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Simulation of seismic behaviour of gravity quay walls using a generalized plasticity model

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Content

- Introduction
- Constitutive soil model
- Model validation
- Case study
- Effective stress analysis
- Influence of density
- Conclusions

Introduction

From 1964 to 2003 well-documented case histories of damage to port structures made of gravity retaining quay walls show that the damage is often associated with significant deformation of **liquefiable** soil deposits.

Fig. 1 Results of liquefaction of backfill behind quay wall following Kobe earthquake

Fig. 2 Results of liquefaction of backfill behind quay wall following Chi-Chi earthquake

Quay wall failures due to liquefaction

No.	Type	Earthquake Year (magnitude)	Port	Country	Reference
1	Block	1964(Ms-7.5)	Niigata port	Japan	(Hayashi, *et al.*, 1966)
2	Block	1985(Ms=7.8)	San Antonio port	Chile	Tsuchida et al. (1986): Wyllie et al. (1986) c.f. PIANC (2001)
3	Block	1986(Ms=6.2)	Kalamata port	Greece	(Pitilakis & Moutsakis, 1989)
4	Block	1989(M=6.0)	Port of Algiers	Algeria	Manja (1999) c.f. PIANC (2001)
5	Caisson	1993(Mj=7.8)	Kushiro port West No. 1	Japan	Iai et al. (1994) c.f. PIANC (2001)
6	Caisson	1993(Mj=7.8)	Kushiro port East Quay, Kita Wharf	Japan	Iai et al. (1994) c. f. PIANC (2001)
7	Caisson	1995(Mj=7.2)	Kobe port	Japan	(Inagaki, *et al.*, 1996)
8	Block	1999(Mw=7.4)	Derince port	Turkey	Sugano and Iai (1999) c.f. PIANC (2001)
9	Caisson	1999(Ms=7.7)	Taichung port	Taiwan	Sugano et al. (1996) c.f. PIANC (2001)

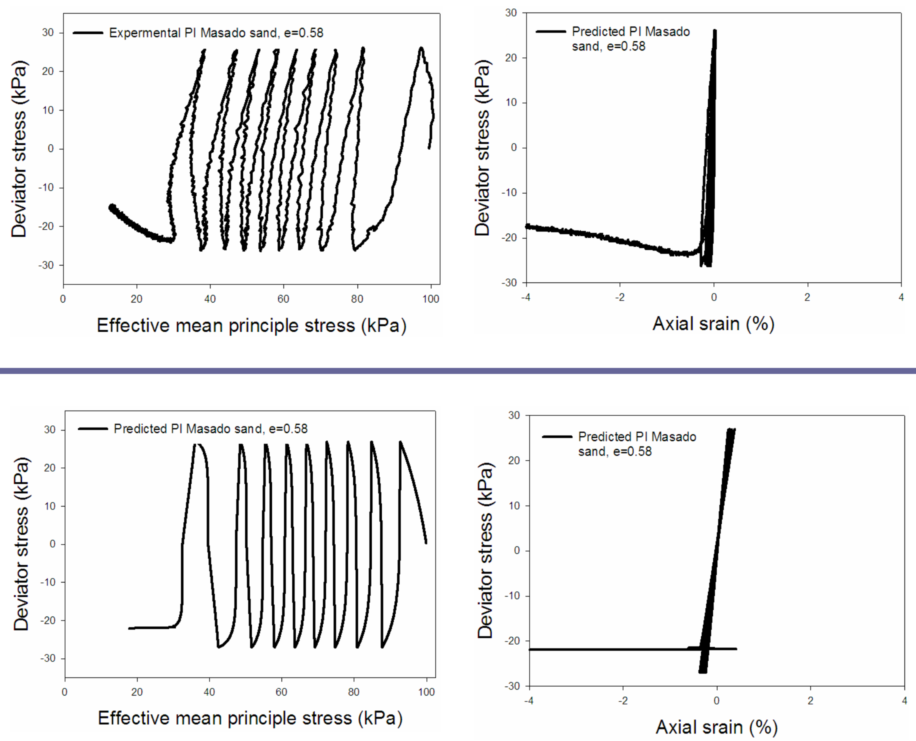
Constitutive soil model

- (Pastor, Zienckiecwz & Chan, 1990) (PZ-III)
- (Elasto-Plasiticity) with minor modifications

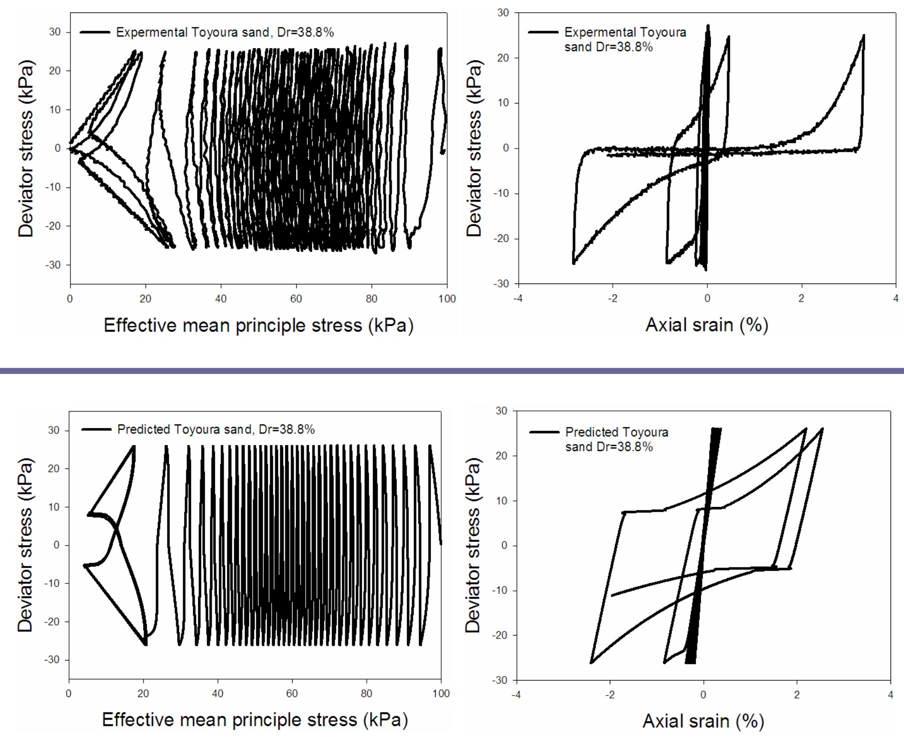
- The progressive decrease in the stiffness of soil with increasing pore pressure
- Accumulation of deformation
- Stress Dilatancy
- Hysteresis loops

- Modified (PZ-III) has 15 Parameters, which should be obtained from monotonic and cyclic traixial tests

Model evaluation



PI Masado sand



Toyoura sand

Test	M_f	M_g	C	α_f	α_g	K_{ev0}	G_{es0}	m_v	m_s	β_0	β_1	H_0	H_{U0}	γ	γ_U	p'_0
Toyota (Toyora)	0.77	1.42	0.85	0.45	0.45	220	140	0.5	0.5	6	0.3	520	19200	6	4.3	100
Toyota (PI Masado)	0.574	1.372	0.9	0.45	0.45	246	120	0.5	0.5	4.45	0.189	470	6950	6	4.3	100

Toyota and his group, 2004

Finite element code

- The UWLC used in this study is a fully coupled finite element code based on the *u-p* formulation

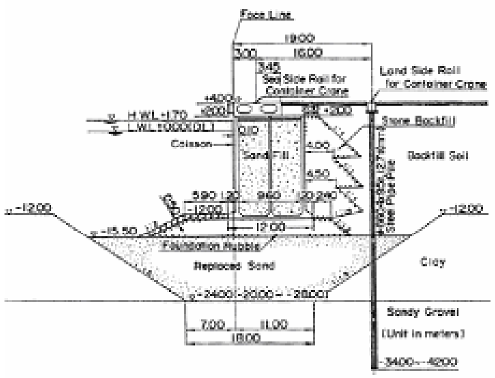
$$\mathbf{M}\ddot{u} + \mathbf{K}u - \mathbf{Q}p = f^{(u)}$$

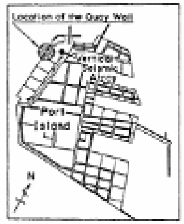
$$\mathbf{Q}^T\dot{u} + \mathbf{H}p + \mathbf{S}\dot{p} = f^{(p)}$$

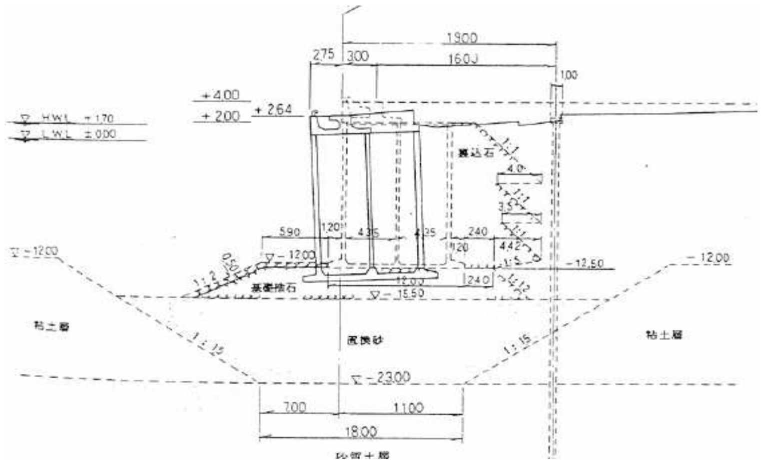
- The primary variables in this form are solid displacements *(u)* and fluid pressure *(p)*
- Newmark method is used to integrate the above equations in time domain

The Case Study

Kobe Port (Port Island Quay Wall) during 1995 earthquake



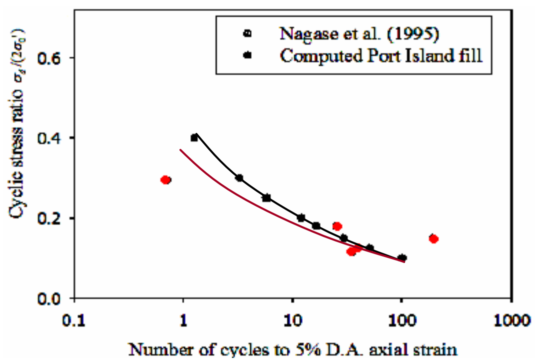




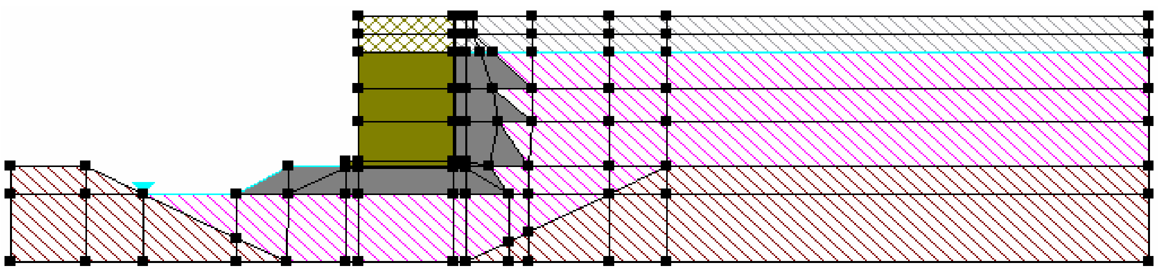
From The Port and Harbour research institute Ministry of Transport, Japan (1997)

Berth	Displacements (m)	
	Horizontal	**Vertical**
PC 1	2.75	1.36
PC 1 extension	3.13	1.01
PC 2	2.33	0.79
PC 3	2.46	1.14
PC 4	2.37	1.40
PC 5	2.30	1.38

Model parameters

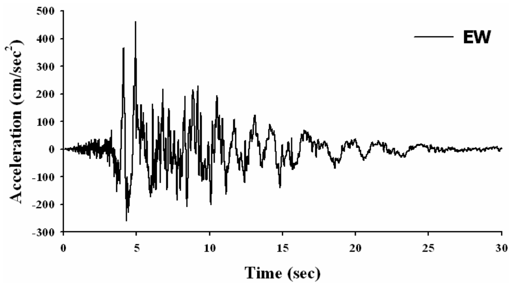


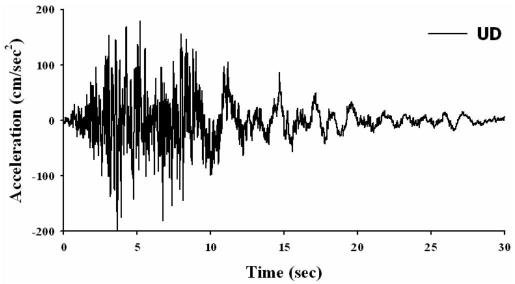
Cyclic stress ratio from triaxial tests on samples from Port Island conducted by Nigase



Geometry (in natural scale) and material zones of the Port Island PC1 quay wall

M_f	M_g	C	α_f	α_g	K_{ev0}	G_{es0}	m_v	m_s	β_0	β_1	H_0	H_{U0}	γ	γ_U	p'_0
0.58	1.3	0.9	0.45	0.45	340	175	0.5	0.5	6	0.76	680	3000	8	7.1	100



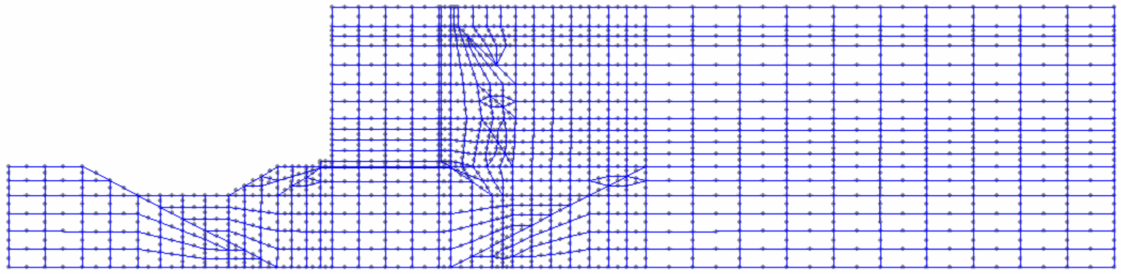


Recorded motions at Kobe Port during the 1995 reported by Iwasaki & Tai (1996)

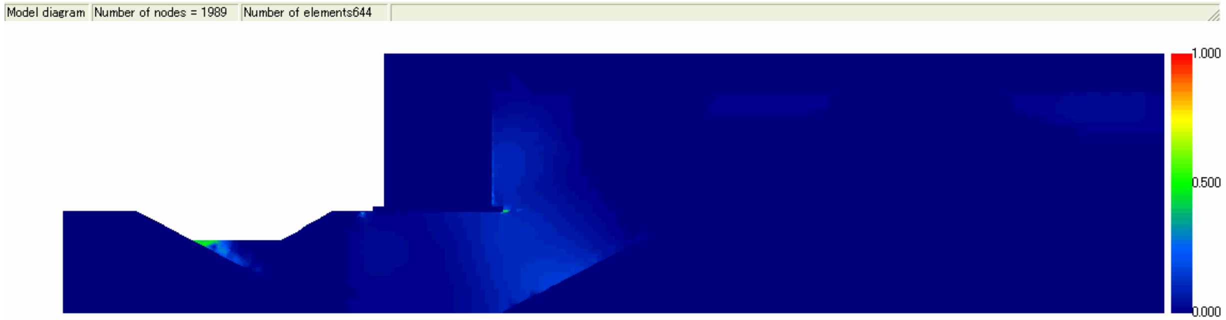
Horizontal (E-W) component 460gal (cm/sec2)

Vertical (U-D) component 200gal (cm/sec2)

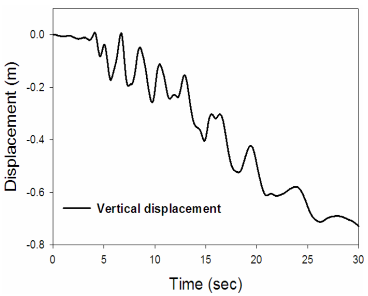
Displacements



Pore pressures built up

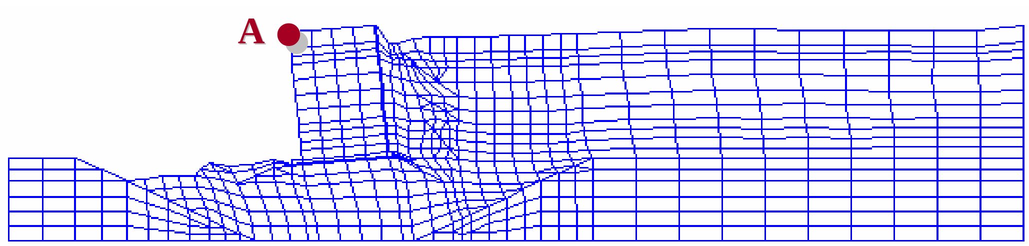


Effective Stress analysis

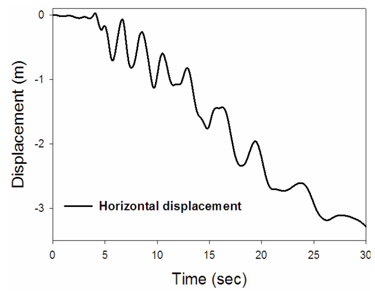


Vertical displacement

0.73m (0.79m to 1.40m measured)

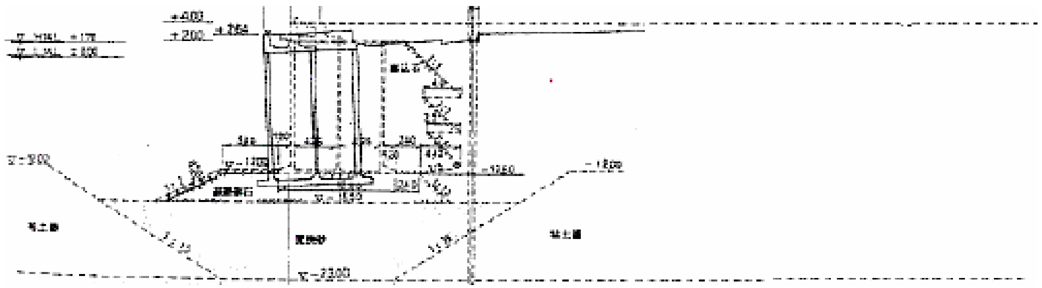


Deformation at the end of earthquake $t=30\text{sec}$



Horizontal displacement

3.28m (2.3m to 3.13m measured)

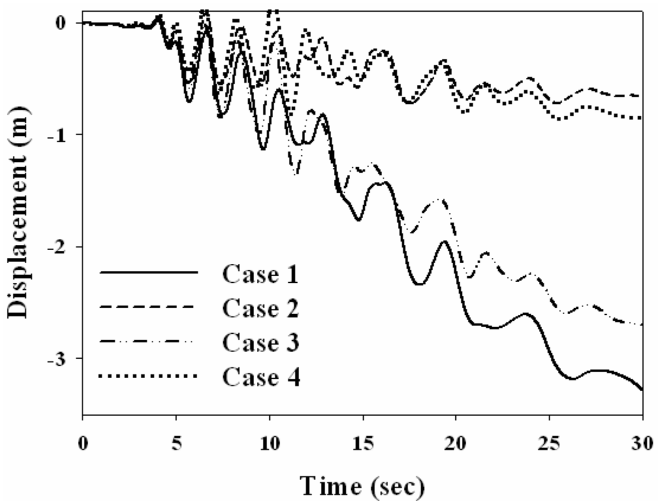


From The port and harbour research institute ministry of transport, Japan (1997)

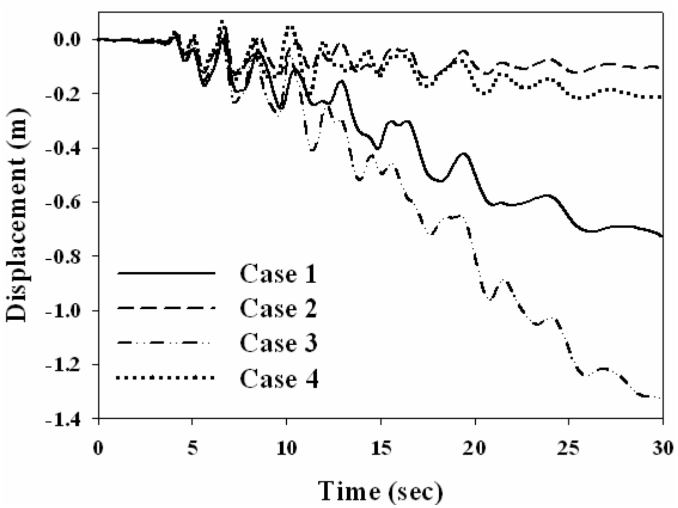
Influence of relative density

Summary of computed results of parameter study for quay wall PC1

Case	Foundation Densification	Backfill and Land fill densification	Displacements (m)		Rotation (degree)
			Horizontal	Vertical	
Case 1	Loose	Loose	3.3	0.74	4.5
Case 2	Dense	Loose	0.66	0.11	1.3
Case 3	Loose	Dense	2.7	1.24	4
Case 4	Dense	Dense	0.78	0.19	1.5

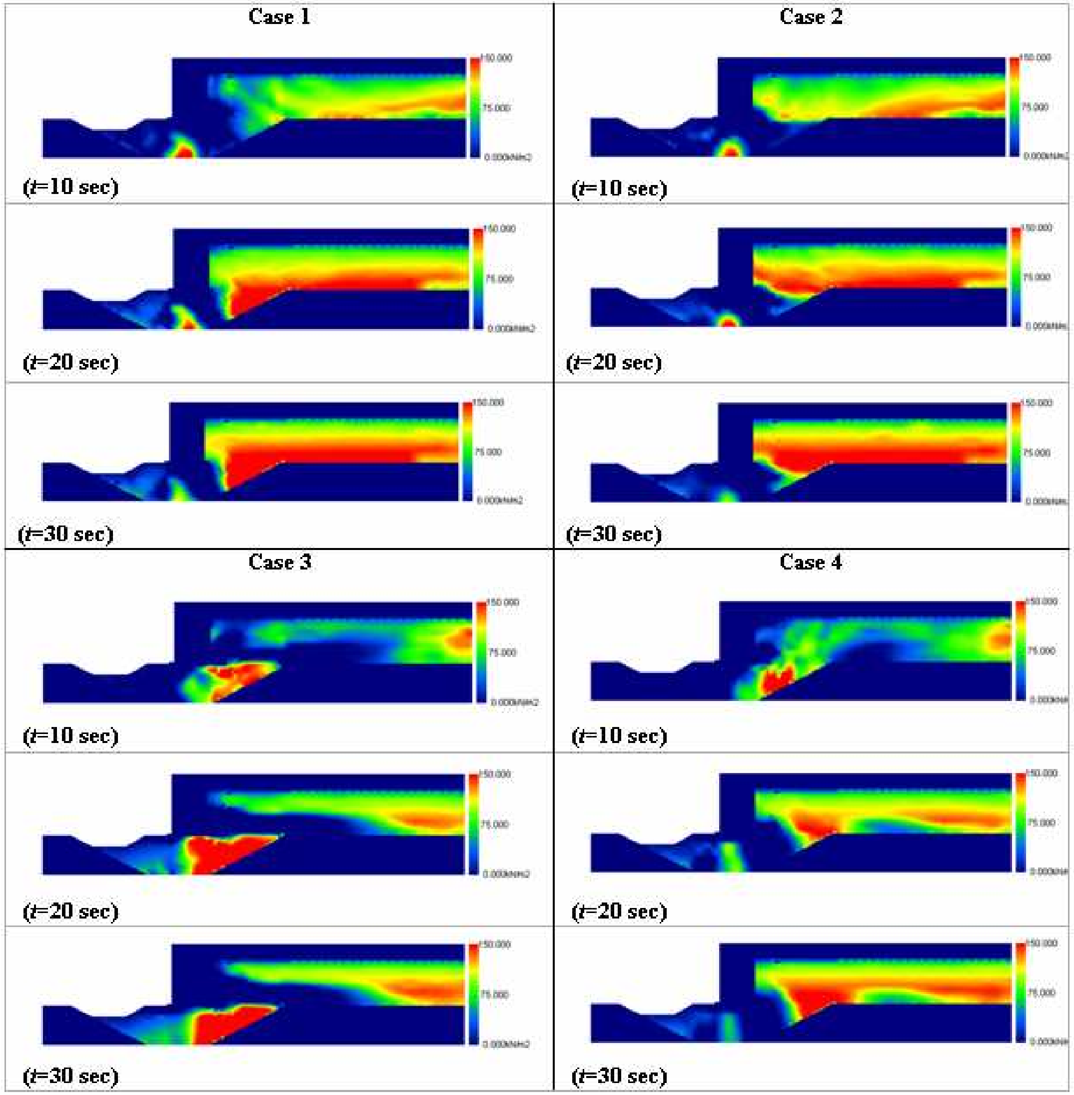


Horizontal displacement



Vertical displacement

Distributions of excess pore water pressure



Conclusions

A two-dimensional effective stress method of analysis based on the elasto-plastic constitutive model of PZ-III with slight modifications has been used for the analysis Port Island quay-wall PC1.

- The model was first validated by simulating published cyclic test results. The results of the testing showed excellent agreement between the physical and numerical experiments.

- Port Island quay walls was then analyzed using a finite element package UWLC

- Computed overall displacement and rotations of the wall were similar to those observed in the field.

- Improving the foundation while the backfill remained loose caused slightly smaller residual deformation of the caisson than when both the foundation and backfill were improved.

- The weight of the wall acting on the foundation leads to increased confining pressure beneath the wall, which prevents the occurrence of liquefaction behaviour.

- Finally, effective stress analysis is a powerful tool that can describe the seismic response of port structures, including liquefaction failure modes.

Thank you