World Academy of Science, Engineering and Technology
International Journal of Civil and Environmental Engineering
Vol:8, No:2, 2014

Prediction of Soil Liquefaction by Using UBC3D-PLM Model in PLAXIS

A. Daftari, W. Kudla

***Abstract*—**Liquefaction is a phenomenon in which the strength and stiffness of a soil is reduced by earthquake shaking or other rapid cyclic loading. Liquefaction and related phenomena have been responsible for huge amounts of damage in historical earthquakes around the world.

Modeling of soil behavior is the main step in soil liquefaction prediction process. Nowadays, several constitutive models for sand have been presented. Nevertheless, only some of them can satisfy this mechanism. One of the most useful models in this term is UBCSAND model. In this research, the capability of this model is considered by using PLAXIS software. The real data of superstition hills earthquake 1987 in the Imperial Valley was used. The results of the simulation have shown resembling trend of the UBC3D-PLM model.

***Keywords*—**Liquefaction, Plaxis, Pore-Water pressure, UBC3D-PLM.

I. Introduction

During an earthquake, when the ground is subjected to strong shaking, certain types of soils liquefy, often leading to ground failures. Ground failure associated with liquefaction of soils are potentially very damaging as forcefully demonstrated by many disastrous earthquakes of the past [1].

The mechanism of liquefaction has been well recognized. The cyclic shearing of saturated granular soils causes a progressive buildup of pore water pressure which eventually approaches a value equal to the initial confining pressures, thereby softening the soil causing large strain. Such a state has been termed as ‘liquefaction’.

The determination of liquefaction potential of soils induced by earthquake is a major concern and an essential criterion in the design process of the civil engineering structures.

The main reason of most of the structure damages during the earthquake is accepted to be liquefaction. In recent strong earthquakes such as Alaska (1964), USA (1987), Japan (1995), Turkey (1999), Taiwan (1999), Iran (2004) and China (2008), many buildings, highway, embankments and other engineering structures have been damaged or destroyed as result of liquefaction.

A.Daftari is PhD candidate in Department of Mining and Special Foundation Engineering, Technical University Bergakademie Freiberg, Freiberg, CO 09599 Germany (phone: 3731-39-3581; fax: 3731 39-3581; e-mail: Abbas.Daftari@mabb.tu-freiberg.de).

W. Kudla is Prof. Dr. Eng. in Department of Mining and Special Foundation Engineering, Technical University Bergakademie Freiberg, Freiberg, CO 09599 Germany (e-mail: wolfram.kudla@mabb.tu-freiberg.de).

Researchers have presented several constitutive models for sand such as: FINN, UBCSAND, UBC3D-PLM, HYPOPLASTICITY, NORSAND, HYPERBOLIC and BOUNDING SURFACE models. Most of these models have been defined base on complicated mathematic formulations. Although, these complex model have could not satisfy the liquefaction process [2].

A constitutive model of a soil describes its stress-strain behavior. The stress-strain behavior of a soil depends on many factors such as the type of soil, stress-strain history, mode of deposition, anisotropy, and stress level dependency of stiffness [3], [4]. A constitutive model may become very complicated if all the above mentioned aspects are included [4].

This type of complex constitutive model may require many input parameter values that are difficult to evaluate from basic soil tests [4]. While selecting a constitutive model, it is necessary that the constitutive model chosen is able to simulate the important features of material behavior of a soil [4]-[6]. Elasto-plastic constitutive equations are generally nonlinear. Numerical integration is performed to implement a constitutive model in a nonlinear finite element program. Many algorithms are presented in the literature to integrate constitutive equations [7]-[16]. It is to be noted that the performance of a nonlinear finite element analysis depends on the accuracy and efficiency of the integration algorithm used. The finite element program PLAXIS was utilized in this study. The UBCSAND model was used in the numerical analyses presented in this study. UBCSAND is a nonlinear elastic-plastic model that is capable of capturing seismic liquefaction behavior of sands and silty sands [17]. The UBCSAND model has been used to assess seismic liquefaction of embankment dams [18]-[21]. The UBCSAND model, with some modifications, has been implemented as a user defined soil model in the finite element program PLAXIS [22]. The PLAXIS version of the UBCSAND model has been utilized in dynamic analyses presented in this study.

II. UBCSAND Model

UBCSAND is an effective stress elastic-plastic model which is capable of simulating the liquefaction behavior of sands and silty sands under seismic loading [17]. The name UBCSAND implies that this model was developed at the University of British Columbia for prediction of liquefaction behavior of sand. An earlier version of the UBCSAND model was used in a case study of dynamic analyses of Mochikoshi tailings dam, in Japan, and the results of these analyses were consistent with the observed failure pattern of the dam induced due to seismic liquefaction [23]-[26]. The UBCSAND model, with some modifications, has been implemented as a user defined soil model in the finite element program PLAXIS [17],[22]. The PLAXIS version of the UBCSAND model is utilized in this study. The material parameters required for the UBCSAND model are [22]:

- Constant volume friction angle φ_{cv}
- Peak friction angle φ_p
- Cohesion c
- Elastic Shear Modulus K_G^e
- Plastic Shear Modulus K_G^p
- Elastic Bulk Modulus K_B^e
- Elastic Shear Modulus Index n_e
- Elastic Bulk Modulus Index m_e
- Plastic Shear Modulus Index n_p
- Failure Ratio R_f
- Atmospheric pressure P_A
- Tension Cut-off σ_t
- Densification Factor fac_{hard}
- SPT value $N1_{60}$
- Post Liquefaction Factor fac_{post}

The constant volume friction angle, the peak friction angle, and cohesion were evaluated from direct shear tests on material. The elastic shear modulus number, the plastic shear modulus number, and the failure ratio were obtained by curve fitting with the direct shear test results too. The elastic bulk modulus number was related to the elastic shear modulus number using the Poisson's ratio. The elastic shear modulus index, elastic bulk modulus index, and plastic shear modulus index were assigned as 0.5, 0.5 and 0.5, respectively. Appropriate values of the densification factor, and the post liquefaction factor were taken as 1, and 0.2, respectively. In Table I the input parameters for the UBC3D-PLM model are presented [22].

TABLE I
INPUT PARAMETERS FOR THE UBC3D[22]

Parameters	Symbol	Unit	Method	Default
Constant volume friction angle	φ_{cv}	(°)	CD TxC or DSS	-
Peak friction angle	φ_p	(°)	CD TxC or DSS	-
Cohesion	c	kPa	CD TxC or DSS	0
Elastic Shear Modulus	K_G^e	-	Curve Fit	-
Plastic Shear Modulus	K_G^p	-	Curve Fit	-
Elastic Bulk Modulus	K_B^e	-	Curve Fit	-
Elastic Shear Modulus Index	n_e	-	Curve Fit	0.5
Elastic Bulk Modulus Index	m_e	-	Curve Fit	0.5
Plastic Shear Modulus Index	n_p	-	Curve Fit	0.5
Failure Ratio	R_f	-	Curve Fit	0.9
Atmospheric pressure	P_A	KPa	Standard Value	100
Tension Cut-off	σ_t	KPa	0	0
Densification Factor	fac_{hard}	-	Curve Fit	1
SPT value	$N1_{60}$	-	In-Situ Testing	-
Post Liquefaction Factor	fac_{post}	-	Curve Fit	0.2-1

III. SUPERSTITION HILLS EARTHQUAKE 1987

The Wildlife site consisted of 2.5m of lean clay/silt underlain by 1m of sandy silt above 3.3m of loose, silty sand. The silty sand was, in turn, underlain by highly plastic clay within which a down-hole instrument was placed at a depth of 7.5m. A series of piezometers was installed in the silty sand. The Wildlife array was subjected to strong shaking in 1987 from the Elmore Ranch and Superstition Hills earthquakes. The Elmore Ranch earthquake of November 23, 1987 was a M6.2 event epicentered 23km west of the WLA and did not produce surficial evidence of liquefaction. The Superstition Hills earthquake, a M6.6 event that occurred, produced sand boils, ground fissures, and permanent lateral displacements at the site. The WLA piezometers recorded pore pressure signals, and that have been the subject of some controversy over the years (Figs. 1 and 2) [27]-[31].

The acceleration records from the Superstition Hill earthquake at the Wildlife Site were downloaded directly from the PEER Strong Motion Database. After that, acceleration data have been imported in Sigmosignal Software. After data analyze the data for velocity and displacement with their diagrams have been produced [2].

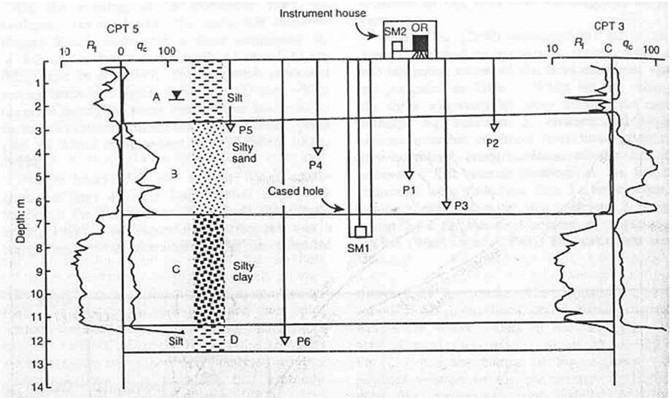


Fig. 1 Down-hole arrays at the Wildlife Site [2]

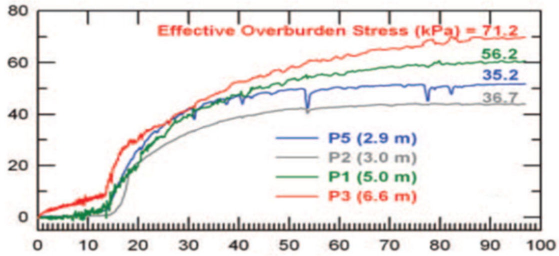


Fig. 2 Recorded pore-pressures at the Wildlife Site [23]

IV. Validation of the UBC3D-PLM for Wildlife Sitein a Finte Element Model

As mentioned before, UBC3D-PLM model have some special parameters. Table II will present the data of wildlife site, for using in this modeling. After calculation the result of pore-pressure generation in 4 piezometers illustrated (See Figs. 3 to 7).

TABLE II
UBC-PLM Parameters in Wildlife

Parameters	Unit	I	II	III	IV	V
Depth	m	0 – 1.2	1.2 – 2.5	2.5 – 3.5	3.5 – 6.8	> 6.8
Young modulus	kN/m^2	4.71e4	4.41e4	7.28e4	7.28e4	9.45e4
Poisson 's ratio	-	0.25	0.25	0.3	0.3	0.322
Unit weight phreatic level	kN/m^3	16.0	19.4	19.7	19.7	20.0
Unit weight below phreatic level	kN/m^3	16.0	21.6	21.8	21.8	22.0
Void ratio	-	0.6799	0.7955	0.7400	0.7400	0.6878
Constant volume friction angle	(°)	21.3	20	22	22	35
Peak friction angle	(°)	21.9	20.625	22.765	23.065	36
Cohesion	kPa	2.00	2.00	0	0	0
Elastic Shear Modulus	-	788.2	798.9	854.6	954.1	934.3
Plastic Shear Modulus	-	185.1	193.6	250	424.7	380.3
Elastic Bulk Modulus	-	551.7	559.3	598.2	667.9	654
Elastic Shear Modulus Index	-	0.5	0.5	0.5	0.5	0.5
Elastic Bulk Modulus Index	-	0.5	0.5	0.5	0.5	0.5
Plastic Shear Modulus Index	-	0.5	0.5	0.5	0.5	0.5
Failure Ratio	-	0.841	0.836	0.811	0.771	0.779
Atmospheric pressure	KPa	100	100	100	100	100
Tension Cut-off	KPa	0	0	0	0	0
Densification Factor	-	0.2	0.2	0.2	0.2	0.2
SPT value	-	6	6.25	7.65	10.65	10
Post Liquefaction Factor	-	0.02	0.02	0.02	0.02	0.02
Permeability	m/s	$5.0*10^{-7}$	$5.0*10^{-7}$	$5.0*10^{-7}$	$2.0*10^{-6}$	$1.0*10^{-8}$
Tangent stiffness for oedometer	KPa	56520	52920	98000	98000	136138
Cohesion	kPa	2.00	2.00	$1.0*10^{-4}$	$1.0*10^{-4}$	$1.0*10^{-4}$
Constant volume friction angle	(°)	21.3	20	22	22	35
Dilatancy angle	(°)	21.3	20.0	19.0	18.0	5.0

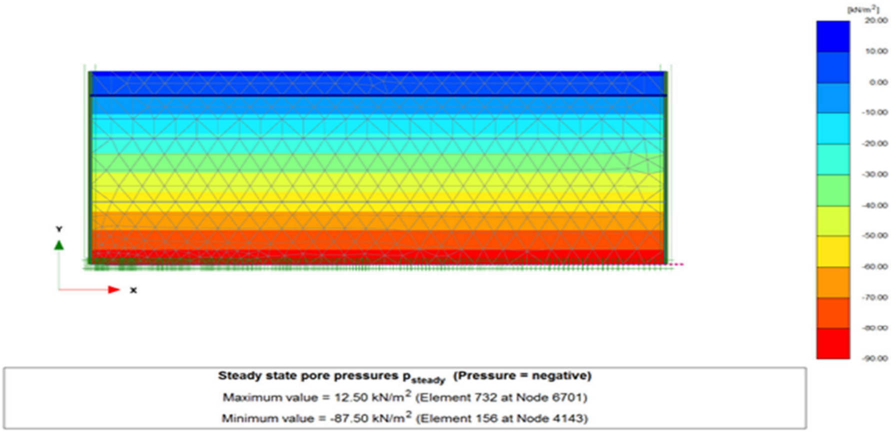


Fig. 3 Steady pore pressures in wildlife site before earthquake

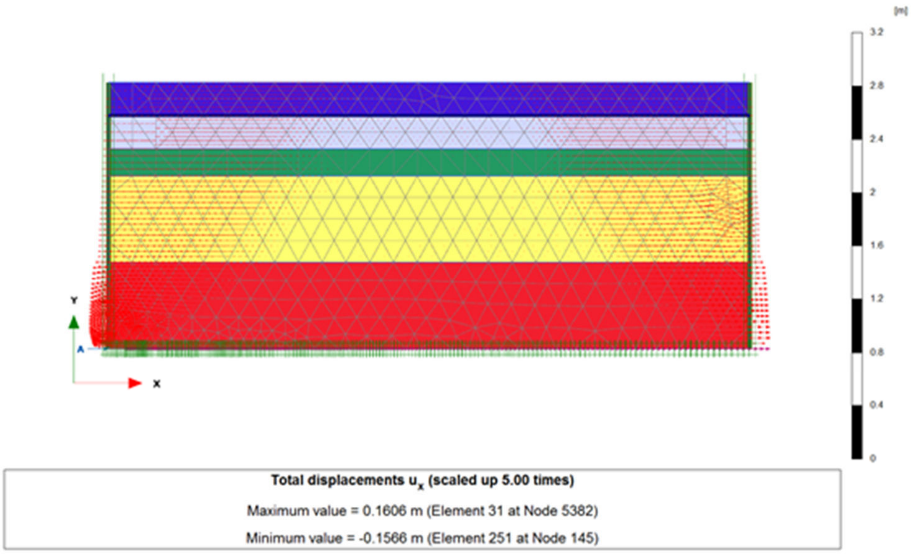


Fig. 4 Total displacement in X-Axis after earthquake

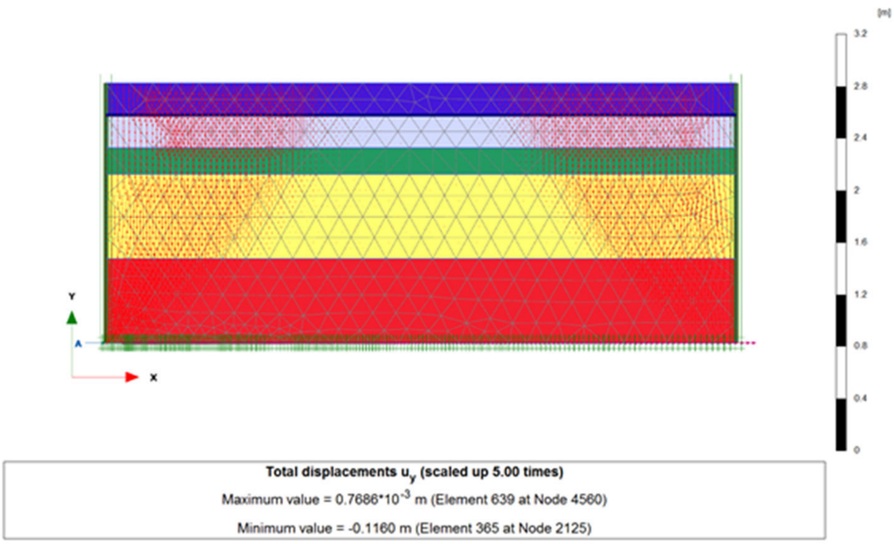


Fig. 5 Total displacement in Y-Axis after earthquake

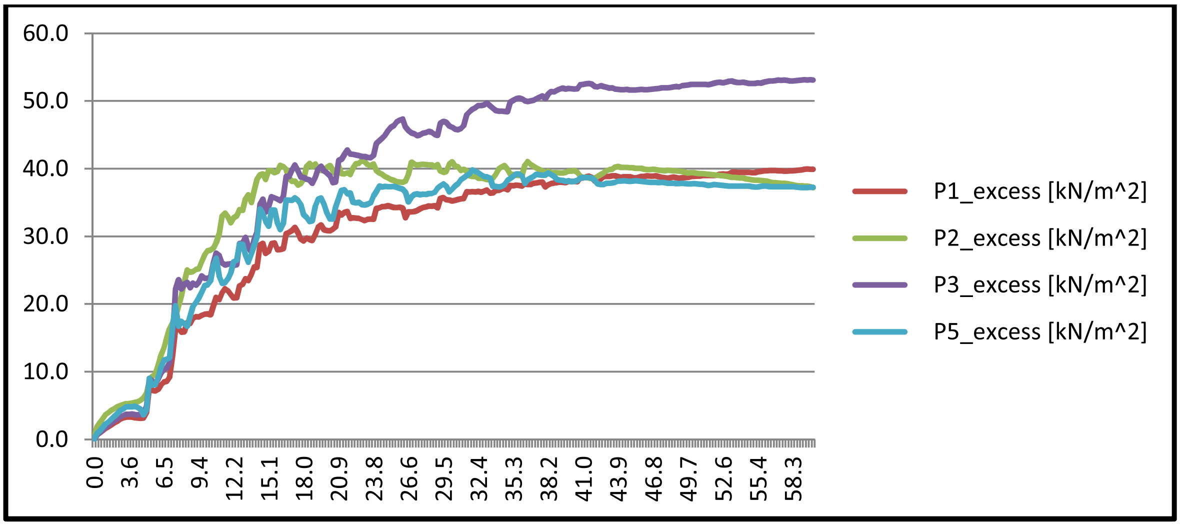
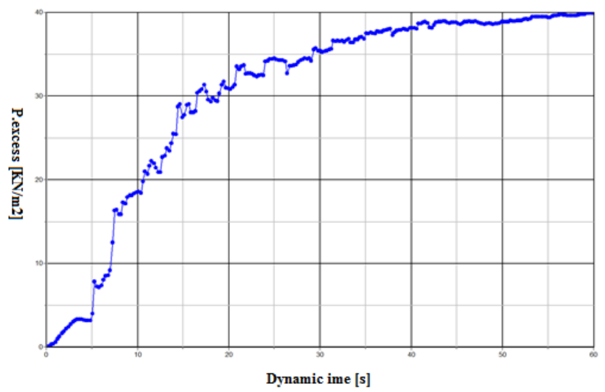
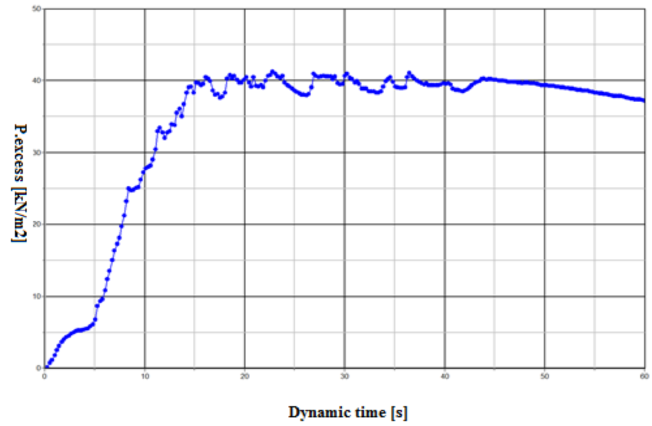


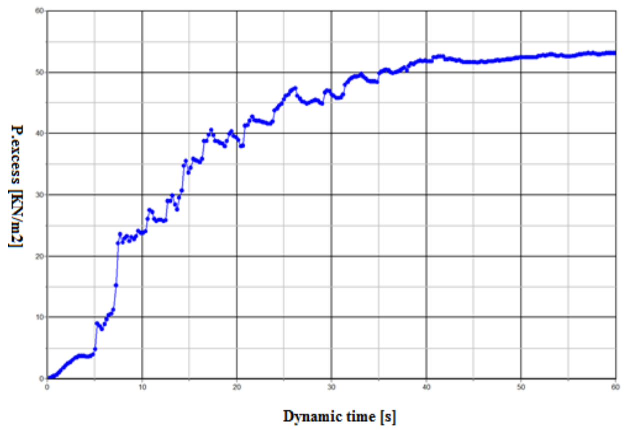
Fig. 6 Calculated pore-pressures at the Wildlife Site



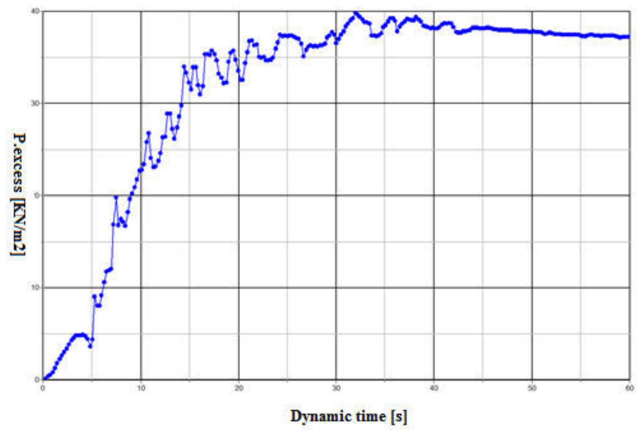
P1- Excess pore-water pressure[KN/m^2)



P2- Excess pore-water pressure[KN/m^2)



P3- Excess pore-water pressure[KN/m^2)



P5- Excess pore-water pressure[KN/m^2)

Fig. 7 Results of excess pore-water pressure in wildlife site liquefaction modeling

V. Conclusion

In this report, after very short presentation of UBCSAND model in liquefaction calculation, the situation and parameters of wildlife site have been introduced. In this site six pore-water pressure transducers, or piezometers, were installed. Five of them are in the liquefiable layer, that is, within the silty sand unit. Piezometer P4 failed to function during the 1987 events. Based on numerical results of Superstition hills earthquake 1987 in the wildlife site the following conclusion can be obtained:

- The model builds the main mechanisms (increasing the excess pore-water pressure) of liquefaction.
- Results show that UBC3D-PLM model can calculate excess pore pressure during earthquake loading by using Densification Factor and Post Liquefaction Factor.
- Results of the simulations show similar trends betweenUBC3D-PLM model and reality.
- Compare between calculated and measured diagrams of pore-water pressure show very good presentation of liquefaction procedure.
- it is flexible and easy to use (most of the material properties are related to SPT)

REFERENCES

[1] National Research Council (NRC), "Liquefaction of Soils During Earthquakes", Washington DC: National Academy Press, 1985.

[2] A. Daftari-Besheli, W. Kudla, "Consideration of Finn-Byrne Formulation in Liquefaction Phenomena", J. World Academy of Science, Engineering and Technology, 78, 2013, pp. 841-848.

[3] R. B. J. Brinkgreve, "Selection of Soil Models and Parameters for Geotechnical Engineering Application", J. Yamamuro, & V. Kaliakin (Eds.), Geotechnical Special Publication, 128, Soil Constitutive Models: Evaluation, Selection, and Calibration Virginia: American Society of Civil Engineers, 2005, pp.69-98.

[4] H. F. Schweiger, "The Role of Advanced Constitutive Models in Geotechnical Engineering", J. Geomechanics and Tunneling, 1(5), 2008, pp.336-344.

[5] D. M. Wood, "Soil Behavior and Critical State Soil Mechanics", New York and Melbourne, Cambridge University Press, 1990.

[6] D. M. Wood, "Geotechnical Modeling". London and New York: Spon Press, 2004.

[7] R. I. Borja, S. R. Lee, "Cam-clay plasticity, part I: Implicit Integration of Elasto-Plastic Constitutive Relations", J. Computer Methods in Applied Mechanics and Engineering, 78(1), 1990, pp. 49-72.

[8] R. I. Borja, "Cam-Clay Plasticity, Part II: Implicit Integration of Constitutive Equation Based On a Nonlinear Elastic Stress Predictor", J. Computer Methods in Applied Mechanics and Engineering, 88(2), 1991, pp. 225-240.

[9] R. I. Borja, K. M.Sama, P. F. Sanz, "On the Numerical Integration of Three Invariant Elastoplastic Constitutive Models", J. Computer Methods in Applied Mechanics and Engineering, 192(9-10), 2003, pp. 1227-1258.

[10] J. Clausen, L. Damkilde, L. Andersen, "Efficient Return Algorithms for Associated Plasticity with Multiple Yield Planes", J. Numerical Methods in Engineering, 66(6), 2006, pp. 1036-1059.

[11] L. X. Luccioni, J. M. Pestana, A. Rodriguez-Marek, "Implicit Integration Algorithm for the Finite Element Implementation of a Nonlinear Anisotropic Material Model Including Hysteretic Nonlinearity", J. Computer Methods in Applied Mechanics and Engineering, 190(13-14), 2000, pp. 1827-1844.

[12] M. Nazem, D. Sheng, J. P. Carter, "Stress Integration and Mesh Refinement for Large Deformation in Geomechanics", J. Numerical Methods in Engineering, 65(7), 2006, pp. 1002-1027.

[13] D. Sheng, S. W. Sloan, H. S. Yu, "Aspects of Finite Element Implementation of Critical State Models", J. Computational Mechanics, 26(2), 2000, pp. 185-196.

[14] J. C. Simo, R. L. Taylor, "Return Mapping Algorithm for Plane Stress elastoplasticity", J. Numerical Methods in Engineering, 22(3), 1986, pp. 649-670.

[15] S. W. Sloan, A. J. Abbo, D, Sheng, "Refined Explicit Integration of Elastoplastic Models with Automatic Error Control", J. Engineering Computations. 18(1/2), 2001, pp. 121-154.

[16] J. Zhao, D. Sheng, M. Rouainia, S. W. Sloan, "Explicit Stress Integration of Complex Soil Models", J. Numerical and Analytical Methods in Geomechanics, 29(12), 2005, pp. 1209-1229.

[17] M. H. Beaty, P. M. Byrne, "UBCSAND Constitutive Model Version 904aR", Retrieved from Itasca Website: http://www.itasca-udm.com/ media/download/UBC Sand/UBCSAND_UDM_Documentation.pdf, 2011.

[18] M. H. Beaty, V. G. Perlea, "Effect of Ground Motion Characteristics on Liquefaction Modeling of Dams", P. Geo congress, State of the Art and Practice in Geotechnical Engineering, USA, 2012, pp. 2108-2117.

[19] M. James, M. Aubertin, "The use of Waste Rock Inclusions to Improve the Seismic Stability of Tailings Impoundments", P. Geo Congress, State of the Art and Practice in Geotechnical Engineering, USA, 2012, pp. 4166-4175.

[20] M. James, "The use of Waste Rock Inclusions to Control the Effects of Liquefaction in Tailings Impoundments", Doctoral Thesis, Ecole Polytechnique, Montreal, Canada, 2009.

[21] T. D. Stark, M. H. Beaty, P. M. Byrne, G. Castro, F. C. Walberg, V. G. Perlea, D. L. Mathews, "Seismic Deformation Analysis of Tuttle Creek Dam", J. Canadian Geotechnical, 49(3), 2012, pp. 323-343.

[22] A. Petalas, V. Galavi, "PLAXIS Liquefaction Model UBC3D-PLM", Retrieved from PLAXIS Website: http://kb.plaxis.nl/models/udsm-ubcsand3d-model. 2013.

[23] H. Puebla, P. M. Byrne, R. Phillips, "Analysis of CANLEX Liquefaction Embankment: Prototype and Centrifuge Models", J. Can Geotech , 34, 1997, pp. 641-654.

[24] M. H. Beaty, P. M. Byrne PM, "An Effective Stress Model for Predicting Liquefaction Behaviour of Sand", Geotechnical Special Publication, 75(I), 1998, pp. 766-777.

[25] M. Seid-Karbasi, P. M. Byrne, "Embankment Dams and Earthquakes", J. Hydropower and Dams, 11, 2004, pp. 96-102.

[26] P. M. Byrne, M. Seid-Karbasi, "Seismic Stability of Impoundments", P. 17th Annual Symposium, Vancouver Geotechnical Society, Vancouver, BC, 2003.

[27] Earth Technology Corporation, "Accuracy of the Pore-Water Pressures recorded at Wildlife Site during Magnitude 6.6 Imperial Valley Earthquake of 24 November 1987", 1991.

[28] B. Hushmand, R. F. Scott, C. B. Crouse, "In-situ Calibration of USGS Piezometer Installations in Recent Advances in Instrumentation, Data Acquisition, and Testing in Soil Dynamics", S. K. Bhatia and G. W. Blaney [Eds], ASCE Spec. 29, 1991, pp. 49-61.

[29] B, Hushmand, R. F. Scott, C. B. Crouse, "In-Place Calibration of USGS Pore Pressure Transducers at Wildlife Liquefaction Site, California, USA", P. 10th Earthquake Engineering World Conference, Balkema, Rotterdam, The Netherlands, 1992, pp. 1263-1268.

[30] T. L. Youd, T. L. Holzer, "Piezometer performance at Wildlife liquefaction site, California", J. Geot. Eng. ASCE, 120, 1994, pp. 975-995.

[31] R. F. Scott, B. Hushmand, "Discussion of Piezometer at Wildlife Liquefaction site by T.L Youd and T. L. Holzer", J. Geotechnical Engineering, ASCE, 121, 1995, pp. 912-919.