doi:10.4186/ej.2009.13.2.1

RELIABITY AND ASSESSMENT TECHNIQUES ON GROUND EXCAVATION

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ABSTRACT

Planning and assessment on the excavation of the brittle materials (soil or rock) can be done by using the machinery and/or explosives. The reliability assessment has been proposed to predict the failure of ground during excavation process. The stability planning on cutting soil (rock) face by machinery can be compared between the deterministic and the statistical method. The risk of using explosives for rock excavation has to concern on the damage and environmental impacts after blasting events.

KEYWORDS

ground excavation, reliability techniques, stability planning, blast impacts, optimized charge weight

doi:10.4186/ej.2009.13.2.1

I . Introduction

Quaternary soil excavation at the construction site for the slope or foundation is normally carried out using the machinery. Stability calculation for the factor of safety (F.S.) of the cutting face can process by using the input data from field and laboratory results. However, this deterministic technique does not concern on the variations of material properties. To improve the possibility chance of failure, the statistical analysis using the reliability method is suggested by the author. The input data are assumed to be normal and lognormal distributions.

Rock excavation at the quarry site in Thailand is normally used the AN-FO (ammonium nitrate and fuel oil). This blasting agent is the major amount of explosives used. Three major types of crushed rocks in Thailand have been used for construction purposes. They are Permian-Ordovician limestone, Cretaceous granite and Tertiary basalt. Most of the potential resource sites and the ongoing quarries are located in the central part of the country. According to our team research, there are 2 sizes of ongoing quarries: the large and small size. A quarry defined as the large size when its production exceeds a limit of 200,000 cubic meters per month, otherwise it is the small size. All quarries of large sizes are limestone quarries and their fragments are mainly used as a raw product in the Portland cement industry. The findings of proper explosive weight together with the required safe distance will achieve the required fragments, and also will lessen the damage effects to building structures and environments.

II. Stability planning using machinery

For the stability planning on cutting slope and foundation using the machines, the material types are important factors. If they are mainly soil materials, the common types of failure are plane or circular failure. But if they are mainly rock materials, failure types of plane, wedge or toppling failure can be detected. The author proposed two ways of statistical analysis. These are:

1). If there is a normal distribution among those input property variables (such as cohesion, friction angle) the empirical equations used the probabilistic method are implied.

$$(F.S.)_{ave} = \frac{R_{ave}}{Q_{ave}} \qquad (1)$$

$$\text{Reliability} = 1 - p\,(f) \qquad (2)$$

Term $(F.S.)_{ave}$ is the mean index value of stability estimation. The mean capacity (R_{ave}) value is to resist movement, and the mean demand (Q_{ave}) value is to develop movement on the failure plane. Another alternative value is the reliability term. It is a value indicating the reliability of excavation and it is the computed probability that a slope or foundation will not fail and is equal to 1.0 minus the probability of failure [p (f)]. The relationship between the probability of failure and the cumulative distribution function, or F (x), while "x" is the assumed random variable, is indicated in equation 3.

$$p(f) = 1 - F\,(x) \qquad (3)$$

The probability model can be set, in which the limit of safety or safety margin (Z) is defined as:

$$Z = R - Q \qquad (4)$$

Figure 1 shows the state of failure for the input data that assumed having variations as the normal distribution. At the boundary of F.S. equal to 1 (one), the Z value is 0 (zero). The standard deviation between the Z value = 0, and the mean Z value (Z_{ave}) is the reliability index (β_N). One can indicate in the empirical equation as:

$$\beta_N = \frac{R_{ave} - Q_{ave}}{\sqrt{(S.D.)_R^2 + (S.D.)_Q^2}} \qquad (5)$$

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The S.D. value in equation 5 is the standard deviation for input data. The failure will occur when Z value is less than one.

2) If there is a lognormal distribution among those input property variables, the random variable y = ln x is normally distributed. The value of factor of safety that is closet to the mean of lognormal distribution is set as the most likely value, or $(F.S.)_{MLV}$. The probability of failure model for lognormal distribution is then set.

$$\beta_{LN} = \frac{\ell n\left[\dfrac{(F.S.)_{MLV}}{\sqrt{1+(COV)_{FS}^2}}\right]}{\sqrt{\ell n\left\{1+(COV)_{FS}^2\right\}}} \tag{6}$$

Term β_{LN} in equation 6 is the lognormal reliability index. The factor of safety in this case is the most likely value, $(F.S.)_{MLV}$ and $(COV)_{FS}$ is the coefficient of variation for factor of safety. The value of lognormal reliability index indicates the number of standard deviation between F.S. = 1.0 (impending failure) and $(F.S.)_{MLV}$ as shown in Figure 2.

The author suggests the value of COV be within the range 15-40%.([1], [2], [3]). The lowest conceivable value [$(COV)_{low}$] is 15%, and the highest conceivable value [$(COV)_{high}$] is 40%. These two values help when there are not enough data in that special case. The Monte Carlo technique is used in the process of calculating the probability of failure. The simulation has generated random values between 100 and 10,000 times.

An example of the calculation for the probability of slope failure, concurrent with the spreadsheet program, is shown in Figure 3. The cross section in this figure shows the dimension, geometry and water forces. Failure occurred on bedding planes striking parallel to the face, and dipping out of face at an angle of 20^{o}. The quarry rock unit weight (γ) is 25.1 kN/m^3. From the observation and laboratory results the friction angle (ϕ) is in the range of 15^{o}-25^{o}. The range of cohesion value (c) is 80-130 kPa.

For the deterministic value for the factor of safety on the slope is:

$$F.S. = \frac{(cL)+[(W\cos\psi_p)-U-(V\sin\psi_p)]\ \ \tan\phi}{(W\sin\psi_p)+(V\cos\psi_p)} \tag{7}$$

The relationship between the deterministic and probabilistic analyses using the assumption on the normal distribution of random variables. For the unsupported slope, the deterministic factor has a value of 1.30, while the probabilistic analysis [4] shows the factor of safety can range from a minimum value of 0.58 to a maximum value of 2.49. The proportion of this normal distribution with a value less than 1.0 is 14.8%. The value of 14.8% represents the probability of failure for cut limestone quarry. When assumed the lognormal distribution of variables, the variation of data is significant. The result on the probability of failure for lognormal data is 16.60%. In comparison, one should use the higher value of "p (f)" for the decision making.

Another example on the stability of frictionless clay soil. The slope of a cutting is 0.625 to 1.0. The soil is saturated clay of unit weight 16.8 kN/m^3, and its undrained cohesion (c_u) is 50 kPa, effective cohesion (c') is 40 kPa. Tension crack and other dimensions indicate in Figure 4.

The factor of safety can find by taking moment around point O in Figure 4.

$$F.S. = \frac{M_R}{M_D} \tag{8}$$

Term M_R is the moment resist to sliding, and term M_D is the moment of driving mass to slide along the arc BE.

From the normal calculation procedure, the factor of safety is 0.77, in which the soil mass will slide along the arc. If the input data have the normal distribution, the probability of failure at the COV set at 15% is p (f) = 91.5 %, and for COV at 40% is p(f) = 68.5%. But if the input data have the lognormal distribution, the probability of failure at the COV set at 15% is p (f)

= 90.5 %, and for COV at 40% is p(f) = 68.0%. This example shows close relationships between the normal and lognormal distribution of the property data.

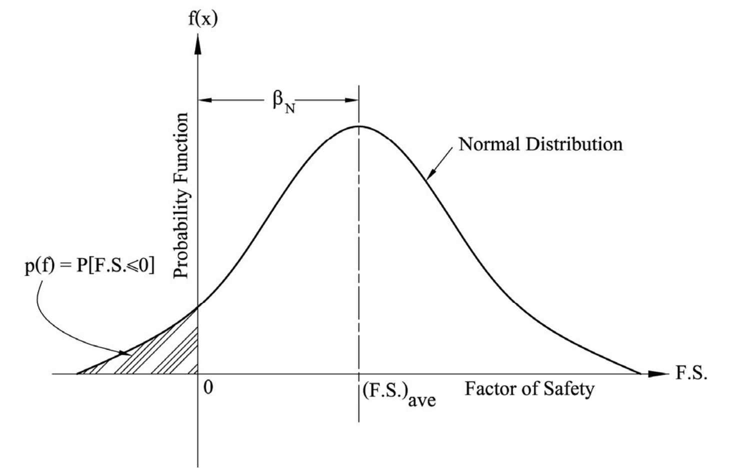

Figure 1
The factor of safety related to the normal distribution of input data.

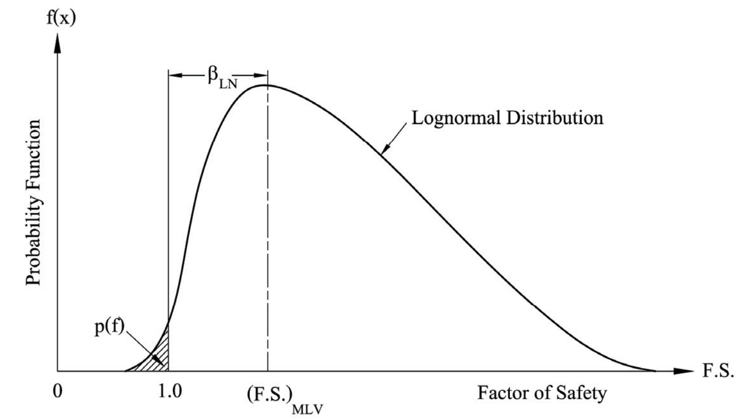

Figure 2
The factor of safety related to the lognormal distribution of input data.

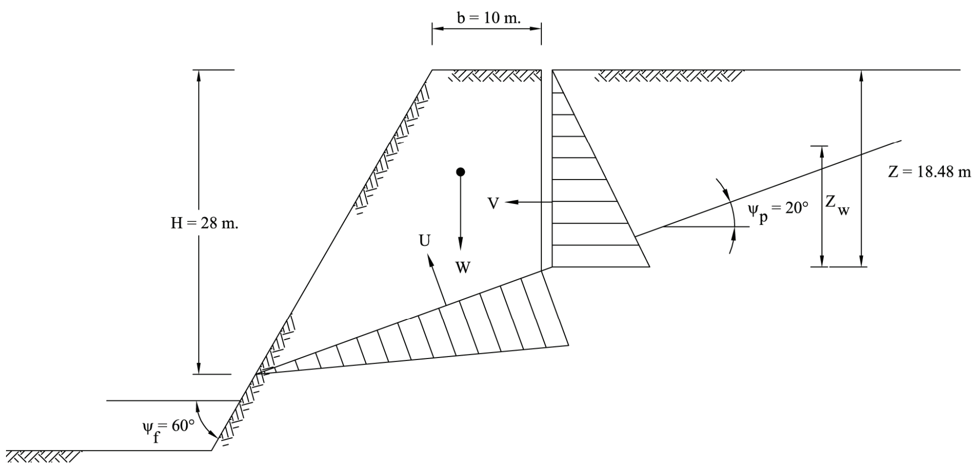

Figure 3
A plane failure on the quarry limestone face which has the tension crack on the upper bench. U is the uplift force and V is the water force in the crack. W is the sliding weight, The maximum value of water height, z_w, is 18.48 m. Other dimensions indicate in this figure.

doi:10.4186/ej.2009.13.2.1

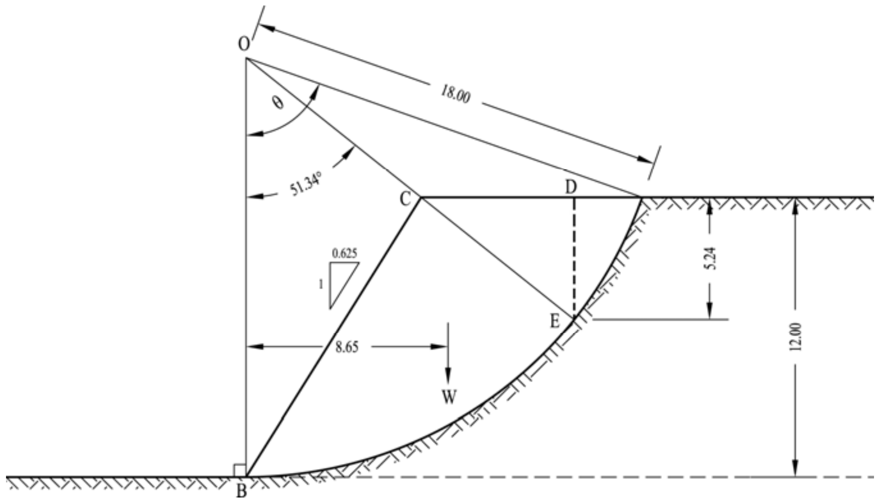

Figure 4
A circular failure on the clay slope with tension crack (DE). The crack filled with water at the maximum height of 5.24 m.

III. Stability Planning using Explosives

A typical explosive charge used in quarry or construction blasting is AN-FO plus gelatine dynamite, detonated with the electric delay caps. The picture shown in Figure 5 was taken from a large quarry that it was well-planned for preventing the damage to environment. A typical bench blasting for a large quarry consists three rows of 200 mm diameter holes of 20 m height with 5.5 to 7.5 m of burden and spacing. The amount of explosive charge ranges from 200 to 800 kg AN-FO per delay. A package program designed by our colleagues [5] was also initiated to calculate the dense volume of blasted rock, explosive consumption, related dimensions of the blast geometry.

Investigation of the impacts and statistical methods to analyze the damage limits are similar to the procedure described in a report of the U.S.Bureau of Mines [6], in which the square root scaled distance has been adopted. Figures 6 and 7 show a conventional vibration analysis and the modified trend line method [7] for improved prediction of recording data measured in limestone quarries operated at various locations. Their comparison of charge weights helps increase confidence to control the peak particle velocity. The U.S. Bureau of Mines set the threshold damage limit of peak particle velocity at the value of 50 mm/sec. For general practice of blasting in Thailand, the acceptable limit value is 25 mm/sec.

Notable results for the minimum particle velocity seem to ensure impacts on ground vibration, and on air blast together with fly rock are within the appropriate damage risk. These normal distribution recorded field data are indicated by a less than 1 in 20 chance (95% probability limit) that they will be outside the limit line (do cause the damage). Thus the damage risk from the suggested particle velocity (25 mm/sec) at any level of blast frequency is less than 5%.

On the assessment of blast impacts, there are 3 stages of recommended regulations. The first stage is the normal case and one can design explosive weights per delay according to the predicted graph (Figure 8). On this graph, the modified trend line applied for the permitted peak particle velocity is 25 mm/s.

For the second case is the awareness case, the suggested values of quarry blasting set that the distance between the community and quarry face can be less than 500 m but not less than 150 m. The peak particle limit is 12 mm/s with any kinds of frequency. A value of scaled distance for this case is 16 $m/kg^{1/2}$. The last case is the extreme one applied for blasting near the historic structure. The distance from the blast source must be more than 150 m. A peak particle velocity must not exceed 4 mm/s.

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Figure 5
A large quarry for cement plant in the central part of Thailand.

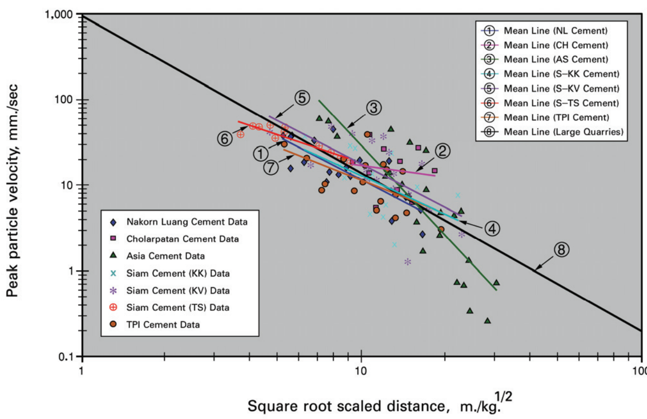

Figure 6
Conventional square root scaled distance analysis is to define the threshold limit due to ground vibration. The field data were consecutive collected during the actual blasts for more than 5 years.

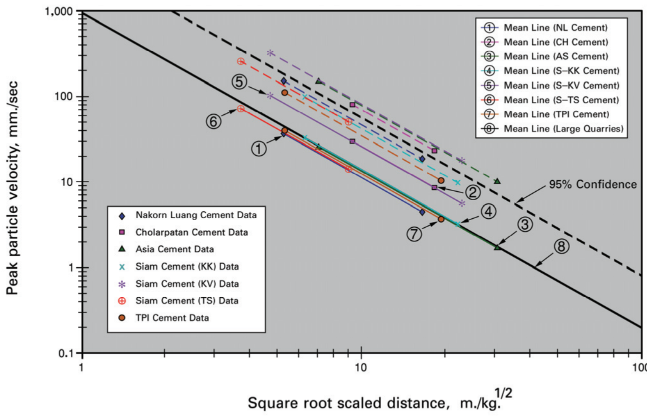

Figure 7
Modified trend line analysis for better prediction of ground vibration effect.

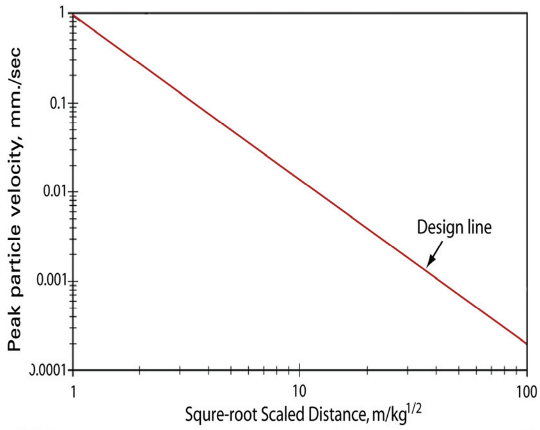

Figure 8
A recommended graph for designing the charge weights (AN-FO).

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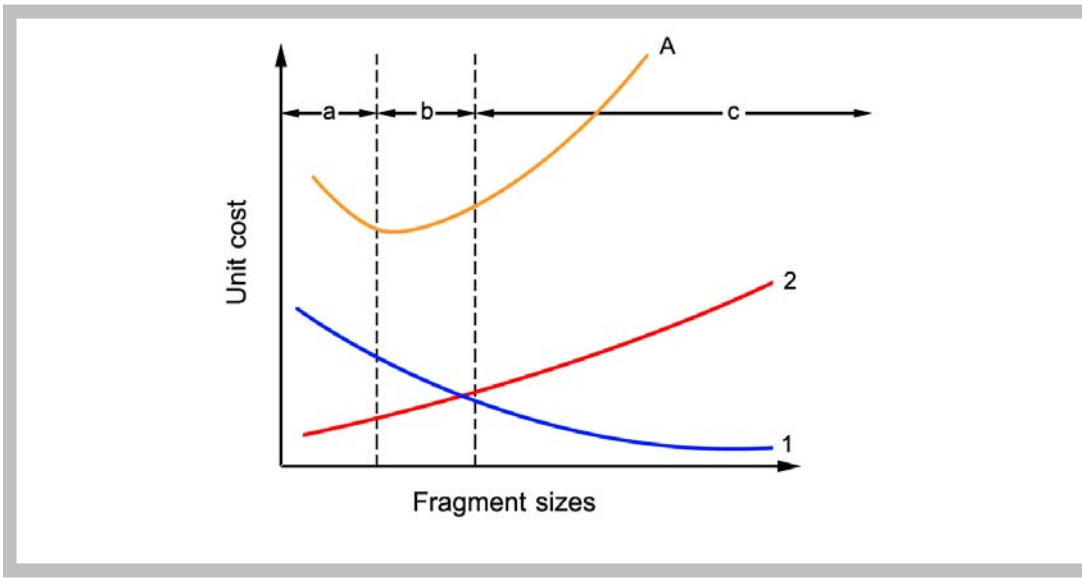
Figure 9
The trial graphs for the optimization process on excavation using machinery or bench blasting No. 1 is the direct excavation cost, 2 is other various costs such as hauling and crushing. Term "A" is the total cost of operation. Range "a" is the small block of fine sizes, range "b" is the medium block material, sizes between 0.2 and 0.7 m, and range "c" is the large block or over sizes.



IV. Conclusion

Regarding the use of reliability and probability of failure a slope or foundation that has the safety value at F.S. = 1.0 might fail. The local factor of safety may be more or less than the value of F.S. calculated by conventional limit equilibrium methods due to the variation of soil (rock) properties.

Various steps in planning and evaluation should be carried out on the stability and optimized operations on the brittle materials. The calculation on output values are to compare with both the convention and reliability method. Back analysis calculations on the results of factor of safety, probability of failure, cost of excavation, and impact factors to environment, are required. The trial graphs as shown in Figure 9 which applied for the rock excavation, could help to confirm the schematic plans represent efficient and safe practices.

ACKNOWLEDGEMENT

The financial sources from Chulalongkorn University and from the Mining Technology Division are highly appreciated. Thanks are due to our research team on their continuous works for several years. Generous permission of the authorized personnel to allow published data is appreciated.

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