Site Response and Shear Behavior of Stone Column-Improved Ground under Seismic Loading

Jin Man Kim
Associate professor, Department of Civil Engineering, Pusan National University, Busan, South Korea

Su-Won Son
Graduate Student, Department of Civil Engineering, Pusan National University, Busan, South Korea

Khalid Mahmood
Ph.D., Department of Civil Engineering, Pusan National University, Busan, South Korea

Jeong Ho Ryu
Ph.D., Department of Civil Engineering, Pusan National University, Busan, South Korea

SUMMARY:
The site response and shear behavior of stone column-improved ground under seismic loading are studied using a series of 1-g shaking table tests. The experimental results show that the stone column can prevent large shear deformation in clayey deposits. The assumption and experimental verification that soft ground and stone column have identical shear strain can lead to simple 1D ground response analysis for stone column improved ground since the improved ground can be considered as a single composite ground.

Keywords: seismic motion, site response, stone column, clayey deposits

1. INTRODUCTION

Stone columns are commonly used for improving soft ground like soft clay and loose sands. Under suitable conditions this technique has proven successful for increasing bearing capacity, slope stability, reducing settlement, increasing the time-rate of consolidation and reducing liquefaction potential (FHWA, 1983). In geotechnical earthquake engineering this technique is commonly used to mitigate the liquefaction phenomena of loose granular soil deposits. In case of liquefaction mitigation the method has thus been well studied and developed. The stone column has been well developed concerning conventional problems in clayey deposits. However, seismic performance of this method in clayey deposits has been very little studied and thus needed to be investigated (i.e., Goughnour and Pestana, 1998).

The site response is one of the most important factors to estimate the seismic performance of both improved and unimproved soft ground deposits. In case of soft clay deposits the geotechnical engineers are more concerned to site amplification and shear deformation due to earthquake loading. Studies of ground motion records from Michoacan (Ms= 8.1) at different sites in Mexico City illustrated the significance relationship between local soil conditions and damaging ground motions and led to important advances in understanding the cyclic response of plastic clays (e.g., Vucetic and Dobry, 1991). The purpose of this study is therefore to investigate the seismic performance of stone column improved clayey deposits using 1-g shaking table scale model tests. The soft ground in these tests has been made using kaolinite clay found in the east southern area of Korea.

2. 1-G SHAKING TABLE TEST PROGRAM

The 1-g shaking table test program includes the assembly of laminar container on 1-g shaking table. The model ground of soft clayey deposit is constructed inside the laminar container

2.1. Facility and equipments

1-g shaking table (3-degresss of freedom) that has a dimension of 5m length and 5m width has been used (Figure 1). The standard laminar container has a dimension of 2.0m length, 1.2m width, 1.8m height, and consists of 40 laminar layers (Figure 21. However, the laminar container used in this study is about 1.0m (21 layers) high.

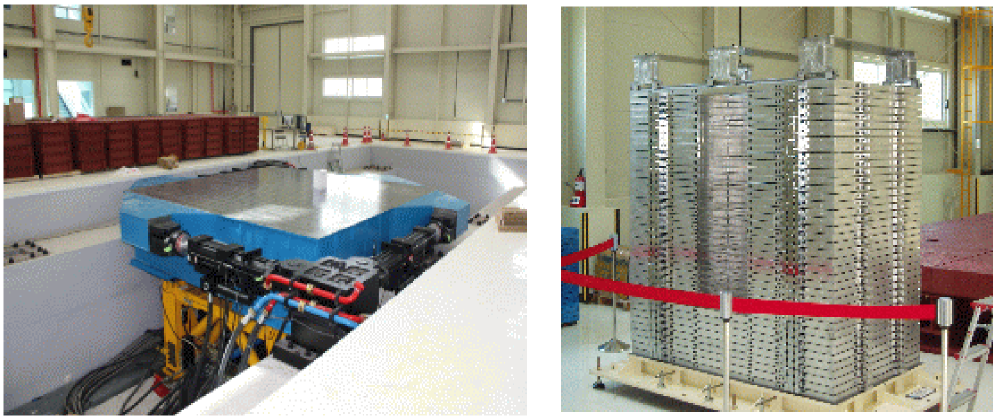


Figure 1. 1-g shaking table and laminar container at Pusan National University, Korea

2.2. Instrumentation

The instrumentation is shown in Figure 2. It consists of 13 accelerometers. Each vertical array of accelerometers has been located between the stone column and model clay to observe the site response of stone column improved model ground. The dynamic shear strain of model ground under seismic loading has been evaluated using double integration technique (i.e., Yang et al., 2006) from acceleration response of model ground**.**

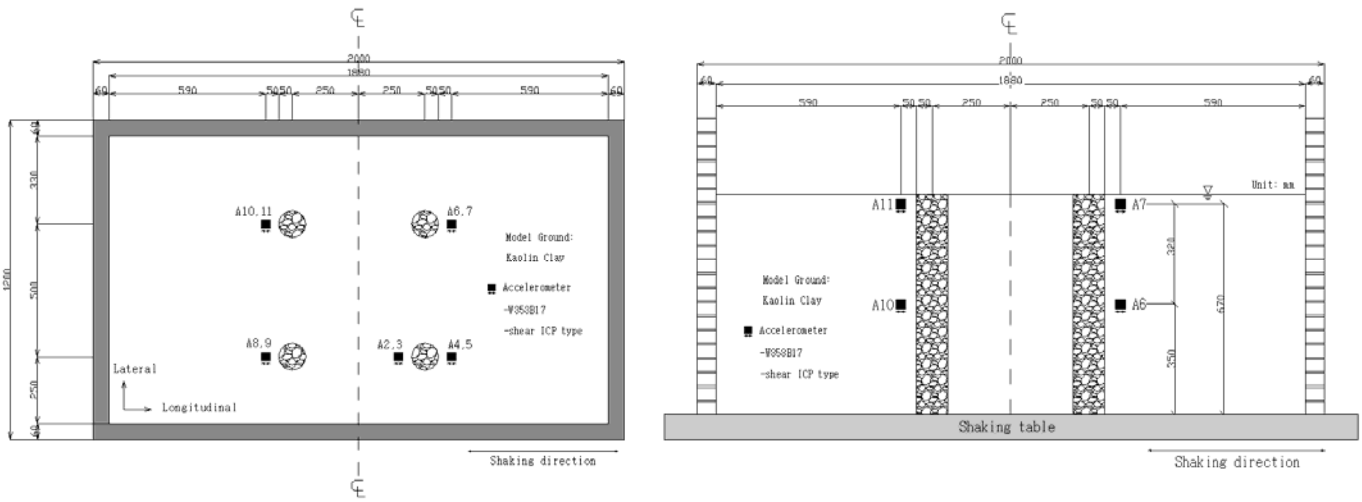


Figure 2. Schematic drawing of the instrumentation installed in the model ground

2.3. Construction of Model Ground

The laminar container is filled with model clay for both unimproved and stone column-improved grounds. In case of the unimproved model ground the test program commences with placing 0.67m high 15 layers of soft clay. This soft clay is mixed at 95~105% of water content. 4 stone columns with 100mm diameter are installed in the improved ground. Figure 3 shows the stone column installation process.

Table 1. Basic Properties of the Model Ground

USCS	G_s	LL (%)	PI (%)
CH	2.6	64.2	31

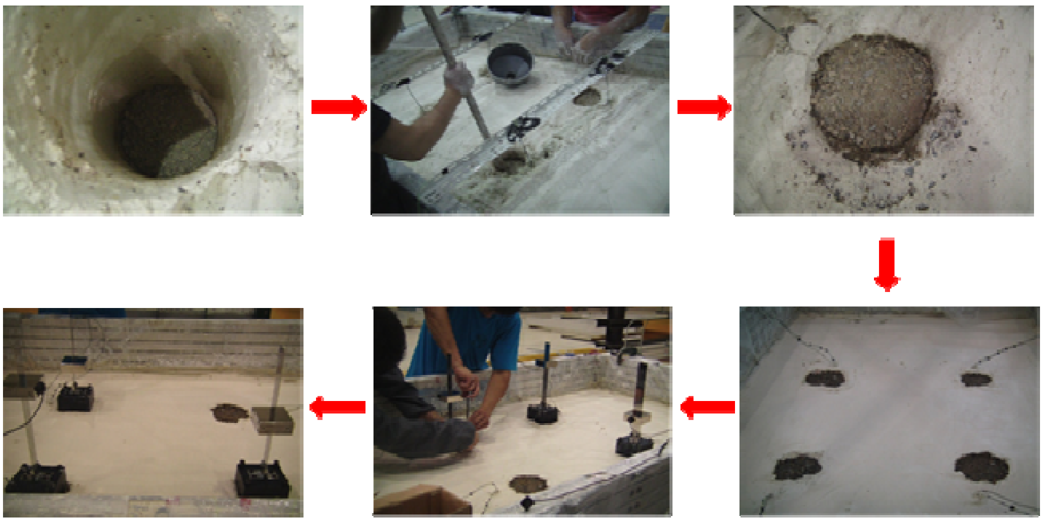
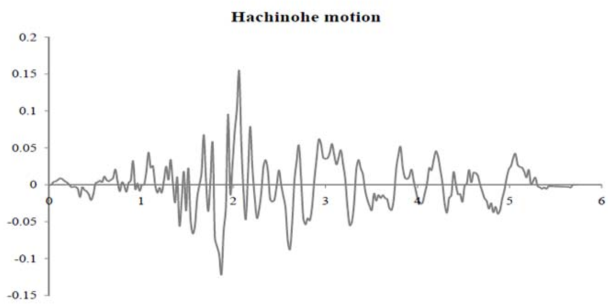


Figure 3. Installation of the stone columns in the model ground

2.4. Test Procedure

Earthquake motions selected for this study are Hachinohe and Northridge earthquakes (Fig 4). The ground motion parameters of these earthquakes are shown in Table 2.



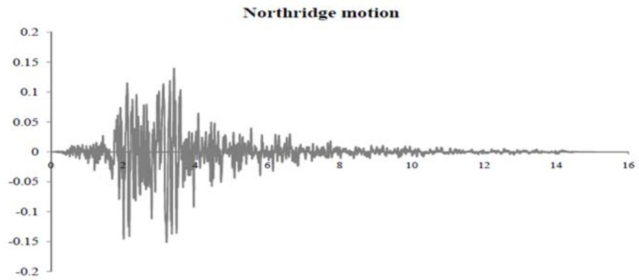


Figure 4. Time-scaled motions for model tests

Table 2. Ground Motion Parameters of Hachinohe and Northridge Motions

	Hachinohe	Northridge
PHA[*1] (g)	0.153	0.151
PDP[*2] (sec)	0.195	0.105
BD[*3] (sec)	2.4	2.8

*1.PHA: Peak Horizontal Acceleration; *2. PDP: Pre Dominant Period; *3. BD: Bracket Duration

3. TEST RESULTS AND DISCUSSION

The results are presented in the form of acceleration, shear strain in time histories, and 5% damped response spectra of acceleration. Data processing and filtering of the acceleration records are considered by zeroing the mean value and providing baseline correction for each record to evaluate the shear strain in time histories.

3.1. Site Responses in the Model Ground under Hachinohe Motion

Figure 5 shows the site responses of unimproved and improved model grounds under Hachinohe motion. The site responses of the improved model ground in terms of the maximum acceleration were around 12% of the unimproved model ground.

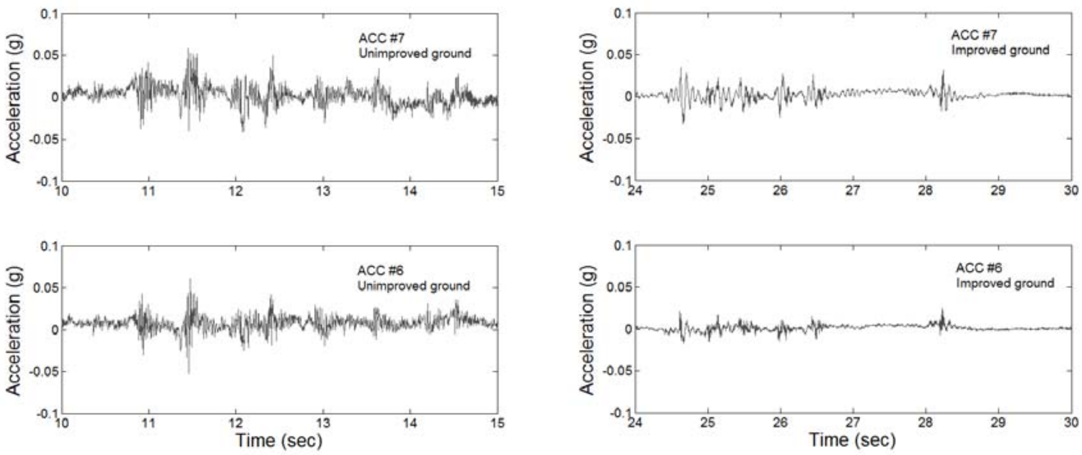


Figure 5. Site responses of unimproved and improved model grounds under Hachinohe motion

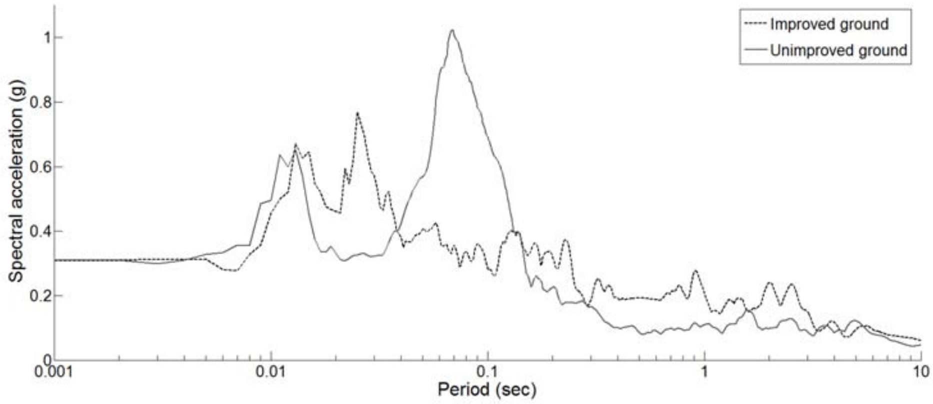


Figure 6. Peak spectral accelerations of unimproved and improved model grounds under Hachinohe motion

Figure 6 shows that the periods for peak spectral accelerations are quite different. In case of unimproved and improved grounds, the peak spectral acceleration occurs in the range of 0.1 sec and 0.04~0.05sec respectively. The stone column increases the stiffness of the ground. This increase in stiffness makes the natural ground deposit have short periodic characteristics and attenuate ground acceleration in the predominant period of the scaled Hachinohe motion.

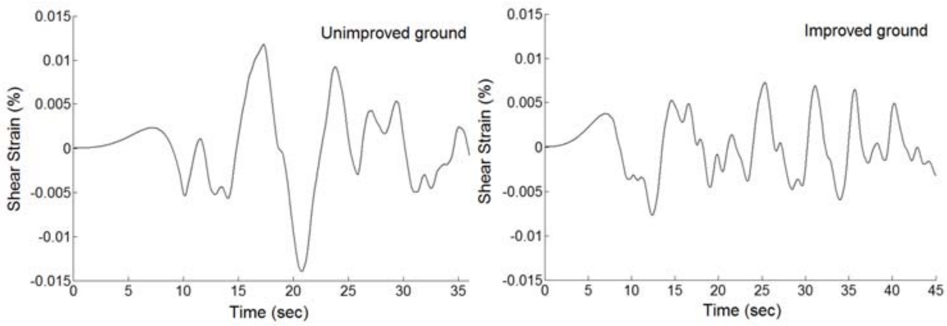


Figure 7. Maximum shear strain for unimproved and improved model grounds under Hachinohe motion

Figure 7 shows that in case of the scaled Hachinohe motion the maximum shear strain for unimproved and improved model grounds are 0.014% and 0.0087%, respectively. These results show that the stone column improved ground can prevent earthquake-induced shear deformation up to 38% that of unimproved ground under the scaled Hachinohe motion

3.2. Site Responses in the Model Ground under Northridge Motion

Figure 8 shows the site responses of unimproved and improved model grounds under Northridge motion. The site responses of improved model ground in terms of maximum acceleration was around 7% of the unimproved model ground.

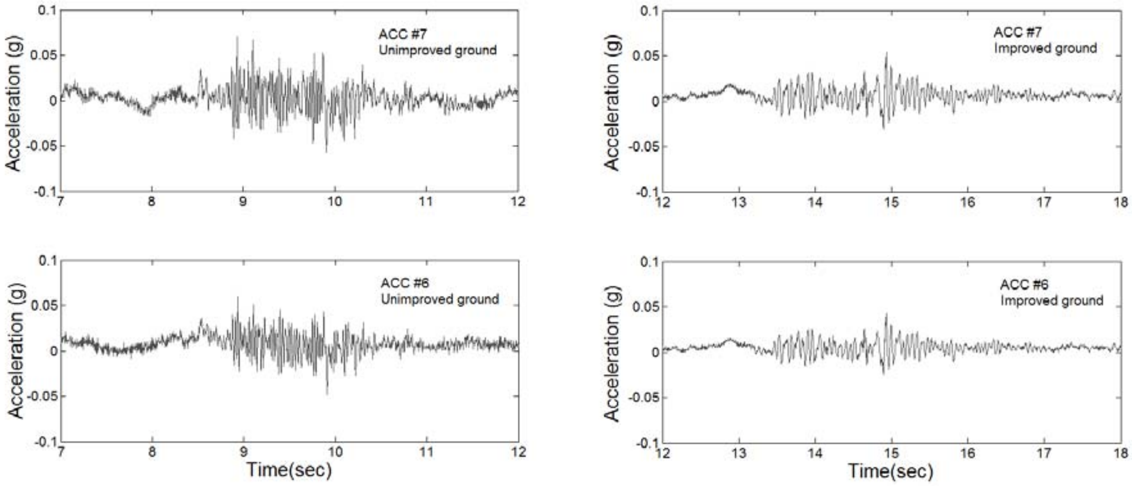


Figure 8. Site responses of unimproved and improved model grounds under Northridge motion

Figure 9 shows that the periods for peak spectral accelerations are quite different. In case of unimproved and improved grounds, the peak spectral accelerations occur in the range of 0.05~0.07 sec and 0.02~0.03sec respectively. The stone column increases the stiffness of the ground. This increase in stiffness makes the natural ground deposit have short periodic characteristics and attenuate the ground acceleration in the predominant period of scaled Northridge motion

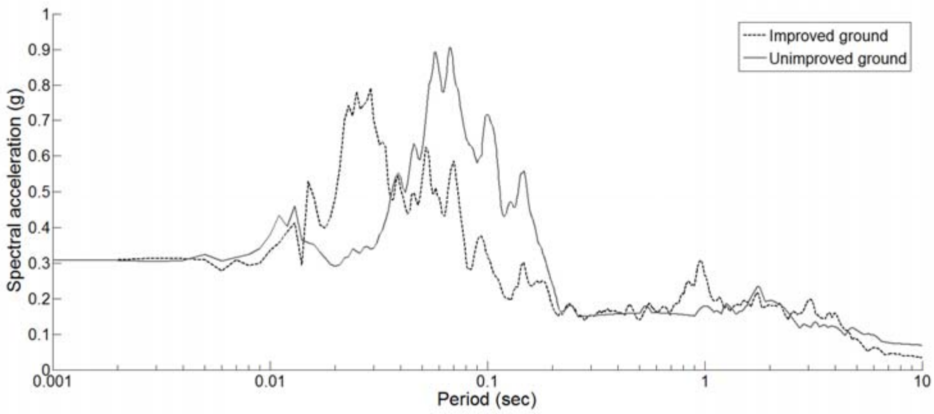


Figure 9. Peak spectral accelerations of unimproved and improved model grounds under Northridge motion

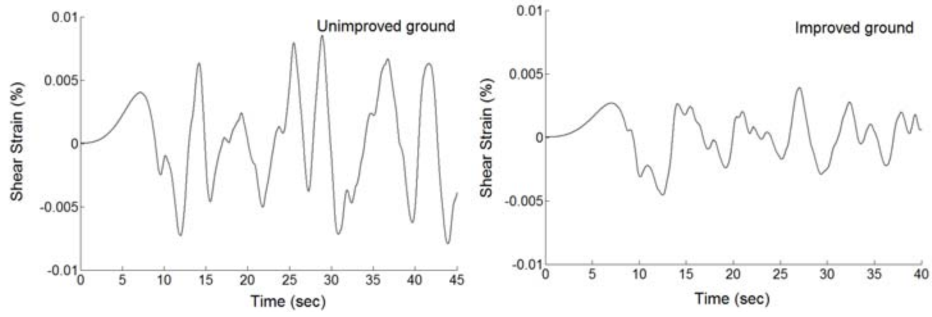


Figure 10. Maximum shear strain for unimproved and improved model grounds under Hachinohe motion

Figure 10 shows that in case of the scaled Hachinohe motion the maximum shear strain for unimproved and improved model grounds are 0.081% and 0.051%, respectively. These results show that the stone column improved ground can prevent earthquake-induced shear deformation up to 36% that of unimproved ground under the scaled Hachinohe motion.

3.3. Shear Behaviours of soft ground and stone column

Figures 11 shows that ACC #3 and #5 have difference as 0.2% only in terms of the acceleration level and the phase difference between ACC #3 and #5 is also little as 4.5 millisecond. Therefore, it can be concluded that the accelerations at the interface between the stone column and clay deposit are almost same. This result may support Baez's assumption (Baez, 1995). This assumption can lead to simple 1D ground response analysis for the stone column improved ground as a composite ground, which has single dynamics stiffness, cyclic nonlinear shear strain – shear stress relationship.

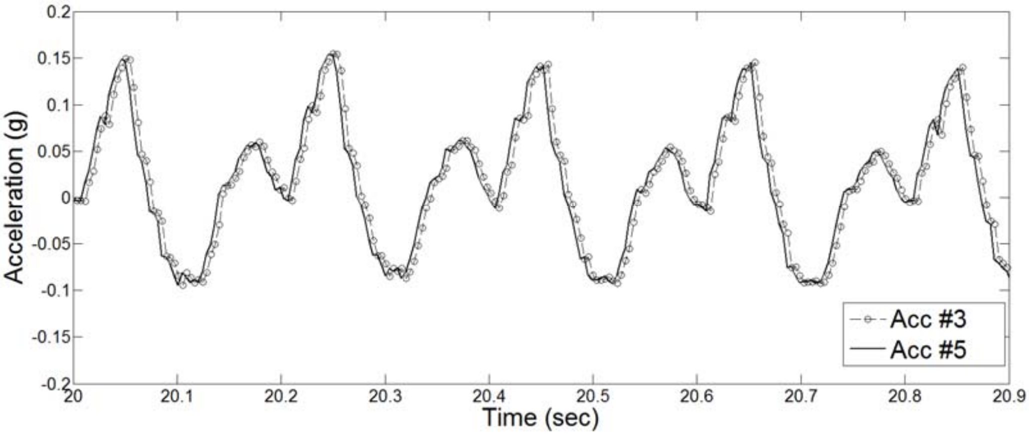


Figure 11. The difference of acceleration response between ACC#3 and ACC#5

4. CONCLUSION

The seismic performance of the stone column improved ground has been investigated by using the 1-g shaking table tests.

The seismic response of the stone column improved ground depends on frequency content of earthquake motion. The stiffness increase due to stone column installation in the soft ground causes to reduce the natural period of the improved ground.

The test results show that the stone column improved ground can prevent earthquake induced large shear deformation as compared to that of the unimproved ground.

The assumption and experimental verification that soft ground and stone column have identical shear strain can lead to simple 1D ground response analysis for stone column improved ground since the improved ground can be considered as a single composite ground.

AKCNOWLEDGEMENT

This research is supported by the Ministry of Land, Transport and Maritime Affairs, Korea 2010 research grant (2010 Construction Technology Innovation Program, 10-CTIP-E04)

REFERENCES

Baez J.I. (1995). A design model for the reduction of soil liquefaction by vibro-stone columns. *Ph.D.Dissertation,Univ.of SouthernCalifornia*

FHWA (1983). Design and construction of stone column. *FHWA/RD-83/026, Federal Highway Administration Office of Engineering and Highway Operation Research and Development Washington, D.C. 20590*

Goughnour, R.R., and Pestana, J.M. (1998). Mechanical behavior of stone columns under seismic loading. *2nd International conference on Ground Imporvement Techniques: 8-9 October 1998, Singapore*: 157-162

Yang, J., Li, J.B., and Lin, G. (2006). A simple approach to integration of acceleration data for dynamic soil-structure interaction analysis. *Soil Dynamics and Earthquake Engineering*, 26: pp. 725-734

Vucetic, M. and Dobry, R. (1991). Effect of soil plasticity on cyclic response. *ASCE Journal of Geotechnical Engineering*, 117 (1): 89-107