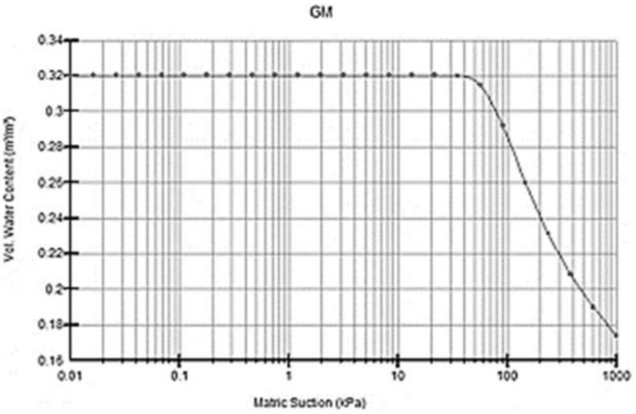

Fig. 2 The function "matric suction- volumetric water content" corresponds to the paper's details [1] for the GM layer

TABLE I
MODELED SOIL PROPERTIES BASED ON KAMAL MOHAMED [1]

soil type	Texture				C_u	C_c	G.I	L.L	P.L.	P.I.	WPI
	%G	%S	%M	%C							
GM	55	38	17	-	5.8	13.8	0	35	25	10	1.7

The first step is to model the creation of initial conditions, because the stability and deformation of the slop they depend on the stresses around the soil. To create the primary stresses, the Jacky's equation is given below. It should be noted that the Sigma/w software is detected by the Poisson's ratio and using (2), the coefficient of lateral earth pressure.

$$K_0 = \frac{\nu}{(1-\nu)} \tag{2}$$

IV. INVESTIGATING THE EFFECT OF REDUCING WATER LEVEL

In this section, the level of water is reduced and its impact on the factor of safety will be examined. In this way, the effect of suction on the shear strength of the soil is evaluated. As shown in Fig. 3, the pore water pressure contour is shown after the water level has been reduced. As can be seen, due to the reduction in water level, a suction is created at the top of the part where the water level is evacuated. It is also shown in Fig. 3 that the maximum amount of this suction is negative at 40 kPa and on the surface of the water this suction is zero and below the water level, the pore water pressure is shown with a positive number indicating the absence of matric suction.

How will this suction affect the stability? Below is a factor of safety analysis that will answer our main question.

TABLE II
SOIL CHARACTERISTICS BASED ON MODEL ASSUMPTIONS

Moisture content %	e	n	S %	θ_w (m^3/m^3)	θ_{wr} (m^3/m^3)	Dry density	Wet density
24	0.656	0.396	99	0.392	0.157	1.85	2.00

V. COMPARISON OF STABILITY SAFETY FACTOR IN INITIAL STATE AND AFTER WATER LEVEL REDUCTION

Fig. 4 shows, the stability safety factor before the water level is reduced, which is equal to 1.480. In Fig. 5, the factor of safety stability increased from 1.480 to 1.815 due to the decrease of the water level as well as the increase in suction in which failure envelope is located. We conclude that matric suction will increase the factor of safety stability. Fig. 6 shows the comparison between the shear strength in the two states after reducing water level and before reducing water level. The difference between these two graphs has resulted in the stability safety factor, partly due to matric suction.

VI. CONCLUSION

In this study, we examined the stability of a slope with a height of 10 meters in silty gravel soils. For this purpose, the modeling was done using the Geostudio 2012 v15 software. The total displacement during the three stages of the excavation was modeled. Results were evaluated in a drained and undrained conditions and an unsaturated behavioral model during the water level reduction process. As can be seen, due to the decrease in water level, a suction was created at the top of the section where the surface of the drained water was generated. This negative pore pressure, which is caused by a decrease in water level, indicates matric suction. Also, the effect of suction on slope stability was investigated. To do this, we conclude by analyzing the safety factor in slope stability, increasing the slope stability with decreasing water level and increasing the suction of the slope stability.

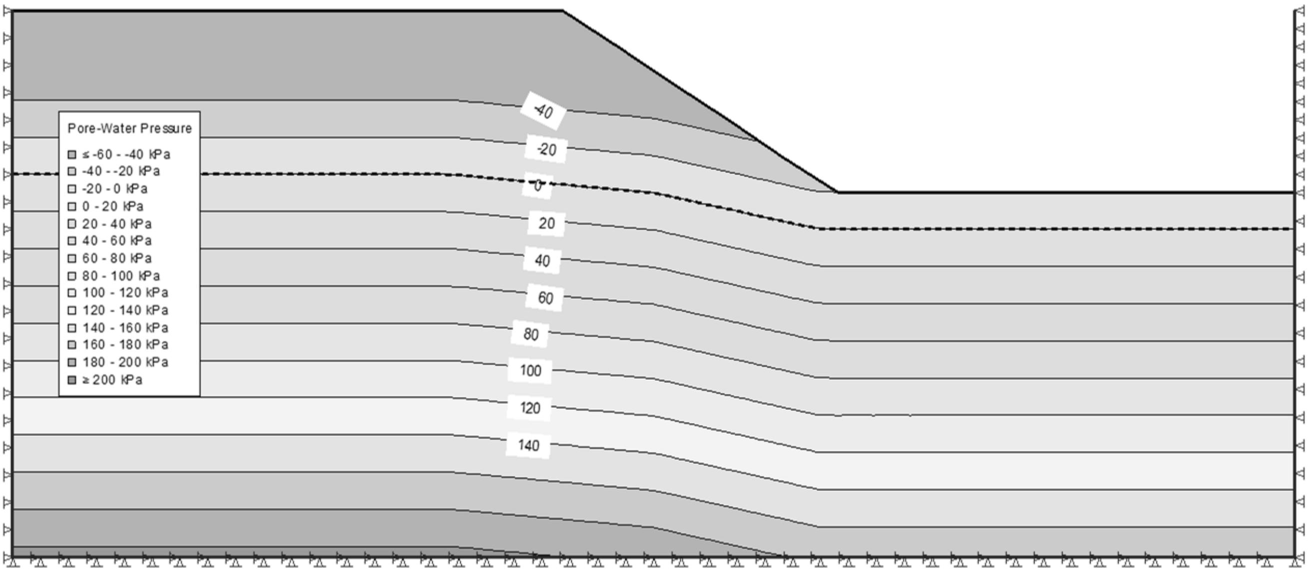

Fig. 3 Pore water pressure cantors after water level reduction

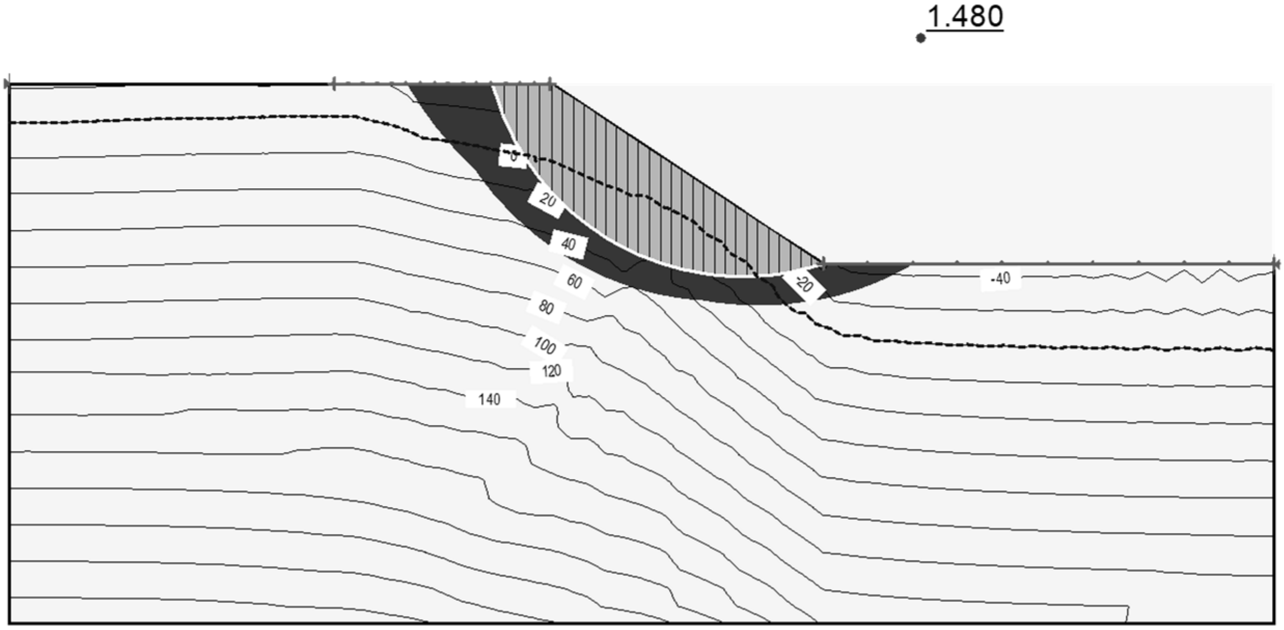

Fig. 4 Stability analysis with a safety factor, 1.480, simultaneously with the display of pore water pressure contours before reducing water level

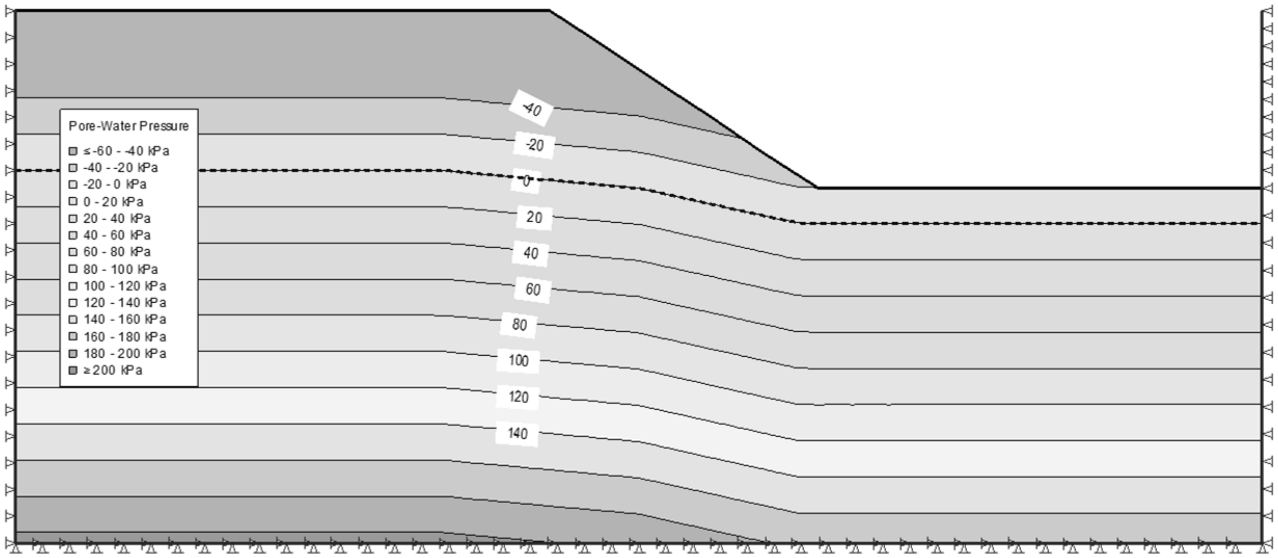

Fig. 5 Stability analysis with a safety factor, 1.815, simultaneously with the display of pore water pressure contours after reducing water level

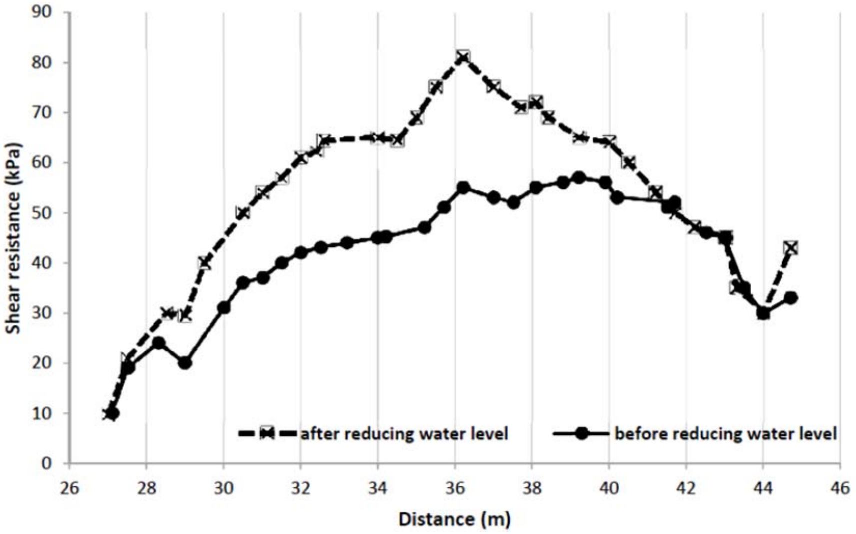

Fig. 6 Shear resistance on the failure envelope

REFERENCES

[1] Zhang, L. M., and Chen, Q, “Predicting bimodal soil-water characteristic curves,” J. *Geotech. Geoenviron. Eng*., 2005, 131(5), 666 670.

[2] X. Li, L. M. Zhang, and J. H. Li. “Development of a Modified Axis Translation Technique for Measuring SWCCs for Gravel Soils at Very Low Suctions,” *Geotechnical Testing Journal*, 2009, Vol. 32, No. 6.

[3] Fredlund DG, Xing A, Fredlund MD, Barbour SL. “The relationship of the unsaturated soil shear strength to the soil– water characteristic curve,” *Can Geotech J*., 1995, 33:440–8.

[4] Kamal Mohamed, “Effect of percentage of low plastic fines on the unsaturated shear strength of compacted gravel soil,” *Ain Shams Engineering Journal*., 2015, 6, 413–419.

[5] Fredlund, D. G. and Rahardjo, H., “Soil Mechanics for Unsaturated Soils,” JohnWiley and Sons, 1993, NewYork.

[6] Fetter, C. W. “Contaminant Hydrogeology,” Macmillan, 1995, New York.

[7] Ng, C. W. W., and Shi, Q. “Numerical investigation of the stability of unsaturated soil slopes subjected to transient seepage,” *Computers and Geotechnics.* ,1998, 22(1):660 1-28.

[8] Tsaparas, I., Rahardjo, H., Toll, D. G., and Leong, E. C. “Controlling parameters for rainfall-induced landslides,” *Computers and Geotechnics*., 2002, 29(1): 1-27.

[9] Rahardjo, H., Ong, T. H., Rezaur, R. B., and Leong, E. C. “Factors controlling instability of homogeneous soil slopes under rainfall,” *Journal of Geotechnical and Geoenvironmental Engineering*., 2007, 133(12): 1532-1543.

[10] Zhang, L. L., Fredlund, D. G., Zhang, L. M., and Tang, W. H. “Numerical study of soil conditions under which matric suction can be maintained,” *Canadian Geotechnical Journal*., 2004, 41(4): 569-582.