Advances in Computational Design, *Vol. 1, No. 3 (2016) 265-274*
DOI: http://dx.doi.org/10.12989/acd.2016.1.3.265

Seismic analysis of dam under different upstream water levels

Shashank Bhatnagar[a], A Kranthikumar[b] and V A Sawant*

Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand 247667, India

(Received March 18, 2015, Revised May 16, 2016, Accepted July 15, 2016)

Abstract. The present paper describes the results of numerical modeling of a dam founded on loose liquefiable deposit using PLAXIS-3D finite element software. Effect of a different dam water level on parameters like displacements, Excess Pore water pressures, Liquefaction potential and Accelerations is studied. El- Centro earthquake motion is applied as input earthquake motion. The results of this study show that different upstream dam water level greatly affects the displacements, excess pore pressure and displacement tendency of the underlying foundation soils and the dam.

Keywords: seismic analysis; earthen dam; excess pore pressure; acceleration; displacements

1. Introduction

Damage or failure of structures such as highway/railway embankments, river dikes, and earth dams has been reported around the world during various earthquakes. When the foundation soils liquefied, damage to embankments have been particularly destructive (Yamada 1966, McCulloch and Bonilla 1967, Adalier and Aydingun 2000), resulting in cracking, settlement, lateral spreading, and slumping of the embankments. The recent 1995-Kobe earthquake emphasized the importance of foundation liquefaction as a potential source of destruction to earth embankments. Such earthquake liquefaction vulnerability necessitates the development of appropriate remediation countermeasures (Marcuson *et al*. 1996, Adalier *et al*. 1998). Applying finite element method, Latha *et al*. (2009) simulated the behavior of strip footings resting on sand beds, with different density of soil, reinforced with geocells of different dimensions. Taiebat *et al*. (2007) worked on numerical analyses of liquefiable sand using critical state two-surface plasticity model and densification model for bounded soil domain. Dewoolkar *et al*. (2009) discussed seismic effects on retaining walls with liquefiable backfills using coupled approach. Sarkar and Maheshwari (2012) discussed the response of geogrid sheet, geosynthetic fiber, and natural coir fiber on liquefaction resistance of Solani sand. Taiyab *et al*. (2014) demonstrated the efficiency of a mitigation technique to prevent damage to quay walls, which involves densification of loose sand around the toe. In this paper, the seismic effect on dam is studied when different water levels exist on its

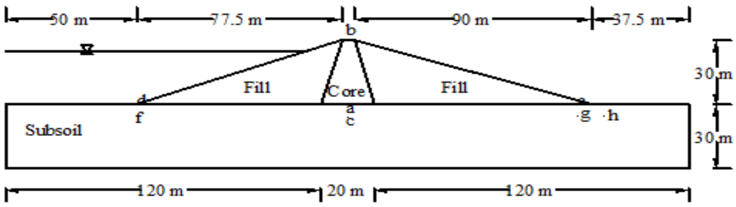
*Corresponding author, Associate Professor, E-mail: sawntfce@iitr.ac.in
[a]Post graduate student, E-mail: shashank306ce@gmail.com
[b]Research Associate, E-mail: kranthikumar0143@gmail.com

http://www.techno-press.com/journals/acd&subpage=7 ISSN: 2383-8477 (Print), 2466-0523 (Online)

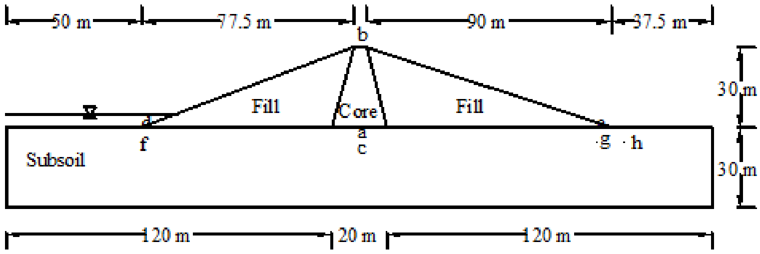
upstream side. This will help in more accurate prediction of the parameters and in design of more effective countermeasures.

2. Problem statement

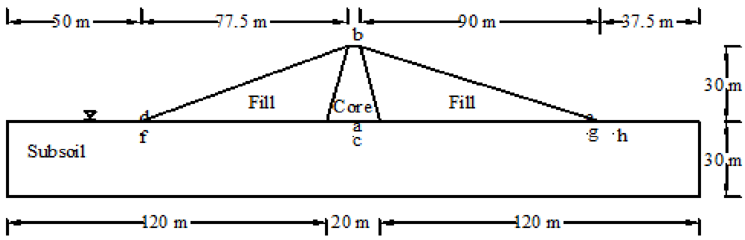
A prototype earth dam of 30 m height and 172.5 m width has been considered for the analysis. It is resting on a 30 m thick sand foundation deposit. The size of domain considered in PLAXIS-3D is 260 m wide and 50 m long. Dam comprises of three type of soil which includes the soil comprising the core of the dam, soil making up the fill of the dam and the subsoil. Upstream water level in the dam is varied between 25 m to 0 m (at ground surface), but downstream water level is always kept constant at 10 m below the ground (Fig. 1). This model is examined for El-Centro earthquake motion. Response in the form of resultant displacements, liquefaction tendencies, excess pore pressure and other parameter are studied. PLAXIS-3D finite element software is used for the analysis. PLAXIS-3D uses the UBC3D-PLM model. This model is extended from UBCSAND model originally introduced by Peubla *et al*. (1997). Formulation of this model as well documented by Petalas *et al*. (2013).



(a) Dam water level of 25 meters



(b) Dam water level of 5 meters



(c) Dam water level at ground level

Fig. 1 Benchmark models for different dam water levels

3. Determination of soil parameters

Proposed equations for generic initial calibration are as proposed by Galavi *et al*. (2013)

$$K_G^e = 434 N_{60}^{1/3}$$
$$K_B^e = 0.7 K_G^e$$
$$K_G^p = 0.003 K_G^e \, N_{60}^2 + 100$$
$$R_f = 1.1 \, N_{60}^{-0.15}$$

SPT values for foundation sands are found out based on Fig. 2. These SPT values are used as the input to find other values using aforementioned formulae. Soil parameters taken for foundation soil are given in Table 1. Core soil consisting the core is assumed to have a saturated unit weight γ_{sat}=20 kN/m^3, E=40000 kPa and Poisson's ratio μ=.2. The dam fill surrounding the core has a saturated unit weight γ_{sat}=18 kN/m^3, E=20000 kPa and Poisson's ratio μ=.2. Permeability of dam fill is assumed to be 6.6×10^{-7}m/s.

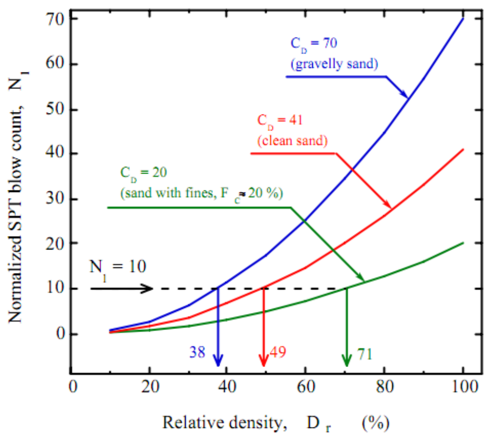


Fig. 2 Relation between normalised SPT value and relative density (After Cubrinovski *et al*. 1999)

Table 1 Input model parameters for UBC3D-PLM

Parameters with description	Value
Dry unit weight γ_{dry} (kN/m^3)	16.75
Saturated unit weight γ_{sat} (kN/m^3)	18
Initial void ratio ($e_{initial}$)	0.55
Co-efficient of permeability k_x=k_y=k_z, (m/s)	6.6×10^{-6}
Peak friction angle (ϕ'_p)	34^0
Friction angle at constant volume (ϕ'_{cv})	33^0
E_{oed}^{ref} (kPa)	24000
Elastic shear modulus number k_G^e (kPa)	934
Elastic bulk modulus number k_B^e (kPa)	684

Table 1 Continued

Parameters with description	Value
Plastic shear modulus number k_G^p (kPa)	380
Power for stress dependency elastic bulk modulus (n_k)	0.5
Power for stress dependency elastic shear modulus (n_g)	0.5
Power for stress dependency plastic shear modulus (n_p)	0.4
Failure ratio R_f	0.78
Reference stress P_A (kPa)	100
Fitting parameter to adjust densification rule f_{dens}	0.45
Fitting parameter to adjust post liquefaction behaviour f_{post}	0.02
Corrected SPT blow counts N_{60}	6.5

4. Numerical model and input ground motion

A geometrical model developed for the present study is illustrated in Fig. 3 showing three distinct zones corresponding to core, fill and base soil. Applied input ground motion (El-Centro

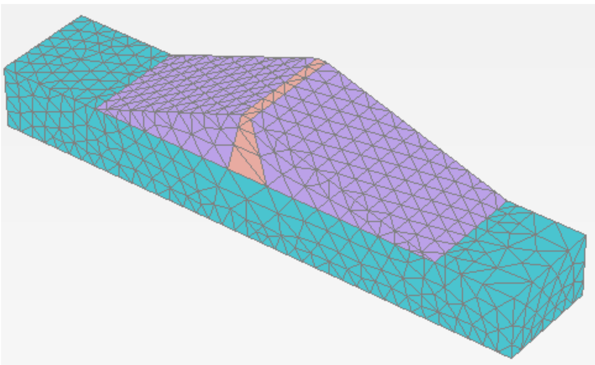


Fig. 3 Finite element mesh of the domain in consideration

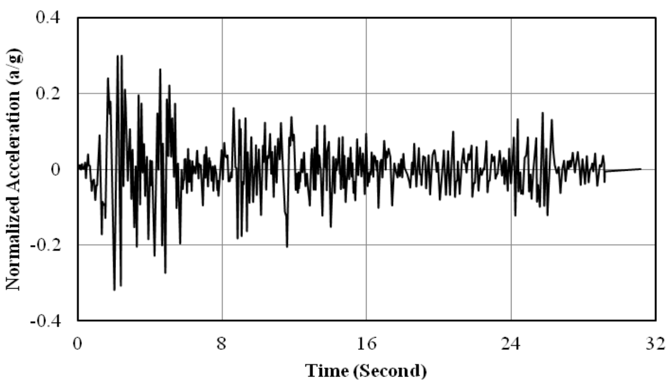


Fig. 4 Normalized input acceleration applied at base

earthquake motion) at the base is presented in Fig. 4.

5. Results and discussion

A detailed numerical study based on effective stress analysis is presented here to demonstrate the effect of liquefaction phenomena and its remedial measure for a case of an earth embankment subjected to seismic loading. When a dam is subjected to an earthquake, movement of the dam and supporting ground takes place during and after the event, resulting in deformation. The shape obtained at the end of the consolidation analysis showing the final deformations are presented in Fig. 5 for different dam water levels. Similarly variation in vertical displacement with time at different locations is depicted in Fig. 6.

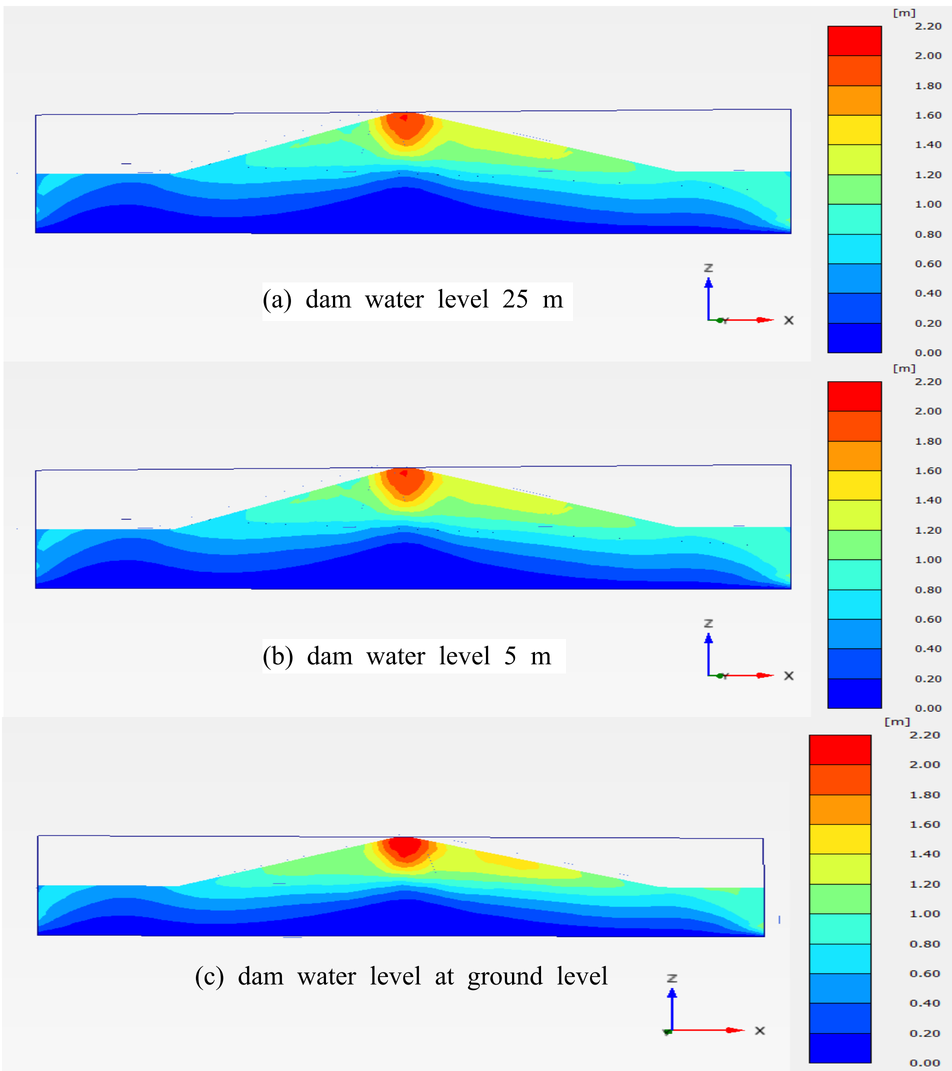


Fig. 5 Vertical displacements for different dam water levels

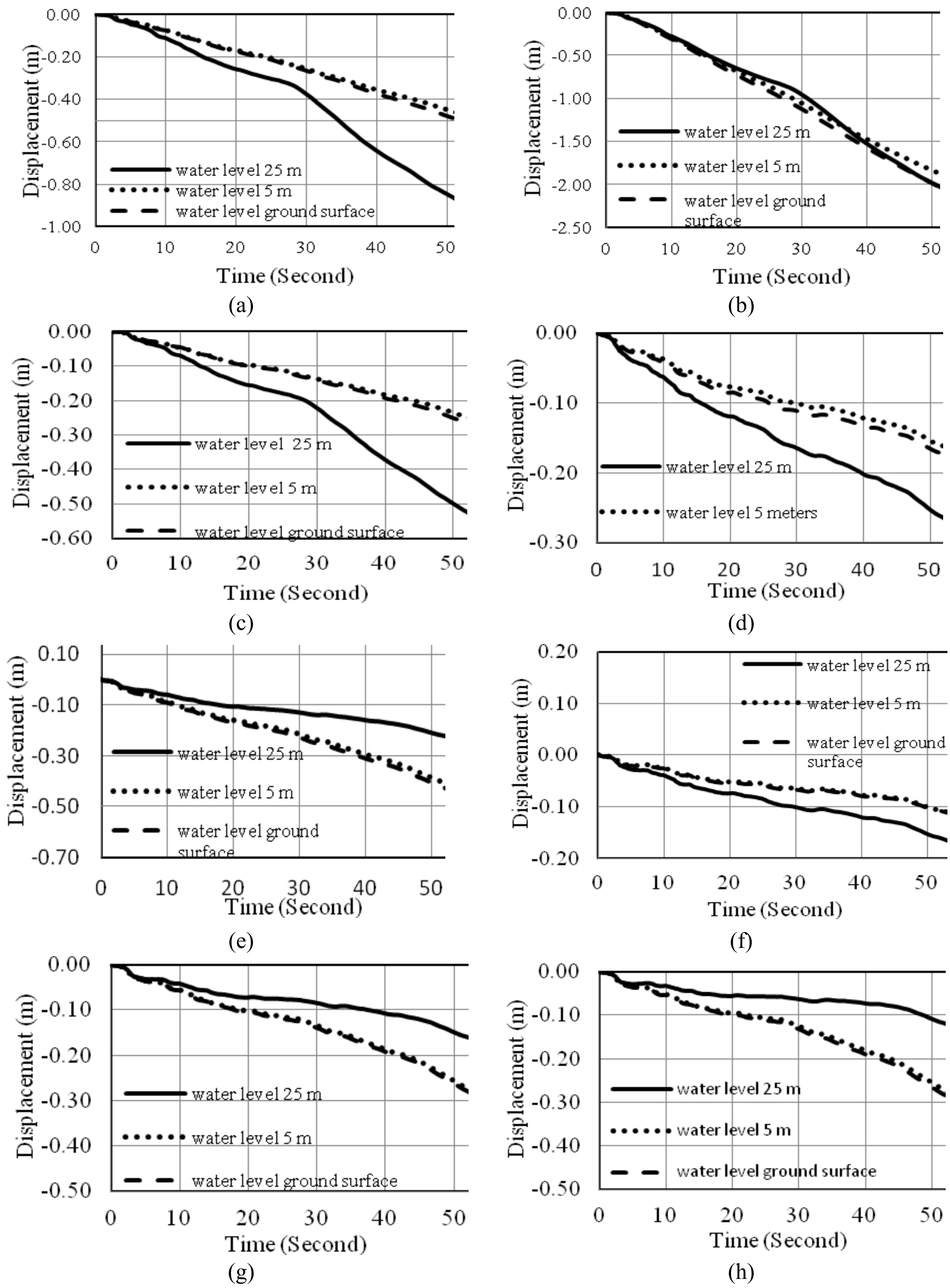


Fig. 6 Computed vertical displacement with respect to time at different points

The maximum vertical displacement is obtained at point b, on the top of dam crest. This vertical displacement here is around 2 meters and remains almost independent of the upstream dam water level. At points a and c, lying directly below the crest of dam, in base foundation soil, the displacement values are .9 and .55 meters for high upstream water level case (at 30 m) and drop to around .5 to .29 meters for case when water level is quite low (at 5 m) or is near ground surface (0 m). At the upstream toe of the dam, the displacement is found to be .28 meters for high upstream water level and is around .18 meters for low water levels of 5 and 0 meters. Point f below the embankment has a deformation of around .15 m for high water level case which goes to .11 m when water level is low in the dam. For points e and g, lying on and below the downstream toe of dam, the displacement values are around .28 m and .18 m for high dam water level case and increase to .45 m and .30 m respectively for lower upstream dam water levels. Randomly selected point h on the downstream side shows a similar trend. Using this data it can be safely said that change in upstream water level has a large impact on the deformation values of almost all points except those at the dam crest. This increase in deformation can vary anywhere between 100% for points lying directly beneath the dam to around 60% for points near and under the toe. On the downstream side there is a perceptible increase in displacement values with the lowering of upstream dam water level. For points at the downstream toe the increase is around 80% and for the randomly selected points, further away downstream, the increase is close to 100%. Maximum values of displacements are summarized in Table 2.

The Excess pore pressure (EPP) values for selected points are shown in Fig. 7. Quite high EPP's of 50 kPa and 80 kPa are detected at points a and c, directly below dam foundation for a high upstream dam water level. At point a, for most of the part, the EPP for low dam water levels, remain below the EPP for high dam water level. For point c, which lies directly below point a, it is clear that EPP for high dam water level always dominates the EPP's for lower dam water levels. EPP's at point h on the downstream side is also shown.

Comparisons between normalized accelerations are shown in Fig. 8. It shows the normalized accelerations at the crest, the accelerations are more or less the same. At point d which is the upstream toe, it is observed that acceleration is highest when the dam water level is high. At point e, which is the downstream toe, it is seen that maximum amplitudes are observed when the dam water levels are at their minimum. This explains the high displacement occurring in the upstream side and less displacement on the downstream side for high water levels in the dam.

Table 2 Maximum Displacements at different points

Location	**Dam with upstream water level of 25 m**			**Dam with upstream water level of 5 m**			**Dam with upstream water level of 0 m**		
	*U*x (m)	*U*y (m)	*U*z (m)	*U*x (m)	*U*y (m)	*U*z (m)	*U*x (m)	*U*y (m)	*U*z (m)
a	0.68	-0.01	-0.91	0.02	-0.01	-0.48	-0.01	0.01	-0.52
b	0.73	0.05	-2.15	0.10	0.03	-1.97	0.07	0.09	-2.13
c	0.43	-0.01	-0.54	-0.05	-0.02	-0.25	-0.07	-0.02	-0.28
d	-0.22	-0.06	-0.28	-0.62	-0.04	-0.16	-0.69	-0.05	-0.19
e	1.40	0.37	-0.40	0.73	0.52	-0.71	0.85	-0.02	-0.45
f	-0.20	-0.02	-0.17	-0.47	0.01	-0.10	-0.55	0.00	-0.12
g	1.50	-0.02	-0.15	0.76	0.02	-0.27	0.73	0.01	-0.29
h	1.41	-0.01	-0.13	0.73	0.03	-0.28	0.70	0.02	-0.31

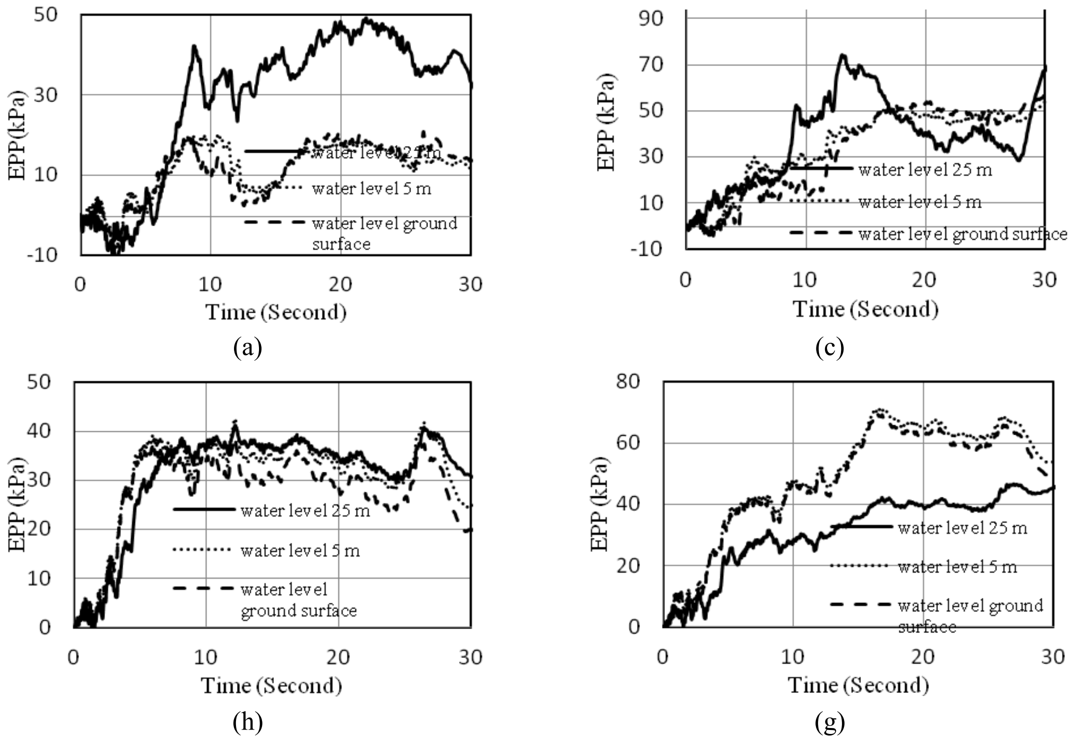


Fig. 7 Computed EPP with respect to time at different location of foundation

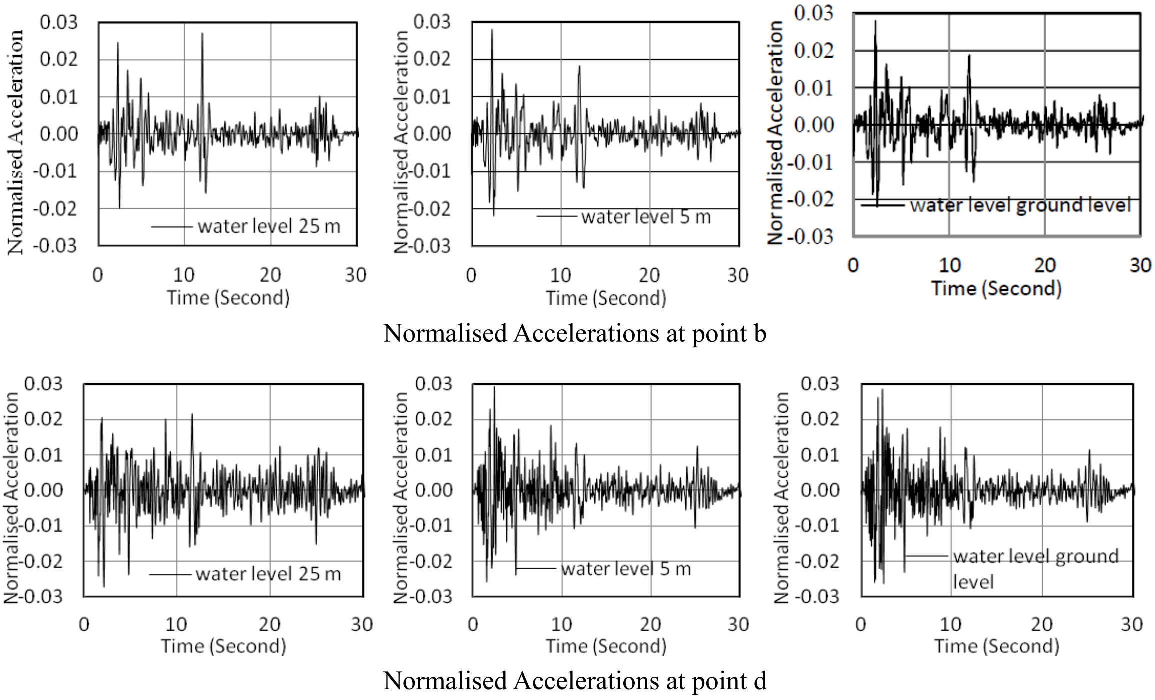
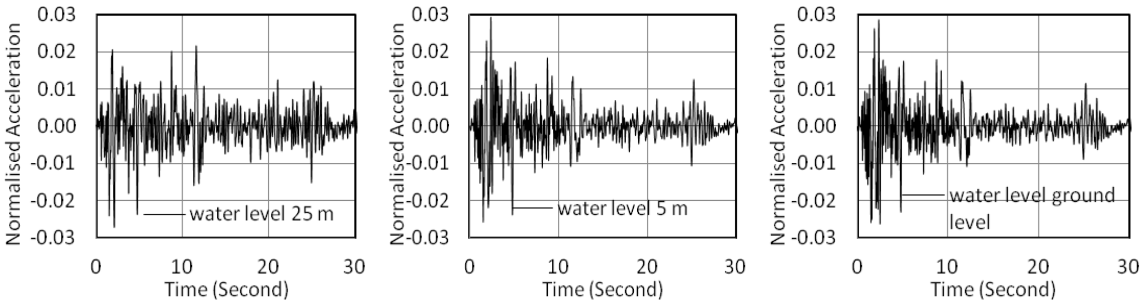


Fig. 8 Normalized accelerations at different points



Normalised Accelerations at point e

Fig. 8 Continued

Table 3 Maximum Displacements and EPP at different points for Bhuj Earthquake motion water level of 25 m

Location	*U*x (m)	*U*y (m)	*U*z (m)	EPP (kPa)
a	0.539	0.250	0.541	291.5
b	0.613	0.379	0.574	0.0
c	0.524	0.287	0.546	263.3
d	0.513	0.321	0.527	101.9
e	0.450	0.331	0.599	83.4
f	0.490	0.277	0.549	172.8

Detailed study was conducted El-Centro earthquake motion as applied input ground motion at the base, where maximum normalized acceleration is around 0.3 and total time of earthquake motion is 31 sec. To examine the effect of earthquake motion, Bhuj earthquake motion was applied as input ground motion for one case (water level 25 m) on same model. The maximum normalized acceleration for Bhuj earthquake motion is around 0.7 and total time of earthquake motion is 133.5 sec. The maximum vertical displacements and maximum generated EPP obtained at different points are summarized in Table 3. Though maximum displacement is of the order of 0.6 m only, effect on generated EPP is significant. Quite high EPP's of 291 kPa and 263 kPa are detected at points a and c, directly below dam foundation for a high upstream dam water level. These values are considerably higher than the response El-Centro earthquake motion. Excessive rise in EPP may be attributed to high acceleration level (0.7 g) and longer time duration of earthquake (133.5 sec) over which it accumulates without dissipation.

6. Conclusions

A good comparison has been done for the dynamic behavior of the employed earthen dam for different upstream water levels. On the upstream side the vertical displacements increase with an increase in dam water level whereas on the downstream side, displacements are more when dam water level is less. Vertical displacement of the crest is minimally affected by water level in the dam. Lateral displacement for crest and soil under the crest is maximum when dam water level is the highest. On the other hand lateral displacements on downstream side are maximum and are lower on the upstream side for higher water level. Thus vertical and lateral displacements follow opposite trends. The highest foundation excess pore pressures on downstream side are also observed when the dam water level is high. On the upstream side high dam water level inhibits the development of Excess Pore water pressures. The strongest and weakest embankment acceleration responses (relative to base excitation) were observed in the compaction. Parameters of base input motion such as maximum acceleration and time duration has significant impact on the response.

References

Adalier, K. and Aydingun, O. (2000), “Liquefaction during the June 27, 1998 Adana-Ceyhan (Turkey) Earthquake”, *J. Geotech. Geol. Eng.*, **18**(3), 155-174.

Adalier, K., Elgamal, A.W. and Martin, G.R. (1998), “Foundation liquefaction countermeasures for earth embankments”, *J. Geotech. Geoenviron. Eng.*, ASCE, **124**(6), 500-517.

Brinkgreve, R.B.J., Engin, E. and Swolfs, W.M. (2012), PLAXIS, Finite Element code for soil and rock analysis, user’s manual. www.plaxis.nl

Cubrinovski, M. and Ishihara, K. (1999), “Empirical correlation between SPT N-value and relative density for sandy soils”, *Soils and Foundations*, Elsevier, **39**(5), 61-71.

Dewoolkar, M.M., Chan, A.H.C., Ko, H. and Pak, R.Y.S. (2009), “Finite element simulations of seismic effects on retaining walls with liquefiable backfills”, *Int. J. Numer. Analytic. Meth. Geomech.*, **33**(6), 791-816.

Galavi, V., Petalas, A. and Brinkgreve, R.B.J. (2013), “Finite element modelling of seismic liquefaction in soils”, *Geotech. Eng. J.*, **44**(3), 55-64.

Latha, G.M., Dash, S. and Rajagopal, K. (2009), “Numerical simulation of the behavior of geocell reinforced sand in foundations”, *Int. J. Geomech*., ASCE, **9**(4), 143-152.

Maheshwari, B.K., Singh, H.P and Saran, Swami (2012), “Effects of reinforcement on liquefaction resistance of solani sand”, *J. Geotech. Geoenviron. Eng*., ASCE, **138**(7), 831-840.

Marcuson, W.F., Hadala, P.F. and Ledbetter, R.H. (1996), “Seismic rehabilitation of earth dams”, *J. Geotech. Eng.*, ASCE, **122**(1), 7-20.

McCulloch, D.S. and Bonilla, M.G. (1967), “Railroad damage in the Alaska Earthquake”, *J. Geotech. Eng. Div*., ASCE, **93**(5), 89-100.

Puebla, H., Byrne, P.M. and Phillips, P. (1997), “Analysis of canlex liquefaction embankments prototype and centrifuge models”, *Can. Geotech. J.*, **34**(5), 641-657.

Taiebat, M., Shahir, H. and Pak, A. (2007), “Study of pore pressure variation during liquefaction using two constitutive models for sand”, *Soil Dyn. Earthq. Eng.*, **27**(1), 60-72.

Taiyab, M.A., Alam, M.J. and Abedin, M.Z. (2014), “Dynamic soil-structure interaction of a gravity quay wall and the effect of densification in liquefiable sites”, *Int. J. Geomech.*, ASCE, **14**(1), 20-33.

Yamada, G. (1966), “Damage to earth structures and foundations by the Niigata Earthquake, June 16, 1964”, *Soil. Found.*, **6**(1), 1-13.

CC