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CHALLENGES OF NEW REACTOR SITING EVALUATIONS IN THE GEOTECHNICAL ENGINEERING FIELD

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ABSTRACT

With the renewed interest in nuclear energy worldwide, new reactors have been designed, new nuclear power plant sites are being planned, and some are already under construction in the United States. While new reactor technologies have significantly advanced, none of the new reactor designs have actually been built in the U.S. for the past 30 years, especially at deep soil sites, therefore it is no surprise that there are many challenges not only related to the new reactor technologies, but also to siting and safety evaluations. As new regulations and industrial standards are established and new technologies become available, some of the conventional engineering practices no longer meet the new reactor requirements, as in the case in the geotechnical engineering field.

During the new reactor design and new reactor siting evaluations, the geotechnical engineers now are facing many challenges, such as: how to reasonably account for the great variability when determining subsurface material and mechanical properties in a practical way; how to determine design parameters for the subsurface materials with adequate safety margin while not being over-conservative; how to ensure that the static and dynamic properties of the in-place backfill soil will have the same as, or better than the design properties that were used in structural and foundation stability analyses; how to conduct a confident soil liquefaction evaluation when so many uncertainties, from soil property to seismic loadings, are involved; how to estimate the dynamic bearing capacity of the foundation when there is no well-established and commonly accepted method that considers the actual failure mode and soil property changes under seismic loading; how to realistically estimate the lateral earth pressure under seismic loading, as assumptions used in available analysis method are generally over-simplified and the models still need to be verified; how to account for the effect of induced settlement from seismic loading in foundation and slope stability analyses; what method can be used to adequately and realistically evaluate slope stability under the worst loading combination conditions; and what is the best and most practical acceptance criteria when evaluating the stability of subsurface materials, foundations, and slopes to meet the new reactor design and regulation requirements in place of the commonly used factor of safety.

This paper summarizes the challenges in new reactor design and siting evaluations in the geotechnical engineering field and discusses some new developments, both technical and regulatory, related to these challenges. It also explores possible ways to meet these challenges based on lessons learned from current combined license application reviews by the U.S. Nuclear Regulatory Commission (USNRC).

Note: This paper was prepared, in part, by an employee or employees of the U.S. Nuclear Regulatory Commission on his or her own time apart from his or her regular duties. NRC has neither approved nor disapproved its technical content.

INTRODUCTION

During the past decade, new reactors have been designed, new nuclear power plants have been planned and some are already under construction, however none of the new generation of reactors has actually been built and operated in the U.S up to date. It is therefore no surprise that there are many challenges that regulators and engineers are facing in new reactor siting and safety evaluations. As new regulations and industrial standards are being established or updated, and new technologies become available, the conventional engineering practices need to be improved in order to meet today's needs.

Since siting evaluation is an important part of new reactor applications, and geotechnical engineering is heavily involved in the siting evaluations, it is necessary and important for geotechnical engineers to clearly identify the new challenges and find solutions to ensure the safety of new reactors from the geotechnical engineering point of view. This paper discusses some lessons learned during new reactor application siting evaluations, which are related to the new requirements in regulations and criteria in the new reactor designs, in addition to a wide range of uncertainties involved in geotechnical engineering practices. This paper also discusses some methods that may have the potential to help us to meet the challenges and to increase the level of confidence in siting evaluations for new reactors.

NEW CHALLENGES IN NEW REACTOR SITING EVALUATIONS IN THE GEOTECHNICAL ENGINEERING FIELD

The challenges that are associated with the new requirements in regulations and new reactor design criteria in the geotechnical engineering field include, but are not limited to the following:

1) How to determine subsurface material engineering properties that reasonably account for the variability of subsurface materials in a practical way;

2) How to determine design parameters for subsurface materials with adequate safety margin without being overly conservative;

3) How to ensure that the assumed static and dynamic properties of foundation backfills, when actually placed in the field, will be the same or better than the design properties that were used in structural and foundation stability analyses, especially if/when the source of the backfill material may be unknown during the design stage;

4) How to conduct a confident soil liquefaction evaluation when so many uncertainties, from soil property to seismic loading, are involved and no liquefaction would be expected at a new nuclear power plant site;

5) How to estimate the dynamic bearing capacity of the foundation when there is no well-established and commonly accepted method that considers the actual failure mode and soil property changes under seismic loading conditions;

6) How to realistically estimate the lateral earth pressure under seismic loading while many simplified assumptions used in currently available analysis methods still need to be verified and the models need to be further validated;

7) How to adequately evaluate slope stability that can determine the realistic mode of failure and sliding surface under the worst loading combination conditions; and

8) How to determine the best and most practical acceptance criteria other than the traditional factor of safety measure when evaluating the stability of subsurface materials, foundations and slopes, thus to meet the new reactor design and regulation requirements.

Based on lessons learned from new reactor application reviews by the USNRC, some of the challenges are discussed in the following sections.

Seismic soil liquefaction potential analysis in new reactor siting evaluation

Seismic soil liquefaction potential at a nuclear power plant site is a very important issue that will directly affect the stability of foundations and structures. None of the new reactor designs that USNRC has reviewed to date allowed liquefaction to occur for the materials supporting safety related structures at a nuclear power plant site.

Currently used methods for liquefaction potential evaluation

The USNRC Regulatory Guide (RG) 1.198 provides guidance on assessing soil liquefaction potential under seismic loading at nuclear power plant sites. The siting evaluation for soil liquefaction potential is measured by a factor of safety, FS, against liquefaction and it is defined as

$$FS = CRR/CSR \tag{1}$$

where CRR (cyclic resistance ratio) is the available soil resistance to liquefaction, expressed in terms of the cyclic stresses required to cause liquefaction, and CSR (cyclic stress ratio) is the cyclic stress induced by the design earthquake.

The magnitude-corrected cyclic stress ratio $CSR_{7.5}$ at a particular depth z (m) is given by Seed and Idriss (1971) as

$$CSR_{7.5} = 0.65\ \frac{PGA}{g}\frac{\sigma_v}{\sigma_v'}\frac{r_d(z)}{MSF(M)} \tag{2}$$

where PGA (g) is the geometric mean of peak ground accelerations of two horizontal components at the ground surface (Youd et al., 2001); g is the gravitational acceleration; σ_v' and σ_v are the initial effective vertical overburden stress and the total overburden stress at the depth z, respectively; MSF (M) is the magnitude scaling factor and is given by $MSF(M)=(M/7.5)^{-2.56}$ (Youd et al., 2001); and rd(z)is the shear stress reduction factor and is given by Liao et al. (1988) and Youd et al. (2001) as

$$r_d(z) = \begin{cases} 1.0 - 0.00765z & for\ z \le 9.15\ (m) \\ 1.174 - 0.0267z & for\ 9.15 < z \le 23\ (m) \end{cases} \tag{3}$$

The CRR can be determined by laboratory tests or empirical methods that are widely used in routine engineering practices. The often used empirical methods are based on the standard penetration test (SPT), cone penetration test (CPT) and shear wave velocity (Vs) test to evaluate liquefaction potential. The empirical SPT, CPT and Vs methods are illustrated in Figure 1.

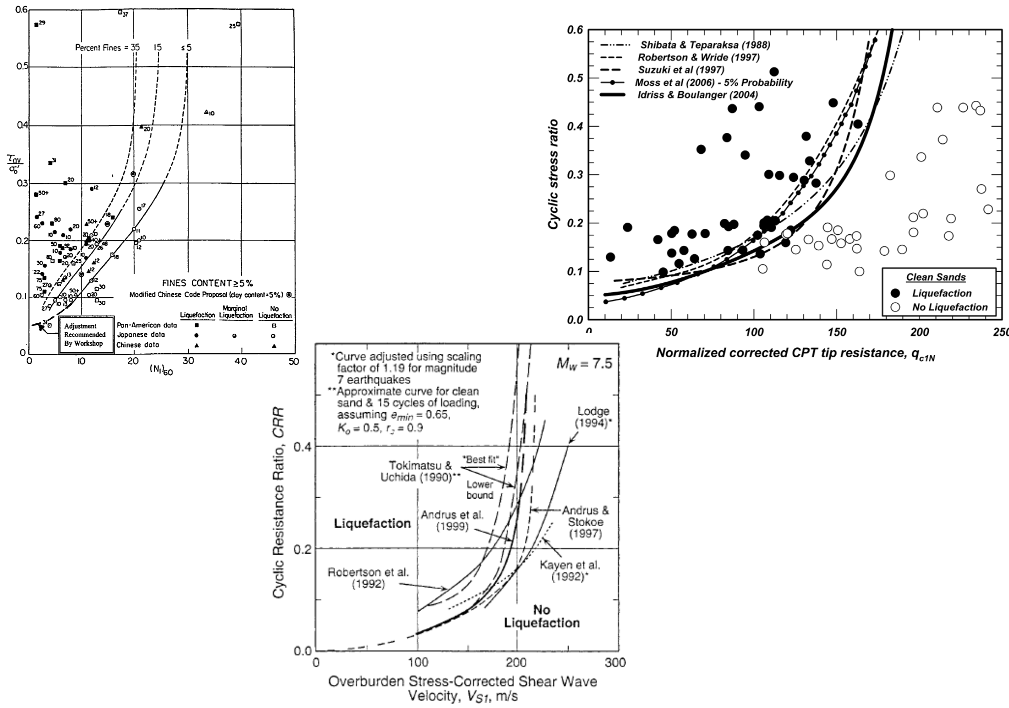

Figure 1. Empirical Methods Used in Seismic Liquefaction Potential Evaluation

Challenges associated with the currently used liquefaction potential evaluation methods

The USNRC allows the use of both laboratory testing based and empirical methods to estimate the seismic liquefaction potential in siting evaluation. The U.S Regulatory Guide (RG) 1.198 (2003) allows use of a factor of safety, FS, in empirical procedures for the evaluation of liquefaction potential.

Although the guidance specifies the FS values that can be used in evaluation of liquefaction potential, there are many questions that need to be answered when engineers are trying to draw conclusions on how reliable the liquefaction potential evaluation is. As there are so many uncertainties related to engineering input parameters, the seismic input parameters, the quality of laboratory test results, etc., it is questionable that the FS value can adequately takes those uncertainties into consideration. Another important issue is that no model, neither analytical nor empirical, can provide 100 percent accuracy to predict the liquefaction potential. Figure 1 clearly illustrates the range of variation among all three empirical methods; therefore the FS cannot provide us confidence of the analysis results even if a higher value of FS is obtained. There is no doubt that a better method is needed in order to assess the seismic liquefaction potential with a certain confidence level in new reactor siting evaluations.

Seismic soil lateral earth pressure analysis in nuclear power plant structural stability evaluation

In nuclear power plant structure stability analyses, the lateral earth pressure on the foundation wall needs to be determined for evaluation of sliding and overturning stability, as well as the structural stability of the foundation. The total lateral earth pressure includes pressures induced by surface surcharge, side fill soil self-weight and compaction, seismic and hydraulic loadings. Among all components of the total earth pressure, it is very important to realistically estimate the seismic loading induced earth pressure.

Currently used methods for seismic soil lateral earth pressure analysis

The seismic loading induced earth pressure includes “active” and “at-rest” earth pressures. The active pressure is often estimated by using the Mononobe-Okabe (M-O) method that was published in the late 1920’s. The M-O method is based on the following assumptions: the backfill materials are dry cohesionless materials; the retaining wall yields equally and sufficiently to produce minimum active soil pressure; the active soil pressure is associated with a soil wedge behind the wall which is at the point of incipient failure and the maximum shear strength is mobilized along the potential sliding surface; and the soil behind the wall behaves as a rigid body and the acceleration is uniform in the soil wedge. The M-O model is expressed by

$$P_{AE} = 0.5\gamma H^2 (1 - Kv) * K_{AE} \tag{4}$$

where P_{AE} is the active thrust per unit length of the wall; γ is unit weight of the soil; H is the height of the wall; Kv is vertical wedge acceleration (in g); and K_{AE} is the seismic active earth pressure coefficient, which is a function of the angle of internal friction of the soil, the angle of wall friction, slope of ground surface behind the wall, slope of the wall relative to the vertical, and angle of the vertical and horizontal seismic forces acting on the wall, $\theta = \tan^{-1}(Kh/(1-Kv))$, where Kh is horizontal wedge acceleration (in g).

The M-O method and the associated analytical relationships were later simplified by Seed and Whitman (1970) for design of earth retaining structures under dynamic loads. Using the developed charts, the designer only needs to know the basic properties of the backfill (the angle of internal friction) and the peak ground acceleration to obtain the seismic soil pressure.

Since the amplifications of the motion in the soil mass around the non-yielding (at-rest condition) foundation walls were found to be significant in some cases, efforts have been made to establish models to estimate the seismic loading induced at-rest earth pressure. Currently, the mostly used methods are the Wood method and Ostadan method.

Wood’s method is an equivalent static elastic solution of seismic soil pressure on non-yielding walls. This solution is based on finite element analysis of a soil-wall system in which a wall rests on a rigid base and a uniform soil layer is behind the wall. In general, Wood’s solution yields a lateral force that acts at about 0.63 times the height of the wall above its base and the soil pressure is approximate to a parabolic distribution, instead of M-O’s inverted triangular distribution. Wood’s solution predicts a larger (a factor of 2-3) seismic soil pressure compared with that predicted by the M-O method. The elastic solution proposed by Wood has been adopted by the ASCE Standards for nuclear power plant structures (1986). Wood’s solution requires knowledge of the maximum ground acceleration along with the density and Poisson’s ratio of the soil to calculate the seismic soil pressure behind the wall.

The Ostadan method is another method commonly used in nuclear power plant siting evaluation in the U.S. The Ostadan method uses the concept of a single degree-of-freedom (SDOF) system to develop a simplified method to predict the maximum seismic soil pressure for buildings resting on firm foundation materials. This method incorporates the dynamic soil properties and the frequency content of the design ground motion in its formulation and allows soil nonlinear effects to be considered. This method requires the use of conventional one-dimensional soil column analysis to obtain the free field ground soil response at the base of the wall with the use of $\Psi\nu$ factor to account for the soil property of Poisson’s ratio. This factor is expressed by

$$\Psi\nu = \frac{2}{\sqrt{(1-\nu)(2-\nu)}} \tag{5}$$

and the total soil mass involved is expressed by

$$m = 0.50\, \rho\, H^2\, \Psi\nu \tag{6}$$

where ρ is the mass density of the soil (total weight density divided by the acceleration of gravity), and H is the height of the wall.

The Ostadan method consists of four steps by calculating: 1) the total mass for a representative SDOF system using the Poisson's ratio and mass density of the soil; 2) lateral seismic force from the product of the total mass and the acceleration spectral value of the free-field response at the soil column frequency obtained at the depth of the bottom of the wall; 3) the maximum lateral seismic soil pressure at the ground surface level by dividing the lateral force by the area under the normalized seismic soil pressure (the considered area is 0.744 H); and 4) the pressure profile by multiplying the peak pressure using the pressure distribution relationship

$$p(y)= -.0015 + 5.05y - 15.84y2 + 28.25y3 - 24.59y4 + 8.14y5 \quad (7)$$

where y = Y/H is normalized height with Y measured from the bottom of the wall and varies from 0 to H.

Challenges associated with currently used soil lateral earth pressure analysis methods

Although many methods/procedures have been developed to evaluate seismic loading induced lateral earth pressure on nuclear power plant foundations, the USNRC has accepted only a few. A common issue for those methods is the lack of model validation. To illustrate an example, Figure 2 presents the comparison of recorded seismic lateral earth pressure data from a scaled reactor building with predictions by the SASSI and LS-DYNA models, showing a large mismatch at the low frequency range (Xu et al. 2008).

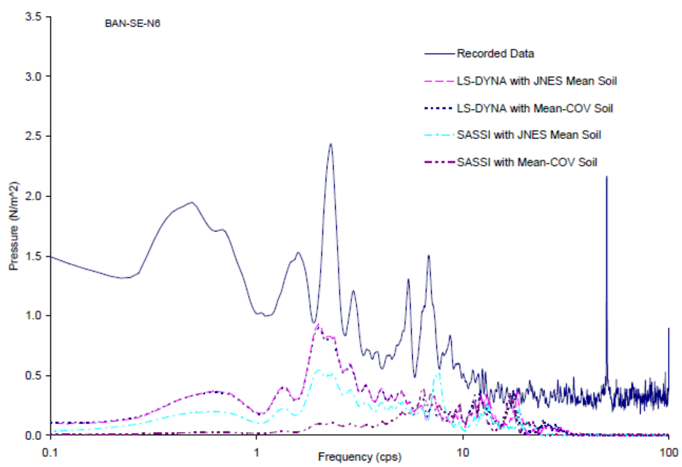

Figure 2. Comparison of Recording Data with Model Predictions (Figure 4.3-7 of NUREG/CR 6957)

The discrepancy between measured data and model predictions raises some questions, such as how much inaccuracy is associated with the uncertainty of the soil properties and seismic loading, and how much is associated with model approximation? More importantly, what level of confidence do we really have when using these commonly accepted methods to estimate seismic lateral earth pressure? Again, it is clear that a better approach is desired.

Dynamic bearing capacity of soil

Soil bearing capacity is another important aspect when evaluating foundation stability. Since the nuclear power plant structures must be able to withstand both static and dynamic (mainly seismic) loadings, the bearing capacity of materials supporting the structure under all loading conditions must meet the design requirement with an adequate safety margin.

Currently used methods for soil bearing capacity evaluations

One of the commonly used methods for bearing capacity evaluations were originally developed to estimate the bearing capacity of soil under static loading conditions. These methods usually assume that the soil below the foundation, along a critical plane of failure (slip path), is on the verge of failure. The bearing capacity is determined by calculating the pressure applied by the foundation which will result in such a failure.

This method provides the ultimate bearing capacity q_u and its general expression is:

$$q_u = cN_c\zeta_c + \frac{1}{2}B\gamma'_H N_\gamma \zeta_\gamma + \sigma'_D N_q \zeta_q \tag{8}$$

where q_u = ultimate bearing capacity pressure, c = soil cohesion (or undrained shear strength Cu), B = foundation width, γ'_H = effective unit weight beneath foundation base within failure zone, σ'_D = effective soil or surcharge pressure at the foundation depth D, γ'_D = effective unit weight of surcharge soil within depth D, N_c, N_γ, N_q = dimensionless bearing capacity factors for cohesion c, soil weight in the failure wedge, and surcharge q terms, and ζ_c, ζ_γ, ζ_q = dimensionless correction factors for cohesion, soil weight in the failure wedge, and surcharge q terms accounting for foundation geometry and soil type.

The general ultimate bearing capacity equation is based on Terzaghi's bearing capacity theory (1948), although it has been improved during the past several decades and other bearing capacity analysis models exist, that assumes a shallow, rough, rigid and continuous foundation supported by a homogeneous soil layer extending to a great depth. The general shear failure of the foundation occurs when the static loading exceeds the strength of the soil. The more advanced analysis methods utilize the finite element method (FEM) to more realistically model soil layers, foundations and structures above the foundation.

In engineering practice, allowable bearing capacity is used in design and it is defined as

$$q_{all} = \frac{q_u}{FS} \tag{9}$$

where q_{all} is allowable bearing capacity, and *FS* is factor of safety. The factor of safety is usually determined by the loading conditions and other factors. For static loading conditions, a factor of 3 to 4 is generally accepted.

Despite the efforts to determine the ultimate bearing capacity of soil under dynamic, including seismic loading conditions, there is no generally accepted method in engineering practices. Engineers normally estimate the allowable dynamic bearing capacity using equation (9) but with a smaller value of FS because both static and seismic loadings are accounted for in foundation dynamic response analysis and the seismic loading is a transient load.

Challenges associated with the currently used soil dynamic bearing capacity analysis methods

The response of a foundation to dynamic loading generally is affected by the (1) nature and magnitude of dynamic loads, (2) number of pulses (or cyclic loading duration) and (3) the strain rate response of soil. Laboratory experiment and field observations have shown that the mechanism of

foundation failure is different under different loading conditions. Foundations normally fail in general shear mode under static loadings, but local shear failure occurs under dynamic loadings. Large settlements at failure have been observed under dynamic loading conditions. Experimental results indicate that for a given value of settlement, the dynamic bearing capacity may be lower than the static bearing capacity for certain type of soils.

Based on the above facts, we need answers to the following questions regarding dynamic bearing capacity evaluation: (1) Are the methods currently used in engineering practices adequate to estimate soil dynamic bearing capacity? (2) Which method(s) can be used to realistically estimate dynamic bearing capacity? (3) What value of FS should be used when determining allowable dynamic bearing capacity for soil and for rock as well? and (4) How to assess the confident level when we use factor of safety to evaluate soil/rock bearing capacity? It is no doubt that we need a method that can better estimate soil dynamic bearing capacity with reasonable accuracy and an acceptable level of confidence.

MEET THE CHALLENGES IN NEW REACTOR SITING EVALUATION IN THE GEOTECHNICAL ENGINEERING FIELD

To meet the challenges in new reactor siting evaluations with respect to geotechnical engineering, we need to study the state-of-the-art and state-of-the-practice in all engineering fields and to identify the methods that best fit geotechnical engineering practices and provide solutions to the challenges.

Among all potential solutions, the performance based design approach may be a good candidate. It is no secret that the USNRC has been making great efforts in the development and implementation of risk-informed performance-based approaches in its regulations since the 1990's. The risk-informed performance-based approach currently is used in USNRC regulatory decision-making, and also applied in some technical evaluation areas. For example, the performance-based approach has been used in determining the site-specific earthquake ground motion response spectrum which is an important factor in the site suitability determination. The performance-based approach may be a powerful weapon because this approach can account for uncertainties. Its probability basis is risk consistent and can provide better confidence level measures.

Although the performance-based method has many advantages, there are challenges when apply this method in geotechnical engineering practice. The first and very basic issue is how to adequately determine the target of performance. For example, what is the reasonable targeted performance goal for liquefaction potential for a site when the coefficient of variation (c.o.v) of soil property is not uncommonly more than 30%? Similar issues exist also for evaluation of bearing capacity, settlement, lateral earth pressure, slope stability, etc. However, despite those challenges, we should first consider applying probability-based methods in some areas as a step forward.

Probability approach application in slope stability analysis

When performing slope stability analysis, uncertainties exist in many variables/parameters, such as geometry of slope, loading conditions, pore water pressure distribution, the shear strength of soils, and dynamic loads including earthquake induced seismic loading. In current engineering practices, factor of safety is normally used to account for the uncertainties, but probabilistic approaches can provide a measure of degree of confidence on the design and analysis results. To illustrate how to apply the probabilistic approach in slope stability analysis, an example is presented as follows.

Deterministic slope stability analysis

For a slope as shown in Figure 3, with input variable parameters as listed in Table 1, the factor of safety can be calculated using different methods, such as Ordinary, Bishop, Janbu, Spencer, Morgenstern-Price and General Limit Equilibrium (GLE) methods. As each method has its own advantages and limitations, either a best suitable method or more than one method should be used to analyse the slope stability in practices. The results of calculations using mean parameter values as input in the GeoSlope program are listed in Table 2.

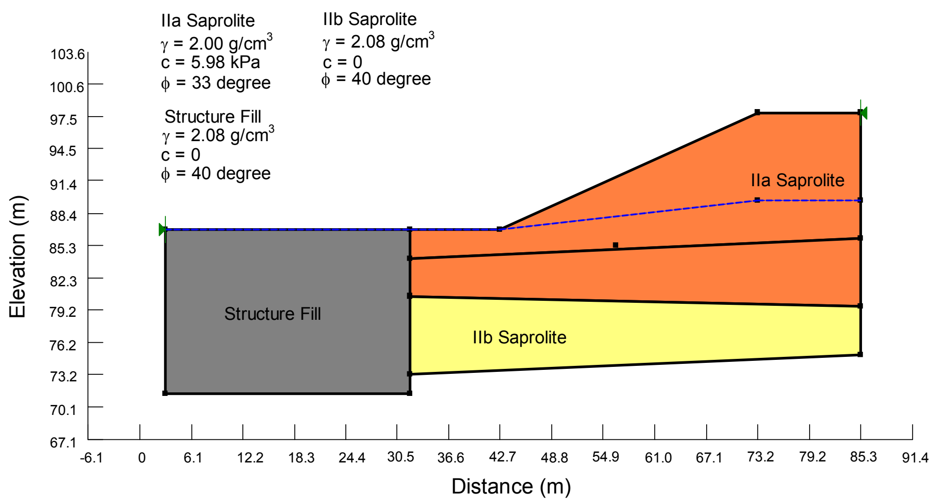

Figure 3. Cross section, material properties of an example slope used in slope stability analysis

Table 1. Slope stability analysis input variables

	Variable	Mean Values	Coefficient of variation V (%)
Zone IIA Saprolite	Unite weight γ, g/cm^3 (pcf)	2.00 (125)	5
	Effective internal friction angle ϕ, degree	33	7
	Cohesion c, kPa (psf)	5.98 (125)	10
Zone IIB Saprolite	Unite weight γ, g/cm^3 (pcf)	2.08 (130)	5
	Effective internal friction angle ϕ, degree	40	7
	Cohesion c, kPa (psf)	0	
Structure Fill	Unite weight γ, g/cm^3 (pcf)	2.08 (130)	3*
	Effective internal friction angle ϕ, degree	40	5*
	Cohesion c, kPa (psf)	0	
Seismic Loading	Horizontal acceleration a_h, g	0.50**	Unknown
	Vertical acceleration a_v, g	0.25**	Unknown

* Assumed value.
** One-half of the peak ground acceleration value is used in seismic slope stability analysis.

Table 2. Factor of safety values using different models

Model	Ordinary	Bishop	Janbu	General Limit Equilibrium (GEL)	Spencer	Morgenstern-Price
Factor of Safety	1.114	1.122	1.049	1.128	1.128	1.128

Probabilistic slope stability analysis

Although the deterministic FS procedure is accepted in current engineering practices, it can be seen that using different models can result in different values of FS with the same input parameters. More importantly, we do not know what level of confidence is associated with the calculated FS values. For example, we cannot tell whether a slope with FS of 1.3 is really more stable than the one with FS of 1.1 when the variation of the input parameters is different. However, the probabilistic method can provide us information on the reliability of our analysis results if the variation of the input is known.

A probabilistic slope stability analysis by using a Monte Carlo simulation was performed for the same slope used in deterministic stability analysis. The results showed that the change of c.o.v for all variables affected the mean value of FS of slope stability insignificantly but greatly on probability of slope failure. When the c.o.v of ground motion acceleration increased from 10% to 100%, the probability of slope failure increased from 0.05% to 43.5%. This example showed that the probabilistic method can provide us with information on the reliability of our analysis results in addition to the FS obtained by conventional deterministic methods, but the wide range of variation existing in geotechnical engineering posts a challenge in its application in practice.

SUMMARY AND CONCLUSIONS

This paper identifies and discusses some challenges in new reactor design and siting evaluations in the geotechnical engineering field based on lessons learned from current combined license application reviews by the U.S. NRC. It discusses some developments, both technical and regulatory, related to these challenges and explores possible solution to meet these challenges. Based on the lessons learned, we can conclude that:

1. Geotechnical engineers face many challenges in today's new reactor design and siting evaluations because of new technology and regulation requirements. We need to identify these challenges and find solutions to meet the challenges.
2. With so many uncertainties and variations existing in our engineering practices, many conventional methods cannot meet today's needs because they either do not utilize the state-of-the-art methods, or cannot provide a result with a known level of confidence in nuclear power plant siting evaluations.
3. To meet the new challenges in new reactor siting evaluations, state-of-the-art and state-of-the-practice methods should be carefully studied. Suitable methods need to be selected or developed, which requires great effort from all people, including engineers, researchers and regulators who are involved in the new reactor siting evaluations. The performance-based approach is one of the solutions but many questions have not been answered, and detailed practical methods/procedures still need to be developed. The example provided in this paper indicates that we may be able to first use the probabilistic method in our engineering practices before fully developing performance-based methods, but many details need to be worked out.

REFERENCES

Das, B. M. (2009. *Shallow Foundations Bearing Capacity and Settlement, 2nd ed.*, CRC Press.

Mononobe, N. and H, Matuo (1929). "On the determination of earth pressures during earthquakes," Proceeding of World Engineering Congress, Tokyo, Vol. 9, Paper 388, 1929.

Ostadan, F. and W. H. White (1998). "\"Lateral Seismic Soil Pressure- an Updated Approach," presented at the US-Japan SSI Workshop, September 22-23, 1998

Richards, R., Jr., Elms, D.G and Budhu, M (1993). "Seismic Bearing Capacity and Settlement of Foundations." *J. Geotechnical Engineering*, ASCE, 119(4):622-674.

Seed, H.B. and R.V. Whitman (1970), "Design of Earth Retaining Structures for Seismic Loads," ASCE Specialty Conference on Lateral Stresses in the Ground and Design of Earth Retaining Structures, June, 1970.

Seed, H. B., and I. M. Idriss (1971). "Simplified procedure for evaluating soil liquefaction potential". J. Soil Mech. Found. Div. 97, 1249–1273.

Wood, J. H. (1973) "Earthquake Induced Soil Pressures on Structures," Doctoral Dissertation, EERL 73-05, California Institute of Technology, Pasadena, CA, 1973.

USNRC Regulatory Guide 1.208 "Performance Based Approach to Define the Site Specific Earthquake Ground Motion." March 2007.

USNRC Regulatory Guide 1.198 "Procedures and Criteria for Assessing Seismic Soil Liquefaction at Nuclear Power Plant Sites." November 2003.

Xu, J., J. Nie, C. Costantino and C. Hofmayer (2008), "Correlation Analysis of JNES Seismic Wall Pressure Data for ABWR Model Structures." NUREG/CR-6957, March 2008

Youd, T. L., I. M. Idriss (2001), "Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, J. Geotechnical and. Geoenvironmental Engineering Vol 127, No. 4, April 2001, pp. 297–313.