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Research Article

Piping Phenomena in an Open-end Pipe Pile of Offshore Structure

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Abstract

This research is conducted to study the piping phenomena occurs with cohesinless soils below different levels of water with different grain size distribution, (i.e. fine, medium and coarse sand) and its effect when excavation process done within pipe pile through experimental model study. The sand was used as a natural soil in this study, poorly graded clean sand and most particles were rounded. The sandy soil was sieved to obtain different grain size distribution of fine, medium and coarse graded according to (ASTM D 422). Total number of (166) models of steel pipe piles test, involving four open-ended steel pipe piles models of 32 mm in diameter embedded to a depth of 500mm within different grain size distribution cohesionless soils prepared with a different relative densities of (35, 50 and 70)%, under various head of water of (20, 30 and 40) cm above soil surface It was found that the water head increase the ultimate load capacity of piles but when excavate inside the pipe pile, piping phenomena will occur when reaching to a certain length of soil inside the pipe pile. Generally this phenomenon affected by many parameters such as soil density, water head and grain size distribution. The results appeared that the ratio of inside soil column length to the embedded pile length which cause that phenomena in fine sand about (9 – 27) %, while in medium sand piping occurs with percent about (6 – 24)% and for coarse sand the percent about (14 – 26)%.

Keywords: *Open pipe pile, piping phenomena in pipe piles, cohesionless soils, grain size distribution*

1. Introduction

Piping is often described using the term backward erosion. This is because piping is the erosion of soil particles at some seepage exit location due to forces imposed by water transport through a porous media. This process results in channels or pipes that progress in an upward gradient back towards the water source.

The phenomenon of piping or tunneling in the soil has been known for some years, particularly to engineers [Terzaghi, 1936]; yet piping has been generally overlooked by hydrologists. Engineers have been mainly concerned with piping failure in earth dams, and a considerable amount of research has been done on this aspect

Many studies specialized with piping phenomena as Schmertmann (2000) developed a method which is depended on backward piping tests at University of Florida. Schmetmann's results indicated a correlation between the gradients which initiated piping erosion, and the uniformity of the sand gradation measured using the coefficient of uniformity Cu and found that critical hydraulic gradient increase with increasing the coefficient of uniformity Cu. Tomlinson S.S and Vaid Y.P (2000) found that the confining pressure and the magnitude and rate of gradient increase may influence initiation of piping. Indraratna and Sujeewa (2002), investigate that the critical hydraulic gradient decreases with increasing the pore diameter in sandy soil. Jacobson (2013) made a relationship between critical gradient with the shearing angle and dry unit weight that explain the critical hydraulic gradient for most soils increase with increasing the angle of failure shear, so it increase with increasing dry unit weight. Chang and Zhang (2013), recently investigated the effects of stress state on critical hydraulic gradients at which suffusion occurs in gap-graded soils. Suffusion is the erosion of finer particles from a matrix of coarser particles as a result of seepage flow.

They performed tests under drained triaxial conditions, isotropic and triaxial extension conditions. They determined that the initiation of a critical hydraulic gradient is determined by the pore structure of the soil. Specifically as the stress ratio increases, porosity in the soil decreases. Therefore the gradient at which failure occurred was a function of the initial stress state of the soil, the applied seepage forces, and the shear strength of the soil with triaxial extension stress resulting in higher gradients for the initiation of piping.

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2. Experimental work and tables

The grain size distribution of the sand used illustrated in figure (2.1), physical soil properties are shown in table (2.1). The pipe pile model used of 3.2 cm diameter having embedded length within cohesionless soil of different relative densities of (35,50 and 70) % and head of water above soil surface is (20, 30 and 40)cm.

The model steel container have dimensions of (60*60*1150)cm the container and set up of model tests with steel frame and load cell of testing explained as shown in plate (2.1) and it manufactured as Yu and Yang (2012) recommendation, the axial load testing for piles is according to ASTM D 1143 – 07. The ultimate bearing capacity of pipe piles model tests are shown in table 2.2.

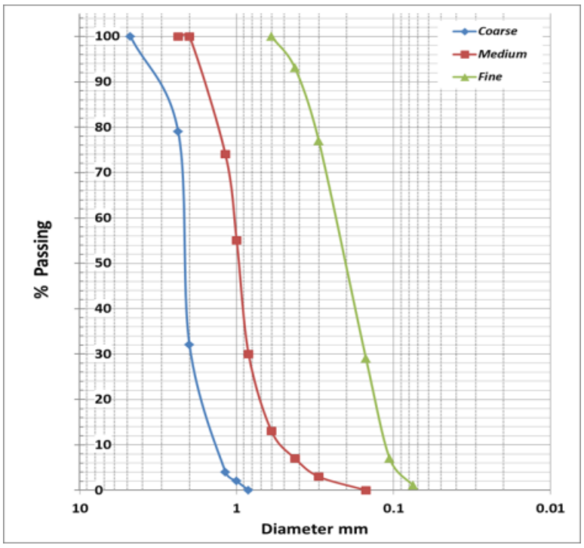

Fig 2.1 The grain size distribution for the soils used

Table 2.1 Experimental procedure parameters

Physical properties	Fine sand	Medium sand	Coarse sand	Specification
Grain size analysis				
Effective size D10, (mm)	0.115	0.51	1.45	ASTM D422-02
D30, (mm)	0.165	0.47	1.90	
D60, (mm)	0.215	1.08	2.05	
Coefficient of curvature, Cc	1.101	0.401	1.214	
Coefficient of uniformity, Cu	1.870	2.118	1.414	
Soil classification (USCS)	**SP**	**SP**	**SP**	
Specific gravity, Gs, @20°C	2.68	2.63	2.60	ASTM D854-06
Dry unit weights (Ɣd)				
Maximum dry unit weight Ɣd(max), (kN/m3)	17.02	17.5	16.63	ASTM D4253-00
Minimum dry unit weight Ɣd(min), (kN/m3)	13.71	14.75	13.8	ASTM D4254-00
Maximum void ratio, emax	0.955	0.783	0.884	
Minimum void ratio, emin	0.575	0.503	0.563	
Dry unit weight at assumed R.D				
35%	14.7	15.61	14.67	
50%	15.18	16.01	15.08	
70%	15.87	16.57	15.68	
Angle of internal friction (Ø°)				
35%	33	33.5	32.1	ASTM D3080-03
50%	35.2	36.8	34.3	
70%	38.1	39.6	37.3	

Fig 2.2 The pipe piles during the tests

Table 2.2: The results of ultimate load capacity

Type of soil	Ultimate load capacity (N)								
	Dr = 35%			Dr = 50%			Dr = 70%		
	hw =20 cm	hw =30 cm	hw =40 cm	hw =20 cm	hw =30 cm	hw =40 cm	hw =20 cm	hw =30 cm	hw =40 cm
Coarse sand	200	201	232	266	288	301	512	542	580
	230	190	281	253	272	242	424	423	601
	222	172	253	212	21.1	105	312	325	142
	190	15.4	95	169	93	105*	105	131	125*
	78	85	95	84	90		102*	120*	
	80*	82	92*	82*	91*				
		81*							
Medium sand	280	287	293	383	450	473	61.9	674	763
	280	282	281	374	421	405	58.3	596	691
	262	271	253	352	365	364	41.7	456	505
	235	248	239	296	295	298	31.1	323	397
	192	199	221	251	211	236	13	130	151
	181	185	103	109	109	116	13.1*	132*	148*
	91	91	95	111*	118*	109			
	95*	94*	98*			119*			
Fine sand	235	222	254	303	322	401	55.8	577	678
	230	271	281	257	288	365	45.8	484	601
	222	248	253	181	204	315	30.7	325	478
	190	162	221	102	105	201	25.1	131	142
	160	80	95	107*	108*	105	12	122*	131*
	80	85*	95			100	122*		
	82*		90*			112*			

3. Results

The effect of grain size distribution can be represent with respect to coefficient of uniformity on critical hydraulic gradient as shown in figure (3.1). The figure shows that coefficient of uniformity increases with increasing hydraulic.

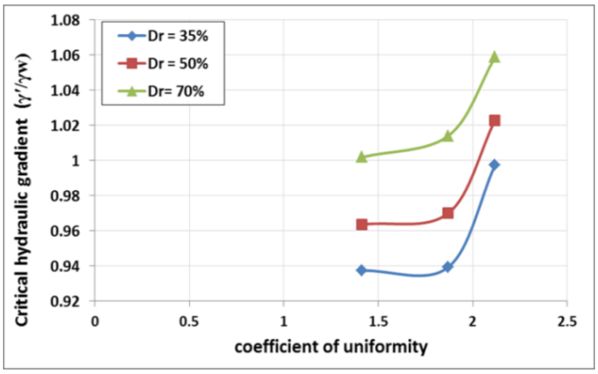

Fig 3.1: Effect of coefficient of uniformity on critical hydraulic gradient

Figures (3.2) to figure (3.4) show critical length of soil column within the pipe piles caused piping phenomena and the behavior of pipe pile during piping phenomena.

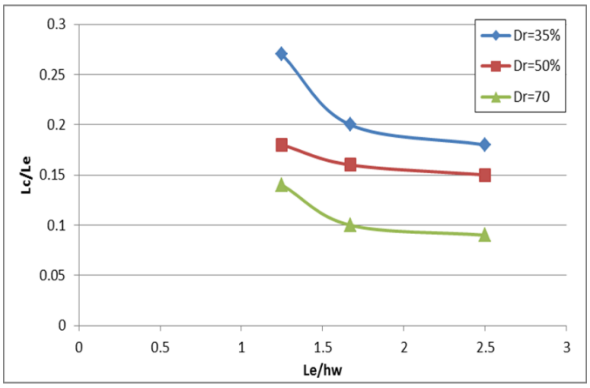

Fig 3.2: Critical length of soil column within the pipe pile cause the piping from model test in fine sand

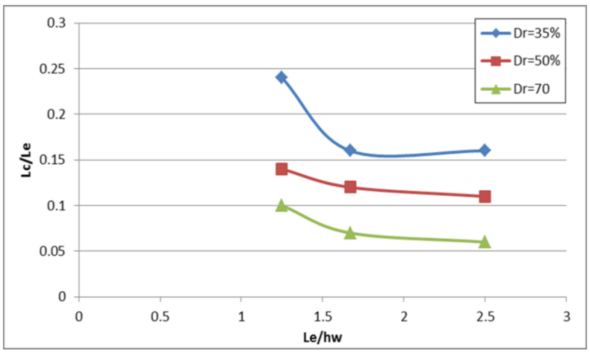

Fig 3.3: Critical length of soil column within the pipe pile cause the piping from model test in medium sand

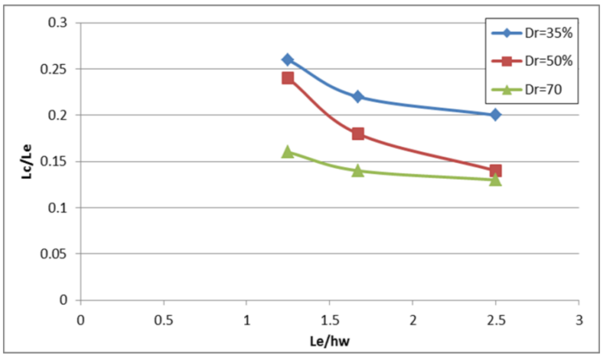

Fig 3.4: Critical length of soil column within the pipe pile cause the piping from model test in coarse sand

Where:

Le : Embedded length of pile
hw : Head of water above soil level
Lc : Critical inside length where piping occur

Conclusions

The following conclusion can be drawn from the model tests:

1) The relationship between critical hydraulic gradient which is direct parameter select the occurring of piping phenomena and coefficient of uniformity (Cu) is positive relationship; it is increase steadily when coefficient of uniformity increase.
2) The Piping phenomena depended on grain size distribution where the medium sand had highest critical hydraulic gradient, it fail with minimum inside length of soil plug, while coarse sand has lowest value of critical hydraulic gradient and fine sand between of them.
3) Length of the soil column within the pipe pile used to resist the piping phenomena depends on the water head level outside the pipe pile.
4) The results appeared that the ratio of inside soil column length to the embedded pile length which cause that phenomena in fine sand about (9 – 27) %, while in medium sand piping occurs with percent about (6 – 24)% and for coarse sand the percent about (14 – 26)%.

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