

Development of a Slope Stability Program for Transmission Towers

*Jung-Tae Kim¹⁾, Youngjong Sim²⁾, Ah-Ram Kim³⁾, Gye-Chun Cho⁴⁾ and
Dae-Hong Kim⁵⁾

^{1), 3), 4)} *Department of Civil and Environmental Engineering, KAIST, Daejeon 34141,
Korea*

²⁾ *Department of Urban & Environmental Research, Land & Housing Institute, Daejeon
34047, Korea*

⁵⁾ *KEPRI, KEPCO, Daejeon 34056, Korea*

⁴⁾ gyechun@kaist.ac.kr

ABSTRACT

Many transmission towers are located in mountainous areas due to ground utilization limitations. Slope failures and damage to transmission towers located on slopes are mainly generated by heavy rainfalls, geological factors, and the presence of a foundation. These disasters can cause not only serious economic losses but also casualties. Therefore, it is important to simulate the stability of a slope, including the foundation of the transmission tower to be placed on it, before construction. Several slope stability programs have been developed (e.g., GeoStudio, Talen); however, numerical simulations of the slope stability considering a reinforced foundation with existing commercial programs are insufficient. In this study, the KISS (KAIST Integrated Slope Stability) program, which considers the effects of the presence of a transmission tower foundation, was introduced and used to analyze an actual testbed site in Gyeonggi province in Korea. Moreover, the optimal position of the foundation is suggested based on a parametric study. It is expected that the developed program can be used to prevent slope failures and reduce human and economic losses.

1. INTRODUCTION

30,000 of the 40,000 current power transmission towers are located in mountainous areas in Korea. Those transmission towers are exposed to danger in the form of slope failures. Landslides are frequently reported, and the slide areas exceeded 4,300 ha between 2005 and 2013 in Korea. Such slope failures cause economic losses

-
- 1) Graduate Student
 - 2) Senior Researcher
 - 3) Postdoctoral Researcher
 - 4) Professor
 - 5) Principal Researcher

and create numerous victims (Lee et al., 2014). Hence, slope stability analyses must be performed, taking into consideration the characteristics of the transmission tower in an effort to prevent these types of damage. At present, many commercial programs, such as GeoStudio and Talen are available for use, but these programs are mainly used for slope stability assessments. However, the presence of a transmission tower on a slope affects the slope stability and therefore must be considered as a factor during a safety calculation. In this study, the KISS (KAIST Integrated Slope Stability) program, which considers the presence of a transmission tower, was developed based on the LEM (Limit Equilibrium Method) using FORTRAN95. LEM is the most widely used method to estimate the slope stability, and it offers straightforward verification given the numerous previous analyses results. FORTRAN95 is the oldest programming language but is still widely used in engineering fields owing to its analysis speed and accurate results. The testbed site in Gyeonggi province was analyzed using the KISS program and the optimal pile positions were suggested by a parametric study.

2. DEVELOPMENT OF THE KISS PROGRAM

2.1 Limit equilibrium method

There are many methods which can be used to estimate the slope stability (e.g., LEM, FDM, FEM). LEM is an especially widely used method to estimate the slope stability because it simplifies the analysis process. Moreover, it uses specific analysis theories (e.g., Bishop, Fellenius, Janbu, and Spencer theories). Those theories provide similar results with differences within 5%, except for the Fellenius theory. The soil properties (e.g., density, cohesion, friction angle) present more critical values than the differences in the theory used (Byeon, 2001). In this study, Bishop's method (Bishop, 1955) was used to develop the program. This method represents the factor of safety as the ratio of the resistance moment and the driving moment. The weight of the soil induces the driving moment and the cohesion induces the resistance moment. The governing equation is given below.

$$F_m = \frac{R \cdot \sum (c' l + N \tan \phi' - u_w l \tan \phi^b)}{R \cdot \sum W \sin \alpha} \quad (1)$$

Here, F_m is the factor of safety, R is the moment arm length, c' denotes the cohesion, $l = b / \cos \alpha$, b is the width of each slice, α is the angle of each slice, N is the normal force, u_w is the pore pressure, ϕ' is the friction angle, ϕ^b is the apparent cohesion, and W is the weight of the soil.

2.2 Theory of the presence of a foundation

The presence of a transmission tower affects the factor of safety. Horizontal force is induced by the weight of the soil in front of the transmission tower foundation. This force is considered in the designs of power transmission towers in Korea and Japan. The horizontal force contributes to the resistance moment in slope stability calculations. The equation used to estimate the horizontal force is given below (Tokyo Electric Power, 1983).

$$R_u = \alpha_0 \frac{W(\cos\alpha + \sin\alpha \tan\phi) + c \cdot A}{\sin\alpha - \cos\alpha \tan\phi} \quad (2)$$

Here, α_0 is the experiment coefficient of 0.6 with $\alpha = 45^\circ + \phi/2 + \theta/2$, and A denotes the sliding area.

2.3 Algorithm

The algorithm used in the KISS program is shown in Fig. 1. The first step is to input the soil properties (e.g., density, cohesion, friction angle, apparent cohesion, geometry). Second step is to decide whether to consider a foundation or not. When considering a foundation, the input parameters are the diameter and the length of the foundation. The third step is the calculation stage. The results are shown as the minimum factor of safety and the coordinates of the potential failure curve.

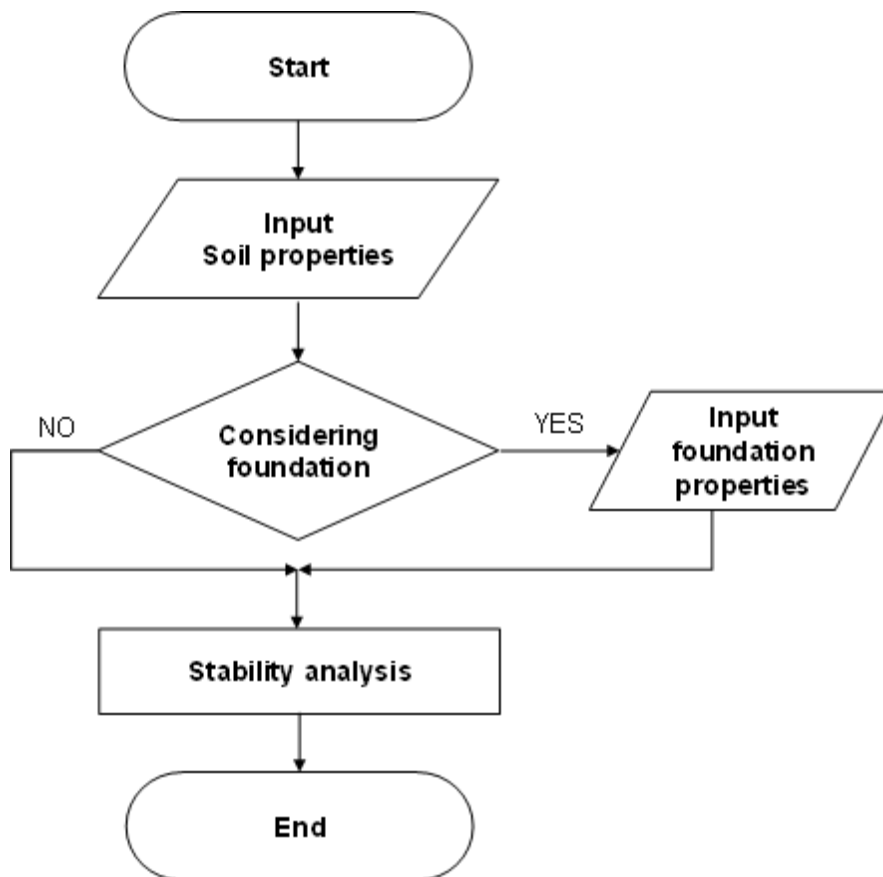


Fig. 1 KISS program algorithm

3. RESULT AND ANALYSIS

3.1 Analysis considering foundations

The failure tendency of a slope including a foundation is that a potential failure line arises in front of the foundation because the horizontal resistance force induced by the soil weight increases the factor of safety. In actual slope failure cases, slope failure occurs in front of the power transmission tower, as shown in Fig. 2. For a comparison of the KISS program and actual slope failure tendencies, a case study was performed. The parameters used in the case study analysis are shown in Table 1. P1 to P6 are the terrain coordinates of the case study and X_1 and X_2 are the position of the transmission tower foundation 1 and foundation 2 from the terrain coordinates (0, 0). The results are shown in Fig. 3. According to the two cases (an analysis with a foundation and without a foundation), the potential slope failure line moves to the front of the foundation with a change in the radius. The factor of safety also increases when the presence of foundation is considered owing to the horizontal resistance force, which has the positive effect of increasing the factor of safety. These results are similar to those from an actual instance of a slope failure, as shown in Fig. 2. These findings indicate that the KISS program can properly consider the effects of a foundation in a slope stability analysis.



Fig. 2 Actual case of a slope and foundation failure (KEPCO, 2013)

Table 1. Input Values for the analysis considering foundations

Density (t/m^3)	Cohesion (t/m^2)	Friction angle ($^\circ$)	Apparent cohesion ($^\circ$)	X_1 (m)	X_2 (m)
1.69	1.0	30.0	15.0	45	55
P1 (x, y)	P2 (x, y)	P3 (x, y)	P4 (x, y)	P5 (x, y)	P6 (x, y)
(0, 16)	(15, 23)	(37, 38)	(50, 41)	(60, 50)	(100, 55)

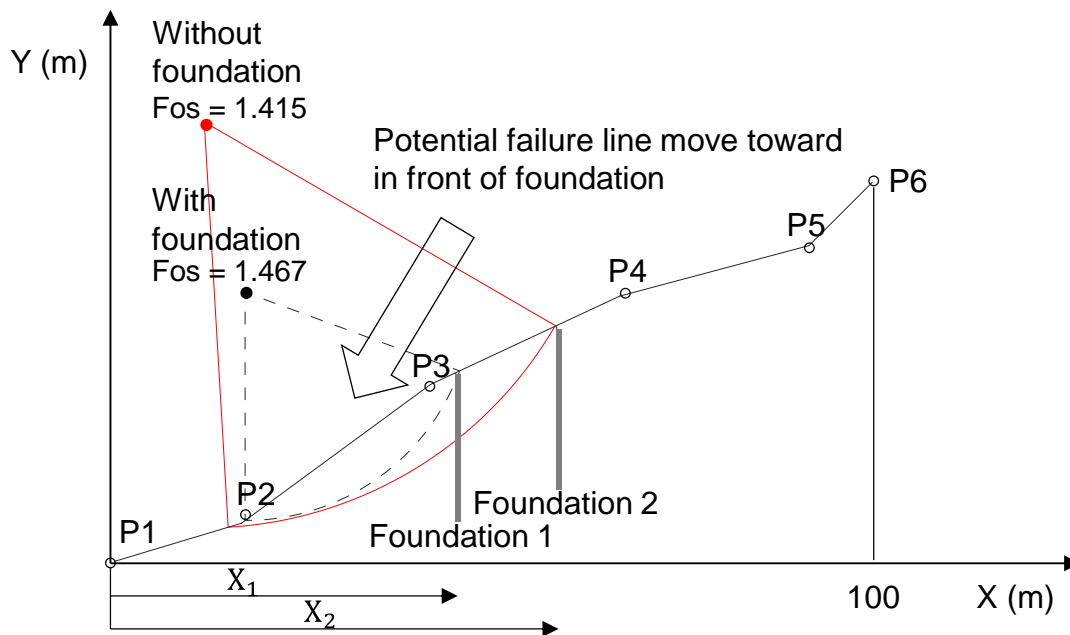


Fig. 3 Potential failure line and factors of safety according to the foundation

3.2 Testbed analysis

A numerical analysis was conducted to evaluate the slope stability of a testbed site in Gyeonggi province. The parameters used in the testbed analysis are shown in Table 2. The position of the power transmission tower did not affect the factor of safety of the testbed according to the analysis results, as shown in Fig. 4. A parametric study was conducted to determine the optimal position of the foundation to increase the initial slope stability. The analysis was iterated while moving the foundations position. The x-axis represents the position of foundation 1 (X_1) in the results graph shown in Fig. 5. The foundation 1 and foundation 2 each have a spacing distance of 10 m. The testbed slope had an initial factor of safety of 1.555 and the foundations had no effects on the stability of the slope. When the foundation is between 10 m and 25 m, the safety factor increases dramatically at the testbed site. The optimal position of foundation 1 was found to be a position 10 m from (0, 0), as shown in Fig. 5.

Table 2. Input properties of testbed

Density (t/m^3)	Cohesion (t/m^2)	Friction angle ($^\circ$)	Apparent cohesion ($^\circ$)	X_1 (m)	X_2 (m)
1.69	1.0	30.0	15.0	45	55
P1 (x, y)	P2 (x, y)	P3 (x, y)	P4 (x, y)	P5 (x, y)	P6 (x, y)
(0, 16)	(15, 23)	(37, 38)	(50, 41)	(60, 50)	(100, 55)

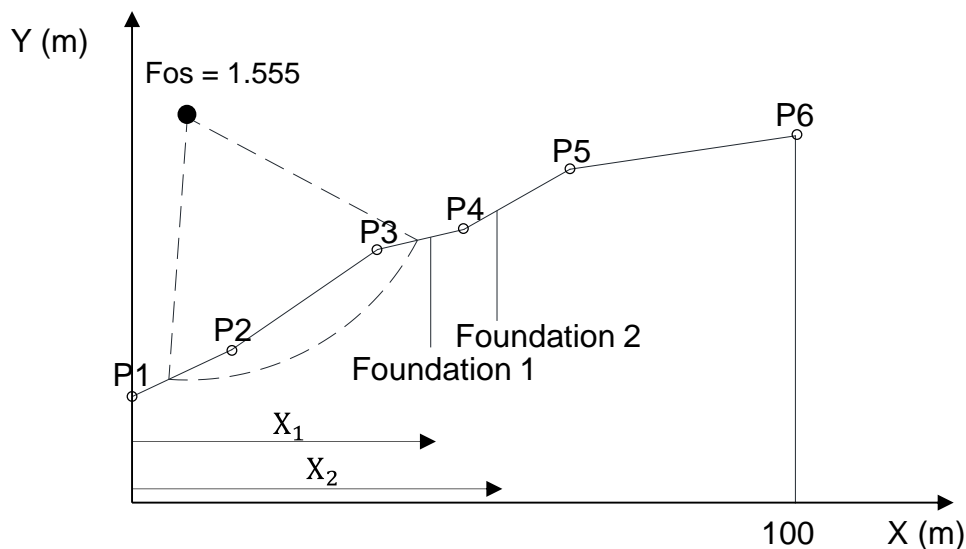


Fig. 4 Potential failure line at the initial foundation position of the testbed

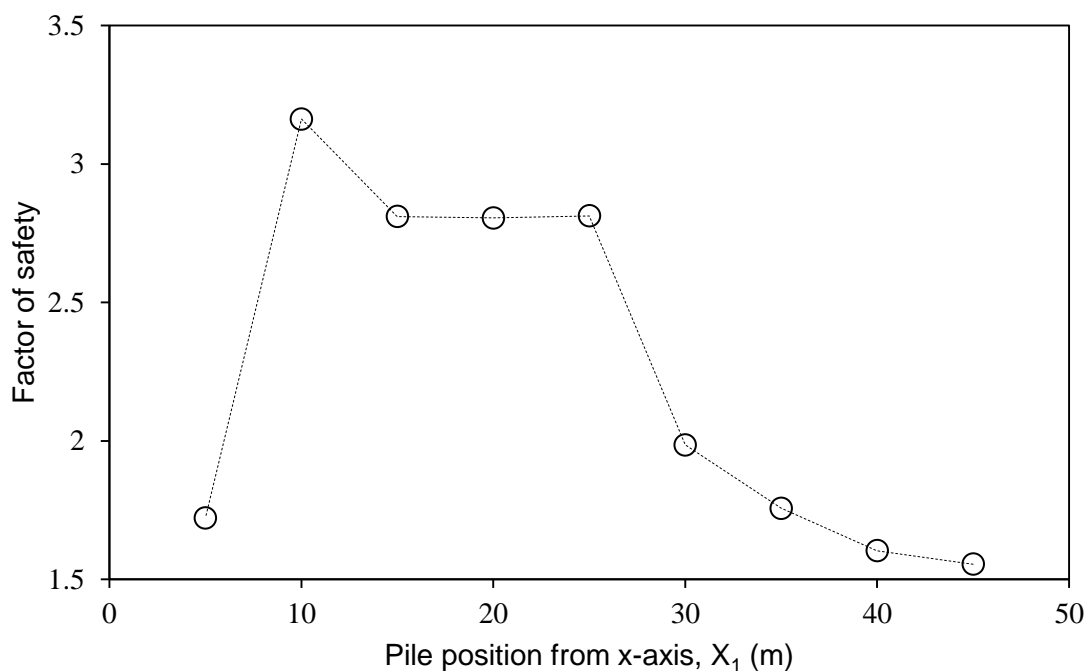


Fig. 5 Variation of the factor of safety with the foundation 1, (X_1) position

4. CONCLUSION

In this study, a slope stability analysis program which takes into account the presence of a power transmission tower, known as the KISS (KAIST Integrated Slope Stability) program, was developed and verified with an actual case of a slope failure. A testbed site was analyzed by the KISS program, and it was found that the positions of piles were not affected by an increase in the factor of safety. The optimal pile position

was determined in a parametric study using the testbed. The suggested pile position increases the slope stability by inducing resistance force onto the area prone to slope failure. It is expected that the KISS program will reduce the economic losses and victims associated with slope failures in conjunction with earlier analysis methods by ensuring the proper placement and conditions before a transmission tower is constructed. As additional research, rainfall infiltration will be studied in a simulation of a transmission tower and related slope conditions during heavy rainfall.

REFERENCES

- Bishop, A.W. (1955), "The use of the slip circle in the stability analysis of slopes." *Geotechnique* (5), 7-17.
- Byeon, W.Y. (2001), "Development of slope stability analysis program considering unsaturated soil characteristics and applying optimization technique", *Master's Thesis*, Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea
- Cheon, G.H. (2015), "Stability analysis algorithm for a power transmission tower-located slope", *Master's Thesis*, Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea
- KEPCO. (2013), Report of slope failure including power transmission tower.
- Lee, J.S., Kim, Y.T., Song, Y.K. and Jang, D.H. (2014), "Landslide triggering rainfall threshold based on landslide type." *The Korean geotechnical society* 30(12), 5-14.

ACKNOWLEDGEMENT

This research was supported by a grant from the Korea Electric Power Corporation (KEPCO). The first author is supported by the "U-City Master and Doctor Course Grant (Education) Program" under the Korea Ministry of Land, Infrastructure and Transport (MOLIT).