Piling in Karstic Rock Ground

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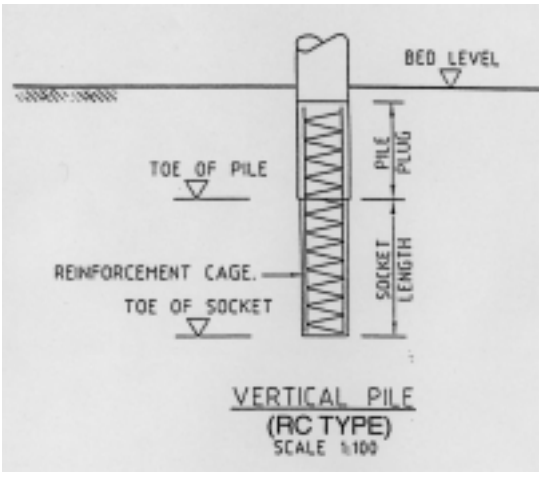
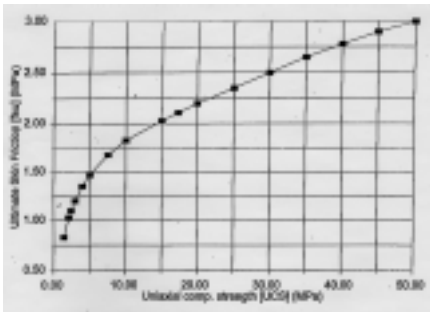
1. Introduction

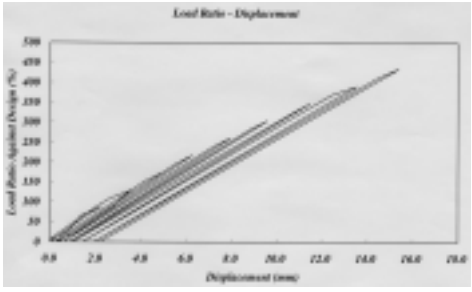
Jetties (LNG Unloading Jetty and Condensate Unloading Jetty) were formed as a part of the LNG plant in Sultanate of Oman. Both jetties comprised of a Trestle, Jetty Head and Dolphins with piles which are penetrated into the Karstic Rock Ground. A Hybrid Pile that consisted of a Steel Pipe Pile (above seabed) and a Cast In-Situ RC Pile called a "Socket" (below seabed) was developed and used. The purpose of using this method was to provide piling with sufficient bearing capacity for Karstic Rock Ground. This report which shows the validity of the Hybrid Pile Method, includes the Trial Pile Test results and also indicates the method of maintaining the quality of the piles in the project.



2. Design Criteria & Trial Pile Test Results

The Existence of cavities studded among the karstic rock was anticipated. Sufficient end bearing could not therefore be expected for the bearing capacity of the socket. The socket was therefore designed as a friction bearing pile. Several equations were considered to predict the friction capacity between socket and rock surface. Amongst them, one conservative equation was employed for socket design. Two trial pile tests and working pile tests were carried out to confirm the actual bearing capacity of the socket. It was proven that the bearing capacity of the designed socket was more than 400% of the design load, while the design requirement of safety factor was 300%.





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3. Quality Control Measure

・ Core boring

In total, 377 piles (122 Vertical Piles & 255 Raking Piles) were installed in the project. In order to maintain proper safety factors against design loads, 329 sets of core borings (for all Vertical Piles and for those Raking piles whose socket toes were far away from Vertical Piles location) were carried out. Socket lengths were determined based on the core analysis reports. This minimized the total quantity of sockets (i.e. required drilling length & concreting volume).

・ Geologist / Socket Design Spread Sheet

After sampling of cores, analysis of the boring data and socket design had to be processed immediately so as not to delay the construction schedule. A Geologist was on site to facilitate immadiate analysis. A spread sheet for socket design was also prepared to enable the socket design to be followed by the site engineers. By inputting the core analysis result, the designed socket length could be calculated automatically. As a result, the spread sheet also helped with quality control of the design.

PILE MD54
Reference Borehole LD 82

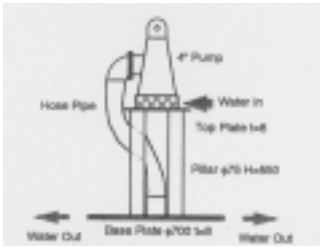
1	Socket length based on an average UCS of 5 Mpa				3.5m
2	rock group	present	total depth	effect on socket length	socket length
	green	yes	0.7m	None	3.5m
3	rock group	present	total depth	effect on socket length	adjusted socket length
	red	yes	4.1m	+4.1m	7.6m
4	rock group	present	total depth	socket length / FoS	Condition
	amber	yes	0.8m		Increase
	blue	yes	2.0m	7.6m / 3.0	socket length
5	reduce length to achieve required FoS=3.0			effect on socket length: +0.0m	adjusted socket length: 7.6m
6	Bending Moment				1550kNm
	Minimum socket length for this bending moment is				5.0m
7	Working socket length				7.6m

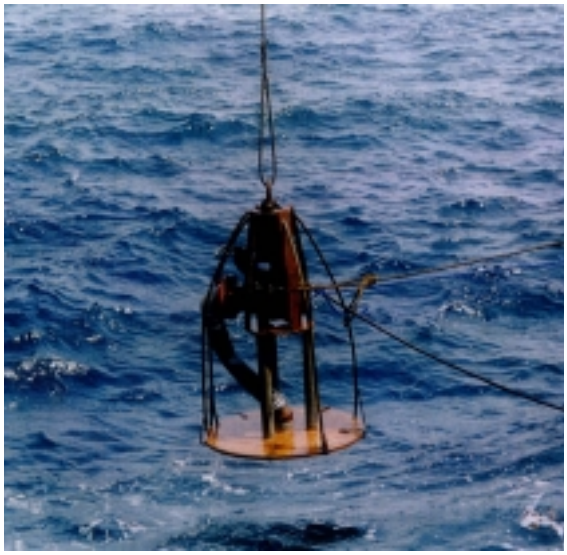
depth range	rock group	strength	depth	UCS	Ult bond stress	Ult capacity
2.0-2.1m	red	*	0.10			
2.1-2.8m	red	gravel	0.70			
2.8-3.9m	red	stiff	1.10			
3.9-4.2m	blue	mod strong	0.30	12.5	1.9	1612
4.2-4.8m	amber	weak	0.40	1.0	0.6	679
4.8-5.3m	green	mod weak	0.70	5.0	1.5	2969
5.3-5.7m	amber	weak	0.40	1.0	0.6	679
5.7-8.5m	blue	mod strong	0.80	12.5	1.9	4298
6.5-8.7m	red	stiff	2.20			
8.7-9.6m	blue	mod strong	0.90	12.5	1.9	4835
Socket Length			7.60			
Ultimate Pile Capacity (kN)						15072
Pile Working Load (kN) Compression						4,900
Factor of Safety (Compression)						3.1
Pile Working Load (kN) Tension						1,550
Factor of Safety (Tension)						9.7

Minimum Factor of Safety in Compression = 3.0
Minimum Factor of Safety in Tension = 3.0
* Allowance for shattering of rock at top of socket

・ Slime Cleaner

The bearing Capacity of each socket depended upon the friction force between the socket concrete and the rock surface. A slime cleaner was developed to remove the slime adhering to the rock surface of the drilled hole to ensure the expected friction force.





4. Conclusion

In restricted (for both technologically and methodologically) conditions, it is very important to establish an appropriate construction method. Under such condition, the Hybrid Pile Method was developed by the combination of existing piling methods. This method needs neither special technology nor special equipment. Through this project, not only the technological validity of this method but also the efficiency of the work was proved. With the further study in designing and further experience in actual construction, it can be an effective pile construction method for rock ground.