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EXPERIMENTAL INVESTIGATION OF PILE GROUP UNDER LATERAL CYCLIC LOAD IN SOFT COHESIVE SOIL

S. Basak

Dept. of Applied Mechanics, Bengal Engineering & Science University, India.

ABSTRACT

The environment prevalent in ocean necessitates the piles supporting offshore structures to be designed against lateral cyclic loading initiated by wave action. Such quasi-static load reversal induces deterioration in the strength and stiffness of the soil-pile system introducing progressive reduction in the bearing capacity as well as settlement of the pile foundation. To understand the effect of lateral cyclic load on lateral capacity of pile group in soft clay, a series of laboratory experiments were performed. This paper presents the experimental observations made and the relevant conclusions drawn there from.

Keywords: Pile group, cyclic load, clay, frequency, amplitude.

1. INTRODUCTION

Offshore structures, namely, oil drilling platforms, jetties, tension leg platforms etc. are mostly supported on pile foundations. Apart from the usual super structure load (dead load, live load, etc.), these piles are subjected to continuous lateral cyclic loading resulting from ocean waves. As reported by other researchers, this type of loading induces progressive degradation of the foundation capacity associated with increased pile head displacement.

A comprehensive review of literature indicates that limited research works have been done in the related areas. The contributions made by Matlock (1970), Poulos (1981& 1982), Purkayastha & Dey (1990), Narasimha Rao & Prasad (1992), Purkayastha et al (1997), Basak (1999), Dyson (1999), Basak & Purkayastha (2003) and Randolph (2003) are worthy of note. Some of the works were theoretical while the others had been experimental (laboratory and field based investigations).

As pointed out by Poulos (1981b), basically the following three reasons have been identified for such degradation of strength and stiffness of pile-soil system : (i) Development of excess pore water pressure generated during cyclic loading in progress. (ii) General accumulation of irrecoverable plastic deformation of soil surrounding the pile surface. (iii) Rearrangement and realignment of soil particles surrounding the pile surface.

All the above types of lateral cyclic loading may be under load-controlled mode or displacement-controlled mode. In former case, the load applied at the pile head varies cyclically with time such that its maximum and the minimum values remain constant for all cycles. In the later case, it is the pile head deflection and not the applied load, which varies cyclically with time such that its maximum and the minimum values remain constant for all cycles.

The offshore pile foundations need to be designed considering two criteria : adequate factor of safety against ultimate failure and acceptable deflection at pile head. The aim of this investigation reported herein is to carry out experimental investigation so as to understand the effect of lateral cyclic loading on the performance of pile foundation.

2. EXPERIMENTAL SETUP

Since no standard apparatus for imparting lateral cyclic load on piles is available, a new multi-purpose set up was designed and fabricated. A schematic diagram and a photographic view of this apparatus are shown in Figs.1 & 2 respectively. Some of its important components are described below:

2.1 Test Tank

A stainless steel tank was designed and manufactured for preparing the soil bed. The tank consisted of three flanged segments each having 200 mm height and 400 mm internal diameter and 5 mm wall thickness. The. flanges of the segments were provided with holes for bolting purpose. Rubber gaskets were provided between the flanges of the adjacent segments to keep the side of the tank water tight as well as soil tight. Provision had been kept at the bottom of the tank to allow drainage of water from the soil bed, whenever required.

Fig 1: Photographic view of the Multipurpose Cyclic Loading Device.

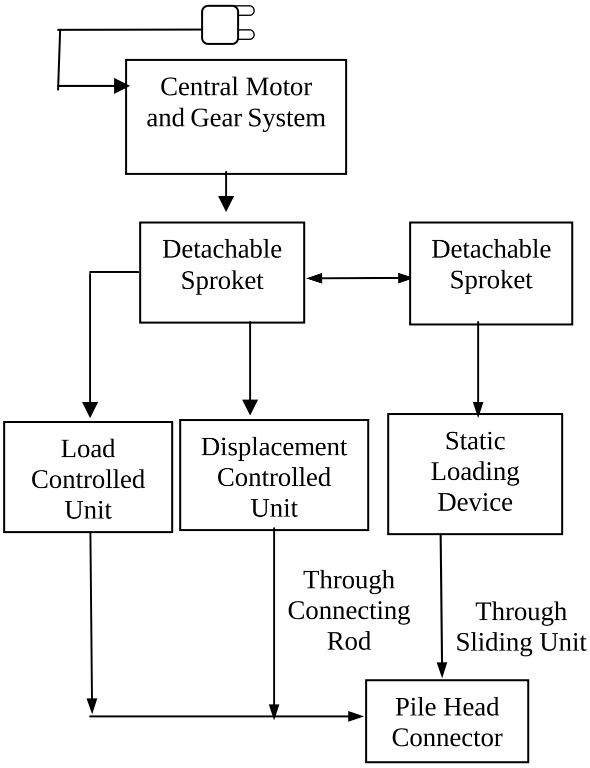


Fig 2: Basic operating principle of the cyclic loading device

2.2 The Loading Device

The loading device consisted of two separate units, one is for static loading and the other for cyclic loading, both being parallely connected with a central motor and gear system, such that one unit could be operated at a time. By chain and sprocket arrangement, each unit could be engaged or detached separately with the motor gear system.

2.3 Central Motor and Gear System

The central motor and gear system consisted of a 2 H.P., 3 Phase reversible, induction type of motor rotates at 920 r.p.m. By means of a 1 : 20 reduction gear box, this speed could be reduced. A PIV Drive (Positive Infinitely Variable Drive), a power transmission system using a slatted chain having input r.p.m. 600 and output r.p.m. minimum 182 and maximum 1272 was used to obtain different speed outputs. To transmit the power from the motor to the reduction gear box a two-step belt and pulley arrangement was used.

2.4 Static Loading Device

For static loading test, the apparatus was designed in such a manner that the strain controlled loading could be applied at the pile head, where the pile was pushed forward at a constant rate of horizontal displacement. By measuring the applied lateral load and the corresponding horizontal deflection of pile cap, the lateral load-deflection curves were plotted.

To serve this purpose, three shafts were connected in series between the output point of the central motor and gear system by means of bevel gears. The end shaft was threaded throughout its length to provide the forward and back ward motion of the holder. At one end, the end shaft is attached with a bevel gear and the other end with a holder wich was welded on the top of a sliding unit. This sliding uniot was connected to the pile head connector through a load cell.

2.5 Cyclic Loading Device

The experimental set up was designed in such a manner that the cyclic loading test could be performed under both the displacement controlled and the load controlled modes. The units for the same were connected in parallel between the pile head and the motor gear system such that one unit could be operated at a time. An adjustable differential cam mechanism was attached in parallel with the central motor gear unit to convert the rotation to horizontal sinusoidal translation, which was finally be applied on the pile head. The adjustable cam-shaft was uniquely designed to get different cyclic displacement amplitudes. The load controlled cyclic loading device, on the other hand, was capable of providing a two-way lateral cyclic load about a zero mean value. It consisted of an oscillating arm supported on a single point joint. At the bottom of the arm a semi-circlular pinion was fixed which was attached with a rack. The other end of the rack was connected to the pile head through load cell. A movable weight could slide over the oscillating arm keeping the pin joint as mean. The weight was provided over the oscillating arm by means of a cylindrical stainless steel container in which different weight blocks could be placed The motion from the main shaft to the crank was provided by means of chain and sprocket arrangement.

2.6 Ancilliary Equipments

A number of ancilliary equipments were attached with the apparatus, as described below:

(1) Load Cell: To measure the axial load applied on the model pile during static test in progress, a load cell with ± 500 kg. capacity was attached between spindle and the pile cap.

(2) Dial Gauge: To measure the pile head deflection in the axial direction a dial gauge with 0.01 mm. least count was used.

(3) LVDT: A Linear Variable Differential Transducer having ± 30 mm displacement measurement capacity was used.

(4) Strain Gauge: Electrical Resistance Strain gauges were used in the Instrumented Pile to measure the strains acting on various points on pile.

(5) Digital Indicator: A digital indicator was used to display the Load Cell reading, LVDT reading and specially the Strain gauge reading digitally.

(6) Pile Head Connector: To attach loading frame with the pile a detachable mild steel plate was used, which can be rigidly fixed with the pile head by threads.

(7) Pile Driving Unit: To insert the pile into the soil bed a screw-jack type arrangement was fabricated. It could be operated by a driving wheel.

(8) Mechanical Counter: To measure the applied number of cycles, a mechanical counter was attached to the main shaft.

3. SOIL, PILE AND TEST PROGRAMME

The soil and the piles used and the testing programme followed are described in this section.

3.1 Soil

Kaolin powder available from local market was mixed with water and this mixture was used for preparing the bed of soft cohesive soil. The soil was light yellowish in colour. Hydrometer test indicated that it contains 60% clay, 40 % silt and traces of sand. The liquid limit and the plastic limit of the soil were found to be 52% and 30% respectively, with the value of plasticity index as 22%. From standard Proctor compaction test, the maximum dry density of the soil was reported as 15.2 KN / m^2 with the optimum moisture content of 28%. The specific gravity of soil particle was obtained as 2.6.

In order to prepare the test bed, the kaolin powder is first of all thoroughly and uniformly mixed with water at a moisture content of 45%. This moisture content is near to the liquid limit of the soil and the workability was also observed to be adequate. After mixing, the soil was filled in the test tank in six equal layers manually. Each layer was compacted initially by hand compaction and thereafter by ten blows of a rammer. After the completion of the filling, the top surface was trimmed off by a spatula to obtain a levelled soil surface. A few samples were taken from finished test bed to carry out triaxial compression test. The average value of c and ϕ were obtained as 5 KN / m^2 and 5^0 respectively.

The rammer used for compacting soil was specially manufactured. It consisited of a base platform to be placed on the soil surface. Compaction was acheived by repeated dropping of a weight of 60 N from a height of 0.6 m on the top of this platform.

3.2 Pile

Experiments were carried out using 2 x 2 pile group, each pile being hollow circular stainless steel bar having 20 mm outer diameter and 600 mm overall length. The depth of embedment was 500 mm (L/d = 20) and the lateral load was imparted at a height of 90 mm above the soil surface. In order to insert the piles easily through the soil medium, the tips of the piles were pointed in shape. The piles were threaded at the top to attach with the pile cap by means of nuts. The piles were attached to a common pile cap which was actually a 16mm thick square steel plate. The c/c distances between the piles in the group was 60 mm. (= 3d).

3.3 Test Programme

The experiments performed were as per the testing programme described in Table-1. The frequency was expressed in cycles per minute (c.p.m.). In case of load-controlled mode, the applied cyclic load amplitudes were normalized by the lateral pre-cyclic caopacitgy of the pile group, whereas for displacement-controlled mode, the cyclic displacement amplitudes were normalized by the external diameter of pile.

Table 1: Experimental Programme.

Type of Test	**Amplitude (%)**	**Frequency (c.p.m.)**	**No. of Cycles**		
Displace Control Test	5	13	100	500	1000
		21	100	500	1000
		34	100	500	1000
	11.25	13	100	500	1000
		21	100	500	1000
		34	100	500	1000
	16.25	13	100	500	1000
		21	100	500	1000
		34	100	500	1000
Load Control Test	17.4	13	100	500	1000
		16	100	500	1000
	22.5	13	100	500	1000
		16	100	500	1000
	27.7	13	100	500	1000
		16	100	500	1000

4. RESULTS AND DISCUSSIONS

4.1 Experimental Observation

During cyclic loading in progress, a pair of gaps was observed to develop progressively in front and the back of the pile on the vicinity of soil surface. Also a heave of soil was developed around the pile.

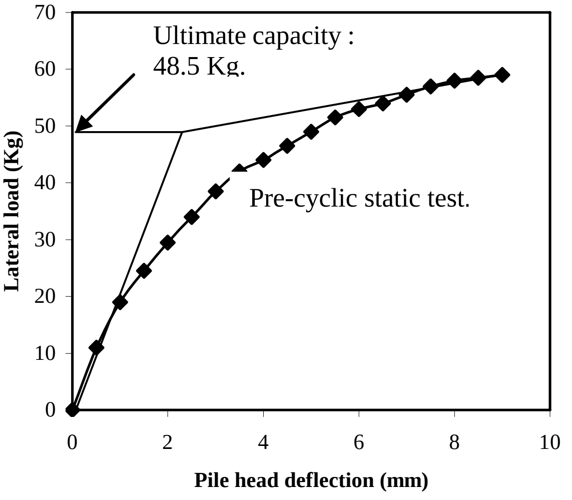


Fig 3: Pre-cyclic static load-deflection curve.

Table 2: Experimental Degradation Factors under Displacement Controlled Tests in Clay.

No. Of Cycles:	Amplitude (%) : 5.00			11.25			16.25		
	Frequency (c.p.m.) : 13	21	34	Frequency (c.p.m.) : 13	21	34	Frequency (c.p.m.) : 13	21	34
100	0.849	0.928	0.969	0.763	0.841	0.887	0.640	0.722	0.784
500	0.722	0.784	0.835	0.619	0.660	0.742	0.590	0.619	0.650
1000	0.660	0.742	0.784	0.546	0.639	0.660	0.501	0.558	0.619

4.2 Load deflection curve

The load deflection response of the pile group in the soft clay soil was found to be hyperbolic in nature. The ultimate capacities were estimated by double tangent method. The pre-cyclic load deflection curve is shown in Fig.3.

Table 3: Experimental Degradation Factors under Load-Controlled Tests in Clay.

No. Of Cycles:	Amplitude (%) : 17.40		22.50		27.70	
	Frequency (c.p.m.): 13	16	Frequency (c.p.m.): 13	16	Frequency (c.p.m.): 13	16
100	0.722	0.742	0.640	0.711	0.594	0.619
500	0.680	0.701	0.598	0.652	0.549	0.577
1000	0.660	0.680	0.577	0.619	0.516	0.557

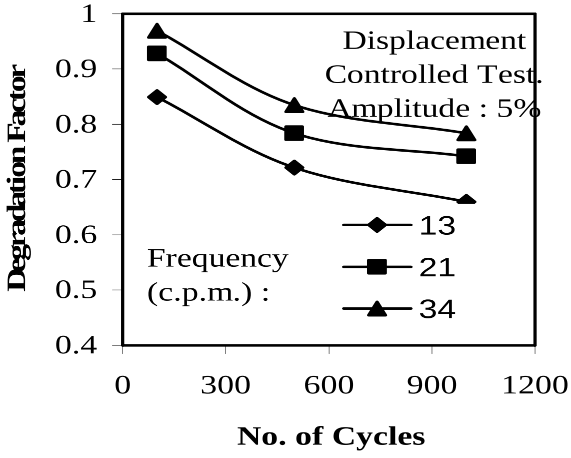


Fig 4: A typical variation of degradation factor with no. of cycles

4.3 Ultimate lateral capacities and degradation factors

As discussed by Poulos (1981b), degradation factor for ultimate lateral capacity of pile groups may be defined as the ratio of its post cyclic to pre cyclic values. For each of the tests carried out, the degradation factor were calculated. The values of experimental degradation factors of the pile groups in the kaolin bed under displacement control and load control modes of testing are given Tables 2 & 3 respectively.

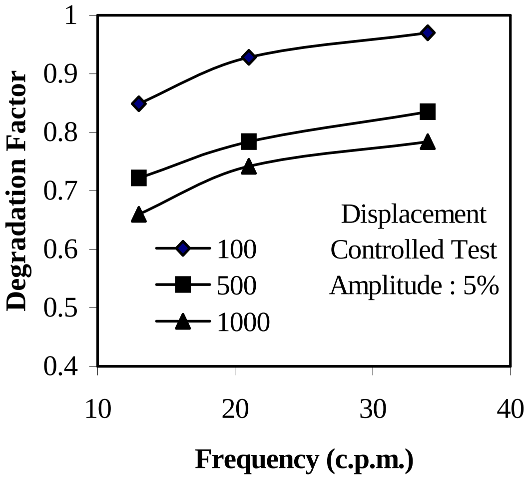


Fig 5: A typical variation of degradation factor with frequency.

The values of degradation factor were plotted against the no. of cycles. Fig.4 shows a typical plot. It was observed that the degradation factor non-linearly decreased with no. of cycle with a tendency of asymptotic stabilisation.

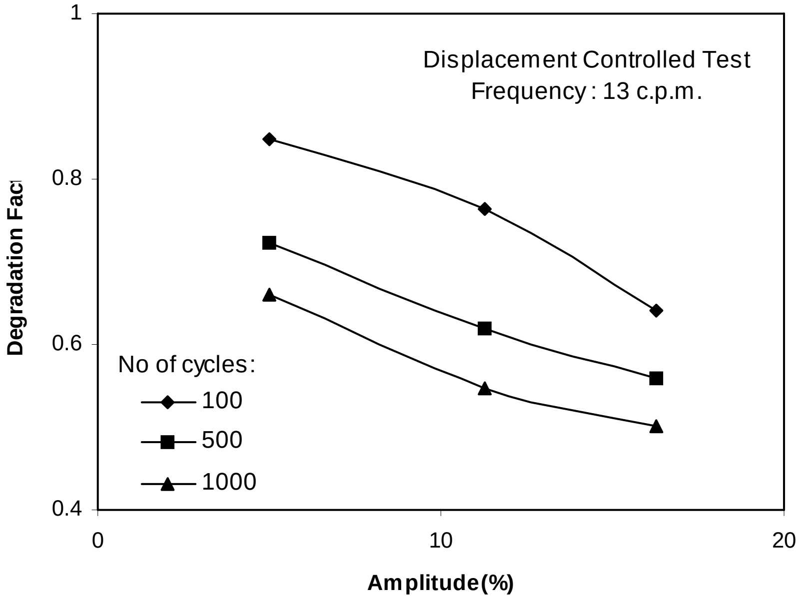
The degradation factors were also plotted against frequency. A representative plot is shown in Fig.5. The degradation factor was observed to increase with frequency with an asymptotic stabilizing tendency.

Finally, the degradation factors were plotted against amplitudes. A typical plot was depicted in Fig.6 (a) & (b) for displacement-controlled and load-controlled tests respectively. It was observed that the degradation factor decreased with amplitude non-linearly, but no definite pattern of variation could be concluded.

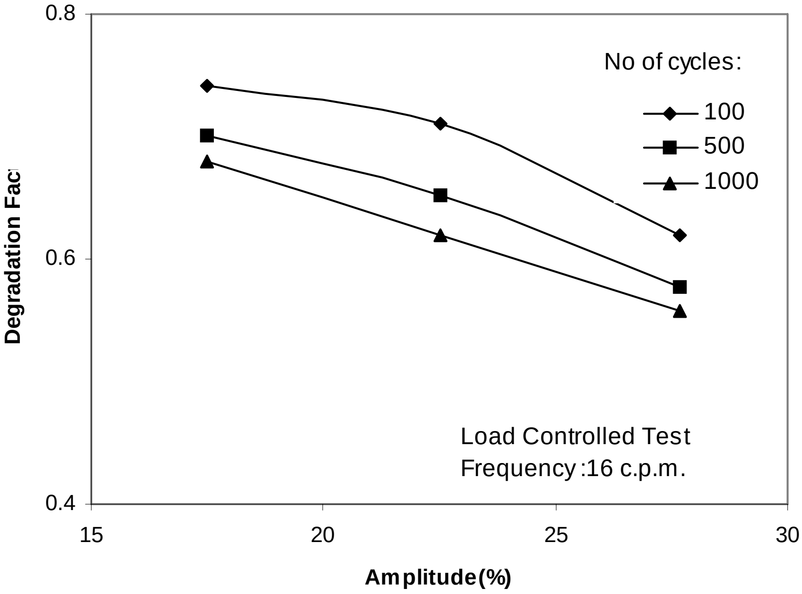
4.4 Variation of degradation factor with cyclic loading parameters

The values of degradation factor were plotted against the no. of cycles. Fig.4 shows a typical plot. It was observed that the degradation factor non-linearly decreased with no. of cycle with a tendency of asymptotic stabilisation.

The degradation factors were also plotted against frequency. A representative plot is shown in Fig.5. The degradation factor was observed to increase with frequency with an asymptotic stabilizing tendency.



(a)



(b)

Fig 6: A typical variation of degradation factor with amplitude for:
(a) displacement-controlled test. (b) load controlled test.

Finally, the degradation factors were plotted against amplitudes. A typical plot was depicted in Fig.6 (a) & (b) for displacement-controlled and load-controlled tests respectively. It was observed that the degradation factor decreased with amplitude non-linearly, but no definite pattern of variation could be concluded.

5. CONCLUSION

From the entire investigation, the following conclusions may be drawn :

(1) In case of experiments in soft clay bed, it was observed that a pair of gaps is progressively developed in front and the back of the pile on the vicinity of soil surface during cyclic loading in progress. Also a heave of soil developed around the pile adjacent to these

groups.

(2) Both pre-cyclic and post-cyclic load-displacement responses were hyperbolic in nature.

(3) Under the effect of lateral cyclic loading on pile groups in soft clay, the pile capacity deteriorates. This alteration was represented by ‘degradation factor’, a non-dimensional quantity given by the ratio of post-cyclic to pre-cyclic ultimate lateral pile capacities.

(4) The degradation factors were observed to vary with number of cycles, frequency and amplitude.

(5) The degradation factor decreased with no. of cycles and increased with frequency non-linearly having a tendency of asymptotic stabilization.

(6) With amplitude, the degradation factor decreased with amplitude non-linearly, but no definite pattern of variation could be noted.

6. ACKNOWLEDGEMENT

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