Comparison Behavior of Pile-Supported Wharves under Monotonic and Cyclic Lateral Load

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Abstract

Pile supported wharf structures are include a concrete slab which supported on substructure from some elements including pile and embankment, soil maintenance structure and other elements. For comparison performance of pile and deck under monotonic and cyclic lateral loading; pile and deck structure with determined geotechnical and structural specifications being under increase lateral monotonic and cyclic load. In modeling of structures, soil-structure interaction was modeled with P-Y curve (Matlock. 1970) and these structures were taken under different surcharge.

Structures under cyclic load due to small lateral displacement receive to critical state in comparison with structure under monotonic loading. In addition, those structures with larger surcharge may tolerate greater lateral deforming under same force.

Key words: monotonic loading, cyclic loading, pile supported wharf, P-Y curve.

Introduction

From an engineering point of view, port structures are soil-structure systems that consist of various combinations of structural and foundation types. Some port structures are mixed and can not be fully characterized by a single structural or foundation type, or stability mechanism. It is also difficult to produce an alternative characterization based on the vulnerability of the structure to damage by strong ground motions. This is due to the relative importance of the soil-fill conditions on the seismic performance of the structure.

A pile-supported wharf is composed of deck supported by a sub structure consisting of piles and dike/slope. The unsupported pile length above the dike/slope surface is variable. When rockfill suitable for construction of the dike is uneconomical, a gravity or sheet pile retaining structure is also constructed to replace a portion of the dike. The seismic response of pile-supported wharves is influenced to a great degree by complex soil-structure interaction during ground shaking. Typical failure modes during earthquakes depend on the magnitude of the inertia force relative to the ground displacement. So studying behavior of pile-supported structures under monotonic and cyclic lateral load could aid to know behavior of these structures under earthquake load correctly.

For comparison performance of pile and deck under monotonic and cyclic lateral loading; pile and deck structure with determined geotechnical and structural specifications being under increase lateral monotonic and cyclic load. In modeling of structures, soil-structure interaction was modeled with P-Y curve (Matlock. 1970) and these structures were taken under different surcharge.

Characteristics of proposed pile –supported wharf

A pile-supported wharf with a water depth of 12 m was proposed for construction. The proposed cross section and plan of the pile-supported wharf shown in Fig.1. Geotechnical parameters, including the coefficient of subgrade reaction, were determined from a geotechnical investigation and are given in Table.1. The wharf supported by four rows of 1.2 m diameter steel pipe piles. Piles in rows 1 through 3 have a wall thickness of 12 mm, and the piles in row 4 have a wall thickness of 14 mm. Structural parameters for these piles are given in Table.2. Loads considered in the design include a 30 kN/m^2 dead weight of the deck, and crane loads of 2400 kN per unit frame work of the pile-deck system. Structure was loaded on two different surcharges. Surcharge no. 1 was 10 kN/m^2 and other surcharge i.e. surcharge no. 2 was 30 kN/m^2.

Fig.1. proposed pile-supported wharf
a) Cross section.
b) Plan.

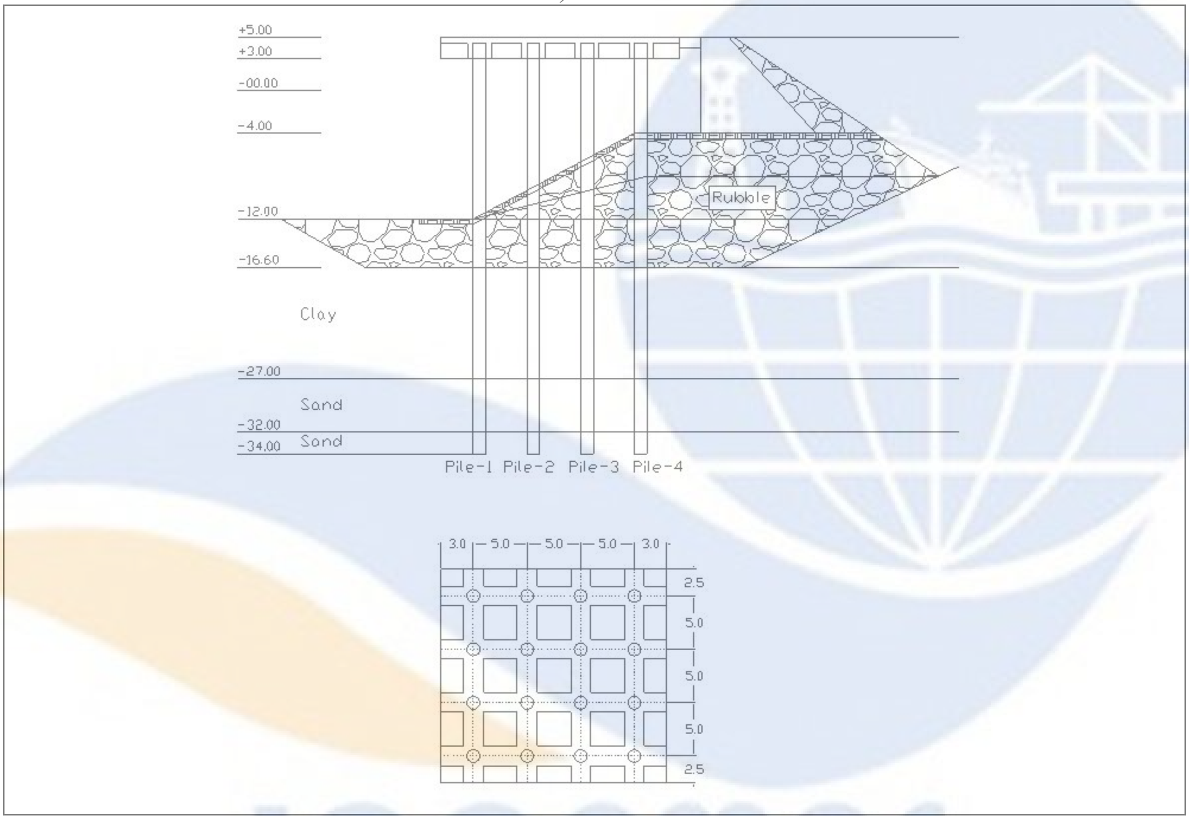


Table.1. Major geotechnical parameters for pile-supported wharf.

Soil layers	Density (t/m^3)	Coefficient of subgrade reaction (kN/m^3)	Internal friction angle or unconfined compressive strength (kN/m^3)
Rubble	1.9	29000	$\Phi=30^o$
Soil layer 1 (Clay)	1.6	29000	$q_u=60$
Soil layer 2 (Sand)	2.0	117000	$\Phi=35^o$
Soil layer 3 (Sand)	2.0	290000	$\Phi=35^o$

Table.2. Major pile parameters.

Type of parameter	Pile parameters	
	Piles 1 through 3	Pile 4
Diameter (m)	1.2	1.2

Thickness (m)*	0.011	0.013
Cross section area (m^2)	0.0410	0.0484
Moment of inertia (m^4)	0.00723	0.00850
Elastic section modulus (m^3)	0.0120	0.0142
Yield stress (kN/m^2)**	315000	315000
Yong modulus (kN/m^2)	$2.06*10^8$	$2.06*10^8$
* Cross section area and moment of inertia are computed by allowing loss of cross section in 1 mm thickness due to correction		
** Steel used was SKK490 in JIS-A-5525		

The unit framework considered for design is indicated by hatching in Fig.2. Soil-structure interaction was modeled by P-Y curve (Matlock. 1970). Lateral load was applied two types: monotonic and cyclic load.

Models were labeled with both alphabet and number that shown type of applied surcharge and type of applied lateral load:

Marker number of applied surcharge,
1=Surcharge equals 10 kN/m^2.
2=Surcharge equals 30 kN/m^2.
Marker word of type of lateral load,
SC=Cyclic lateral load.
SM=Monotonic lateral load.

Model of studying pile-supported wharf

The computer program ANSYS6.1 was used for the analysis. This program has different ability such as static analysis, time history analysis, modal analysis, spectrum analysis and other analysis. In addition, this program could model nonlinear behavior of material, creep, contact mechanism and other ability.

In this modeling, piles element was modeled with SHELL 181 element and for springs modeling that were derived base on P-Y curve were used CONBINE 39 element. Because the deck of structure was rigid, all nodes of piles those were located in top of piles constraint to one point. The inplan rotation of this point was limited. In all model, more over the springs were located in respective nodes, vertical movement of all nodes of piles that were located in bottom of piles were limited. In fact bottom of piles behavior such as roller supports.

Steel stress-strain curve assume with hardness equal 2% elastic module. Lateral load was applied in two types: monotonic and cyclic load. In cyclic lateral load, load was increase 20 mm in any time step. In this case, total displacement was 320 mm. In other type of lateral load i.e. monotonic lateral load, load was increase 4 mm in any time step. Total lateral displacement was 500 mm. Lateral displacements in any type of lateral loads were applied to top of deck. In any time step, with applied lateral displacement could earn applied lateral load in supports and created strain and stress in piles elements.

Results of modeling and analysis

In this chapter, results of four models that were analyzed with computer program ANSYS6.1 were presented. Results of models compared together until effect of different factors in modeling such as difference in surcharge or difference in typical lateral loading determined.

Maximum lateral displacement, maximum element strain, length of plastic hinge, total lateral load and hysterics energy given in Table.3, Table.4, Table.5 and Table.6. Force-displacement curve shown in Fig.2, Fig.3, Fig.4 and Fig.5.

Table.3. Analysis results of 1SM model

D = 29.6 cm				D = 26 cm				D = 19.2 cm				D = 18 cm				D = 16 cm				Displacement	
	LPH	Status	Max strain		LPH	Status	Max strain		LPH	Status	Max strain		LPH	Status	Max strain		LPH[1]	Status	Max strain	Title	
	15	P	.00315			P	.00253			P	.00173			P	.00163					Top	Pile 1
		P[2]	.00163																	Bottom	
	5	P	.00306			P	.00243			P	.00163									Top	Pile 2
																				Bottom	
	30	P	.00325			P	.00263			P	.00173			P	.00163					Top	Pile 3
																				Bottom	
	80	P	.00383		21	P	.00318			P	.00193			P	.00183			P	.00163	Top	Pile 4
																				Bottom	
1360				1245				959				914				828				Total Force (KN)	

D = 34.4 cm				D = 33.6 cm				D = 32.8 cm				Displacement	
	LPH	Status	Max strain		LPH	Status			LPH	Status	Max strain	Title	
	83	P	.00393		75	P			60	P	.00365	Top	Pile 1
		P	.00240			P				P	.00193	Bottom	
	75	P	.00388		65	P			55	P	.00354	Top	Pile 2
		P[5]	.00160									Bottom	
	92	P	.00408		85	P			75	P	.00378	Top	Pile 3
		P	.00181			P[4]	.00163					Bottom	
	133	P	.00491		125	P	.00473		110	P	.00458	Top	Pile 4
		P	.00190			P	.00181			P[3]	.00163	Bottom	
1522				1503				1482				Total Force (KN)	

1. Length of Plastic Hinge (cm)
2. Level of the bottom plastic hinge is -14 m
3. Level of the bottom plastic hinge is -11.5 m
4. Level of the bottom plastic hinge is -12.5 m
5. Level of the bottom plastic hinge is -13 m

Fig.2. Force-displacement curve of 1SM model

Table.4. Analysis results of 2SM model

D = 27.2 cm				D = 18.4 cm				D = 17.6 cm				D = 17.2 cm				D = 15.6 cm				Displacement	
Pic No.	LPH	Status	Max strain	Pic No.	LPH	Status	Max strain	Pic No.	LPH	Status	Max strain	Pic No.	LPH	Status	Max strain	Pic No.	LPH[1]	Status	Max strain	Title	
05		P	.00294	04		P	.00172	03		P	.00166	02		P	.00163	01				Top	Pile 1
		P[2]	.00163																	Bottom	
		P	.00276			P	.00165													Top	Pile 2
																				Bottom	
		P	.00293			P	.00168			P	.00162									Top	Pile 3
																				Bottom	
	50	P	.00351			P	.00198			P	.00187			P	.00180			P	.00163	Top	Pile 4
																				Bottom	
1271				927				891				875				808				Total Force (KN)	

D = 32.8 cm				D = 31.6 cm				D = 30.4 cm				Displacement	
Pic No.	LPH	Status	Max strain	Pic No.	LPH	Status	Max strain	Pic No.	LPH	Status	Max strain	Title	
08	81	P	.00381	07	70	P	.00365	06	40	P	.00341	Top	Pile 1
		P	.00261			P	.00235			P	.00201	Bottom	
	64	P	.00368		49	P	.00348		25	P	.00329	Top	Pile 2
		P[5]	.00160									Bottom	
	88	P	.00388		81	P	.00366		55	P	.00349	Top	Pile 3
		P	.00179			P[4]	.00163					Bottom	
	121	P	.00471		113	P	.00444		90	P	.00422	Top	Pile 4
		P	.00190			P	.00179			P[3]	.00163	Bottom	
1406				1387				1350				Total Force (KN)	

1. Length of Plastic Hinge (cm)
2. Level of the bottom plastic hinge is -14 m
3. Level of the bottom plastic hinge is -11.5 m
4. Level of the bottom plastic hinge is -12.5 m
5. Level of the bottom plastic hinge is -13 m

Fig.3. Force-displacement curve of 2SM model

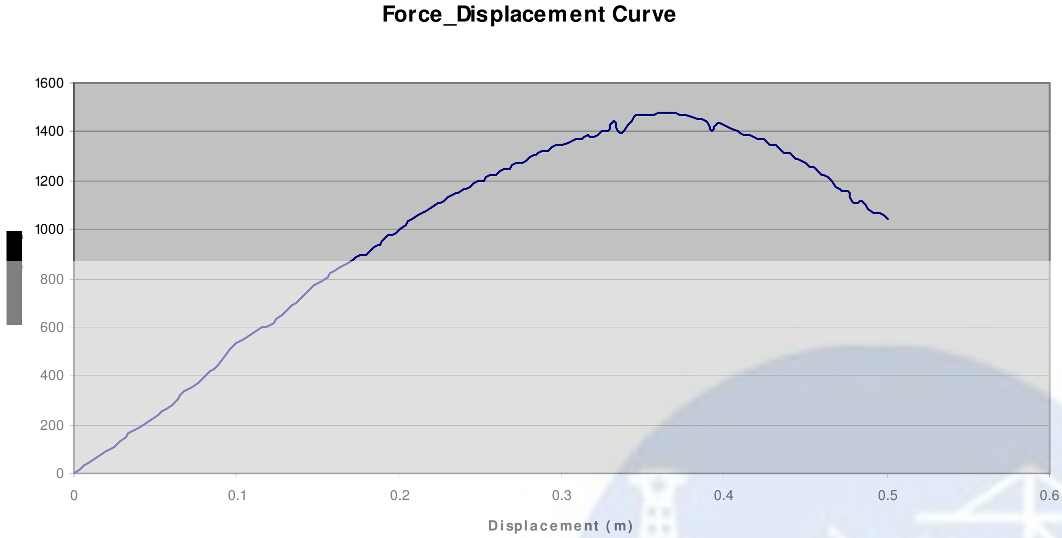


Table.5. Analysis results of 1SC model

D =32 cm				D = 30 cm				D = 20 cm				D = 18 cm				D = 16 cm				Displacement	
E	LPH	Status	Max strain	E	LPH	Status	Max strain	E	LPH	Status	Max strain	E	LPH	Status	Max strain	E[5]	LPH[1]	Status	Max strain	Title	
436	190	P	.01358	394	174	P	.00954	200		P	.00181	120		P	.00163	81				Top	Pile 1
		P	.00223			P[2]	.00186													Bottom	
	203	P	.01958		194	P	.01383			P	.00171									Top	Pile 2
																				Bottom	
	210	P	.02478		203	P	.01786			P	.00205			P	.00166					Top	Pile 3
		P[3]	.00173																	Bottom	
	221	P	.03716		218	P	.02786		50	P	.00324			P	.00209			P	.00163	Top	Pile 4
		P[4]	.00185																	Bottom	
1271				1266				852				796				695				Total Force (KN)	

D = -32 cm				Displacement	
E	LPH	Status	Max strain	Title	
	194	P	.01598	Top	Pile 1
		P	.00224	Bottom	
	207	P	.02288	Top	Pile 2
				Bottom	
	214	P	.02871	Top	Pile 3
		P	.00175	Bottom	
	223	P	.04238	Top	Pile 4
		P	.00186	Bottom	
1643				Total Force (KN)	

1. Length of Plastic Hinge (cm)
2. Level of the bottom plastic hinge is -14.5 m
3. Level of the bottom plastic hinge is -11.5 m
4. Level of the bottom plastic hinge is -12.5 m
5. Hysterics Energy (KN.m)

Fig.4. Force-displacement curve of 1SC model

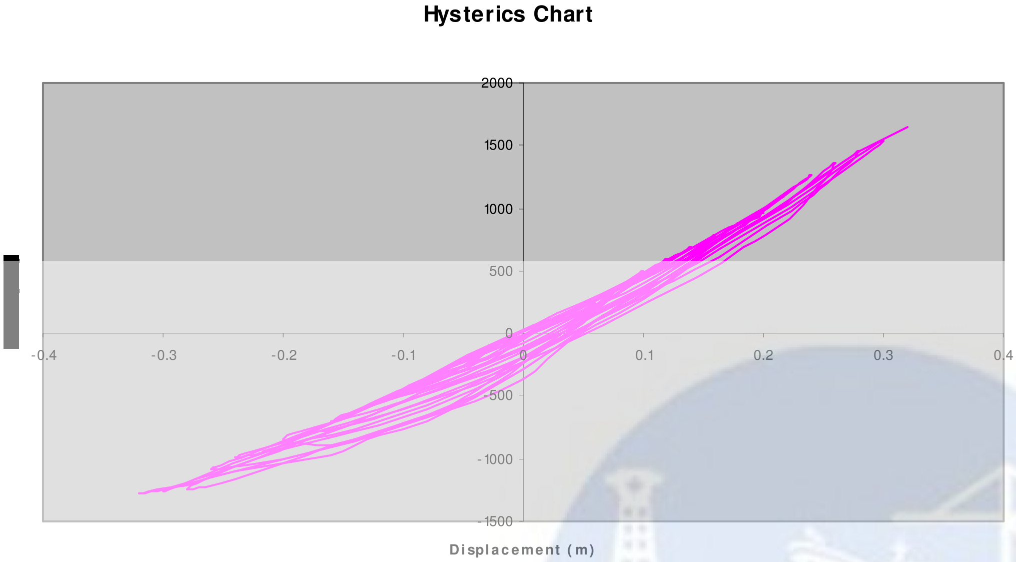


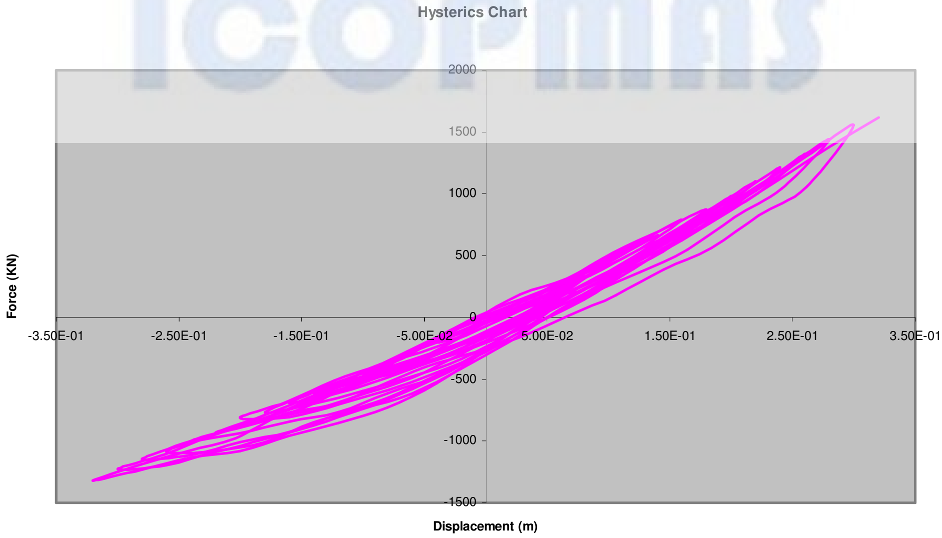
Table.6. Analysis results of 1SC model

D = 30 cm				D = 28 cm				D = 20 cm				D = 18 cm				D = 16 cm				Displacement	
E	LPH	Status	Max strain	E	LPH	Status	Max strain	E	LPH	Status	Max strain	E	LPH	Status	Max strain	E[5]	LPH[1]	Status	Max strain	Title	
364	178	P	.00978	339	142	P	.00670	199		P	.00189	126		P	.00168	80				Top	Pile 1
		P	.00245			P[2]	.00181													Bottom	
	197	P	.01398		178	P	.00951			P	.00176									Top	Pile 2
																				Bottom	
	208	P	.01798		191	P	.01250			P	.00214			P	.00163					Top	Pile 3
		P[4]	.00169																	Bottom	
	216	P	.02808		204	P	.02023		70	P	.00330			P	.00216			P	.00168	Top	Pile 4
		P[3]	.00183																	Bottom	
1226				1147				814				770				693				Total Force (KN)	

D = -32 cm				Displacement	
E	LPH	Status	Max strain	Title	
	195	P	.001633	Top	Pile 1
	40	P	.00338	Bottom	
	208	P	.002303	Top	Pile 2
				Bottom	
	215	P	.002908	Top	Pile 3
		P	.00205	Bottom	
	221	P	.04273	Top	Pile 4
		P	.00223	Bottom	
1616				Total Force (KN)	

1. Length of Plastic Hinge (cm)
2. Level of the bottom plastic hinge is -14.5 m
3. Level of the bottom plastic hinge is -11.5 m
4. Level of the bottom plastic hinge is -12.5 m
5. Hysterics Energy (KN.m)

Fig.5. Force-displacement curve of 2SC model



Conclusion

a) Effect of different surcharge

With comparison of structures model that their surcharge is different and same lateral displacement, because of increase of compressive axial load and increase of compressive strain too, the amount of created elements strain and length of plastic hinge in the structures model were loaded with surcharge no.2 was more than structures model were loaded with surcharge no.1.

Other results gain this comparison is that the structures with the same lateral displacement, the structures with greater vertical loads, created total lateral loads in their supports are less than others i.e. the structures with the same lateral load, the structures with greater vertical loads, created deck lateral displacement are more than others.

Hysterics energy in the structures model was loaded with surcharge no.1 was less than structures model were loaded with surcharge no.2.

b) Effect of typical lateral load

With comparison of structures that their typical lateral load is different and same surcharge load, the amount of created elements strain and length of plastic hinge in the structures were applied cyclic lateral was more than structures were applied monotonic loaded. The reason of this behavior is step by step accumulated damage.

Reference

1. Seismic Design Guideline for Port Structure, Working Group NO.34 of the Maritime Navigation Commission, International Navigation Association, 2000.
2. Bertero, V. V., 1997, Performance-Based Seismic Engineering: A Critical review of proposed guidelines, In: Seismic Design Methodologies for the Next Generation of Codes, Proceeding of the International Workshop on Seismic Design Methodologies for the Next Generation of Codes, Balkema, Rotterdam, P. 1-31.
3. Fajfar, p., EERI, M., 2000, A Nonlinear Analysis Method for Performance-Based Seismic Design, Earthquake Spectra, Vol. 16, NO.3, August 2000, P.573-592
4. SEOAC, 1995, Performance Based Seismic Engineering of Building, Vol.1, April 1995.
5. Kramer, S.L, 1996, Geotechnical Earthquake Engineering, Prentice Hall, 653 p.