Lateral Response of Batter Piles and Pile Bents in Clay

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Introduction

Large lateral loads act on pile foundations supporting structures such as bridge abutments, piers, fenders, delphins and anchorages for water front structures. It has been a design practice to provide batter piles if the lateral load is in excess of about 500 kg per pile (Teng, 1962). Culmann (vide Teng, 1969) presented a procedure for analysing the pile foundations with batter piles wherein, the soil resistance has not been taken into account. Latter Hrennikoff (1950) showed that the Omission of the soil resistance need not always result in conservative design and presented a two dimensional analysis of pile groups consisting of batter piles taking into account the soil resistance. However, the effect of batter on lateral resistance of soil could not be properly accounted for, as the same has not been established in quantitative terms.

Tschebotarioff (1953) while analysing the results of model tests conducted in sand by Matsuo (1938) suggested that the slip surfaces in the cases of piles with positive batter are deflected upwards and in the case of piles with negative batter are deflected downwards as shown in Figure 1. This suggests that the pile with negative batter can offer more resistance to lateral load than the pile with positive batter.

Feagin (1953) reported tests on groups of battered and vertical timber piles with heads fixed in concrete monoliths. The piles were 9.6 m (32 feet) long embedded in coarse sand with gravel. Groups with various arrangements of battered and vertical piles were subjected to lateral loads

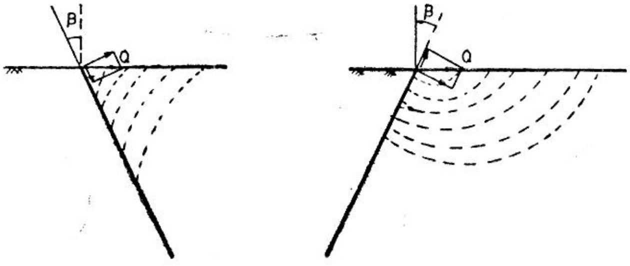

FIGURE 1 Failure surfaces in + ve and — ve batter pile (vide Tschebotarioff, 1953)

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and the results were presented. Analysing the results of these tests, Feagin (1953) concluded among others that :

(*a*) Groups of battered piles combined with vertical piles are more resistant to lateral load either against or in the direction of batter* than are corresponding groups of vertical piles.

(*b*) The resistance to lateral loads in the direction of batter generally exceeds that for loads against the better for similar pile group arrangement, either with or without a vertical load.

Murthy (1964) reported a model study on batter piles and pile bents, embedded in dry sand. The model polies used were aluminium pipes with outer diameter of 1.9 cm. The pile bents were a combination of vertical and batter piles, with batter angles varying from + 45° to — 45°. The results of the lateral load tests indicate that the resistance to lateral load increases as the batter angle varies from 45° to 45°, in that order. He has also observed that the conclusion (b) as above made by Feagin (1953) is not generally true.

Prakash and Subramanyam (1965) conducted a model study to investigate the behaviour of batter piles and pile bents embedded in sand under lateral loads. It was found that lateral resistance of pile with negative batter is about 1.22 B per cent (B-batter angle) greater and that of the pile with positive batter is about 1.4 B per cent less than that of a vertical pile. On pile bents, their conclusions are in agreement with that of Feagin (1953).

The experiments conducted by Awad and Petrasovits (1969) on aluminium model piles in sand show that the lateral resistance of the pile with a negative batter of 37.5° is about 60 per cent more than that of a vertical pile, and the resistance of the pile with a positive batter of 22.5° is less by about 20 to 25 per cent than that of a vertical pile.

The results of the two dimensional theoretical analysis reported by Ramasamy (1974), assuming the soil behaviour to be elasto-plastic also show that groups consisting of batter piles offer more resistance than that of groups consisting of only vertical piles, both in cohesive and cohesionless soils.

The above review indicates that the response of single batter piles and groups with batter piles in sand has been investigated in some detail and even quantitatively expressed, though based on small model piles only.

However, apparently no work on batter piles in clays has been reported in the literature. The present study is therefore carried out on model piles in clay to investigate the behaviour of batter piles and pile bents.

Experimentation

Experimental set-up

(*a*) *Test tank*—The test were conducted in a box of $35 \times 35 \times 50$ cm in size. The box was made of wooden planks stiffened with iron

* Lateral load' in the direction of batter' refers to the case of a negative batter and 'against the batter' refers to the case of a positive batter

stiffeners on all the four corners. Two coats of oil paints were applied on all the inner and outer surfaces of the box so as to guard against absorption of water.

(*b*) *Test bed*—The soil used in the investigation is a locally available clay. The liquid and plastic limits of the soil are 54 per cent and 25 per cent respectively. The clay is classified as clay of high compressibility (CH) as per IS : 1498-1970.

Water was added to a weighed quantity of dry soil and mixed thoroughly. The paste thus prepared is covered with polythene sheet and left overnight for uniform distribution of moisture. The soil was then rolled into small balls and allowed to fall into the box from a height of about 1.5 m. This technique of filling the box was found to give a uniform soil bed (Ranjan, et al, 1977). After placing the soil in the tank, the top was covered with grease layer of 1.0 cm thick to prevent loss of moisture. Moisture content and shear strength were determined at various points at the time of conducting the test. The laboratory vane shear was used for the shear strength determination. The average value of moisture content and the shear strength were 40 per cent and 0.155 kg/cm^2 respectively. The moisture content and the shear strength were maintained constant, with marginal variation, for all the tests conducted.

(*c*) *Model piles*— Aluminium pipe piles of 9.5 mm outer diameter and 36 cm in length were used. The piles were driven into the soil bed using loading jack arrangement. The batter piles were also driven similar to vertical piles, by keeping the box on proper wedges, i.e., by keeping the box in a tilted position and driving the pile vertically. For pile bents, one vertical and one batter pile were driven seperately such that the pile heads are at a spacing of three times the diameter. The two plies were then connected by a pile cap. The driven piles were left for 24 hours before testing.

(*d*) *Loading arrangement*—Horizontal loads were applied to the pile head or pile cap through a Steel wire passing over a pulley. A hanger was attached on one end of the wire for keeping weights. The other end of the wire was attached to the pile head or pile cap.

Testing procedure

Horizontal loads were applied to the pile in increments. The lateral deflection of the pile head was measured using a dial gauge having a least count of 0.01 mm. As the pile is embedded in a saturated cohesive soil the lateral deformations of the pile continue to take place for a length of time. Initially the rate of deformation is large which reduces considerably with time. In preliminary test carried out it was observed that it takes about two hours for lateral deformation to practically cease under an incremental load. Hence, in all the experiments conducted, the lateral deflection under a given incremental load was recorded two hours after the load was applied. The next increment of load was then applied and the procedure continued.

Tests conducted

Tests were conducted on single piles having negative batter angles, —30°, —20° and —10°' positive batter angles, 10°, 20, and 30° and on vertical piles. Tests were also conducted on pile bents having one vertical pile and one batter pile. The batter angle varied from —30° to +30°

in steps of 10° as in the case of single piles. Thus in all, fourteen tests were conducted on single piles and pile bents.

Results and Discussion

Effect of batter on lateral resistance-single piles

Figure 2 shows plots between horizontal load Q_g and horizontal displacement of the pile head, Y_g for piles having batter +30° to 30°. The Figure indicates that at small magnitudes of horizontal load some of these intersect each other and do not indicate a clear pattern. However at higher horizontal loads, these exhibit a definite pattern. For example at a horizontal load of 5 kg the horizontal displacement increases as the batter angle increases from —30° to +30°. For the sake of comparison the percentage increase/decrease in horizontal deflection of batter piles with respect to vertical piles at a horizontal load 2.5 kg is given in Table 1.

It can be seen from the table that no definite trend is exhibited at 2.5 kg load. This may be due to the fact that at smaller loads, the deflections are small and the effect of small variation in local conditions of soil probably dominates that of the batter on horizontal deflection. At 5.0 kg load the percentage decrease in horizontal deflection for piles having negative batter is significant whereas the percentage increase in deflection for piles having positive batter is much small. Though no quanitative correlation between the batter angle and percentage increase/decrease in lateral resistance could be suggested in view of the limited data the test results indicate that the piles with negative batter offer more resistance and piles with positive batter offer less resistance as compared to the vertical piles. This is an agreement with the observations made by Murthy (1964), Prakash and Subramanyam (1965) and Awad and Petrasovits (1969) with regard to batter piles in sand. The reason for such a

TABLE 1

A comparison of lateral resistance of batter piles with respect to vertical piles.

S. No.	Batter angle, in degrees	Horizontal deflection $Q=2.5$ kg (mm)	% Increase (+) /decrease (—) in Horizontal deflection	Horizontal deflection at $Q=5$ kg (mm)	% Increase (+) /decrease (t—) in horizontal deflection
1	2	3	4	5	6
1	0	1.80	—	7.90	—
2	—30	1.30	—27.8	5.37	—32.3
3	—20	1.80	0	6.45	—18.4
4	—10	1.65	—11.1	7.35	—5.6
5	+10	1.75	—2.8	8.15	+3.3
6	+20	2.45	+36.1	8.50	+7.6
7	+30	2.00	+11.1	8.90	+12.6

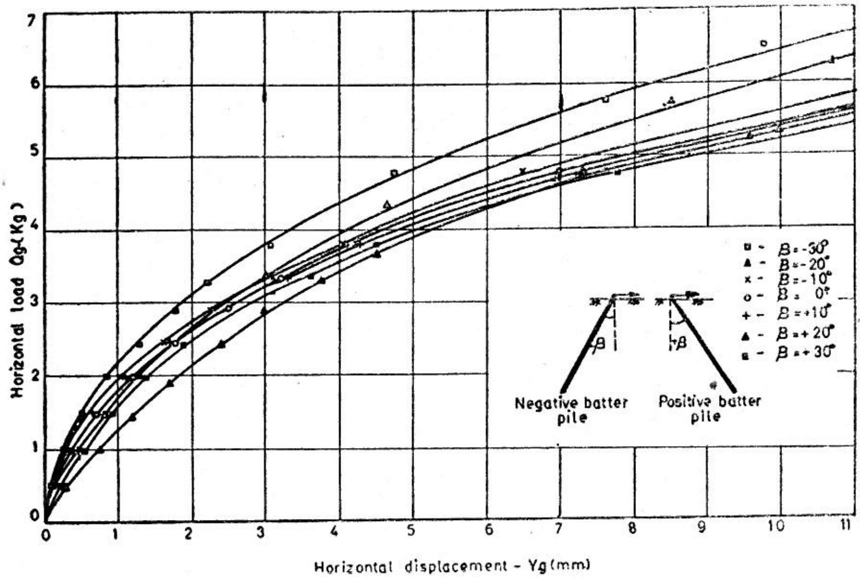


FIGURE 2 Load versus displacement curve for single vertical and batter piles in soft clay.

behaviour is that in the case of the pile with negative batter, the load component normal to the pile axis causes the pile to press the surrounding soil downwards thus forcing the slip surfaces to deflect downards (Fig.1b). This causes higher resistance to lateral deflection. In the case of positive batter piles, the load component normal to the pile axis causes the pile to push the soil outwards, thus forcing the slip surfaces to deflect upwards (Figure 1a), resulting less resistance to lateral deflection.

Effect of batter on lateral resistance-pile bents

Figure 3 gives the plots between horizontal load and horizontal displacement for pile bents with a negative batter pile and Figure 4 gives those for pile bents with a positive batter pile. The plot corresponding to a pile bent with only vertical piles is also shown in Figures 3 and 4. A comparison of these plots show that the pile bents with either negative or positive batter pile show higher resistance than the pile bent with vertical piles only. The higher resistance offered by the pile bent with negative batter pile could be understood in view of the higher resistance exhibited by the single pile with negative batter, whereas the higher resistance offered by the pile bent with positive batter is not in confirmity with the behaviour exhibited by a single pile with positive batter. Though similar observation is made in the case of pile bents in sand (Prakash and Subramanyam, 1965) no satisfactory explanation is reported. In the cases of single pile with positive batter, as the horizontal load is applied the pile head tends to rise since there is no restraint whereas in the case of the pile bent, the pile head of the positive batter pile cannot do so without causing a movement of the pile cap and the other vertical pile. In doing so, the pile cap rotates in such a fashion necessitating the vertical pile to be pushed downwards. This probably causes higher resistance in case of pile bent with vertical and positive batter pile. In addition, in the case of pile bents with either positive or negative batter

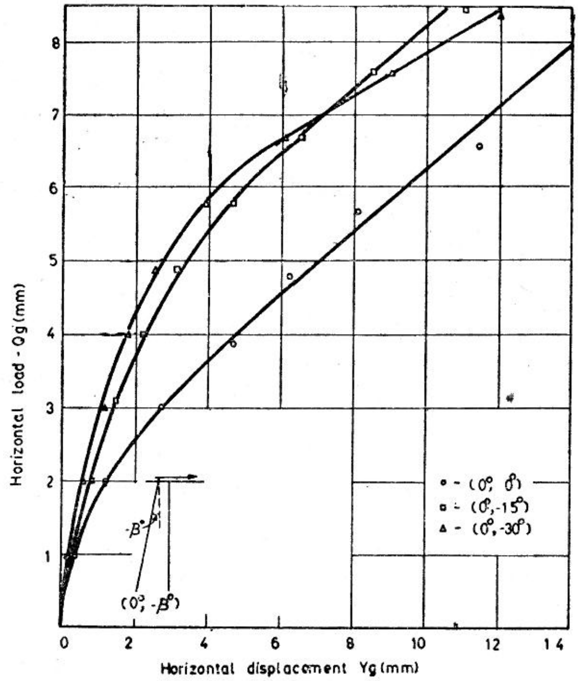
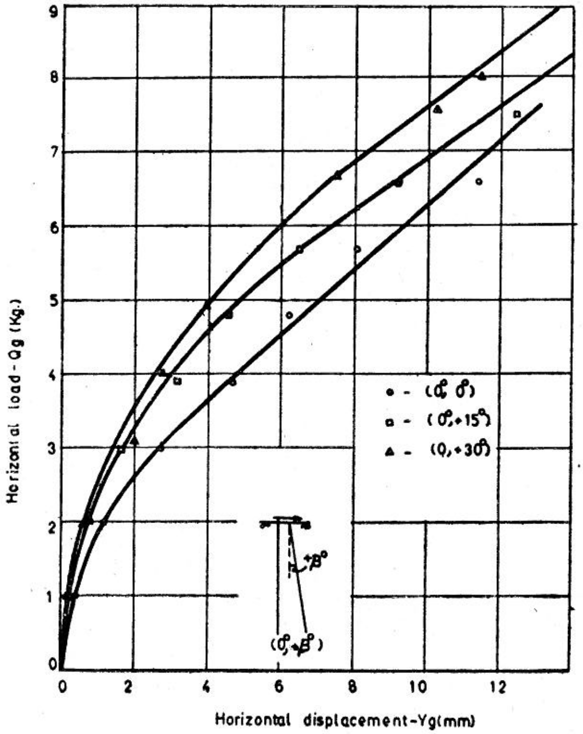


FIGURE 3 Horizontal load versus horizontal displacement curve for single vertical and batter piles in soft clay



FIGER 4 Load versus displacement curve for positive pile bents in soft clay

pile, the spacing between piles increases with depth which also could be a factor contributing to the higher resistance.

In order to compare the relative performance of the bents with negative or positive batter piles, the deflections at various lateral loads are summarised in Table 2.

TABLE 2

Comparison of lateral response of pile bents with negative or positive batter piles

Lateral Load, kg	Batter angle, Degrees	Horizontal deflection, mm	
		Bent with negative batter pile	Bent with positive batter pile
1	2	3	4
3	15	1 4	1.7
	30	1.0	1.4
4	15	2.2	3.0
	30	1.7	2.5
5	15	3.4	4.8
	30	2.7	4.0

It can be seen from the values of deflection that the bents with negative batter pile offer more resistance as compared to bents with positive batter piles. Thus, the factors governing the response of bents with batter piles may be listed as follows.

1. The direction and magnitude of batter, and
2. The deformation pattern of the pile bent as a whole.

Further detailed investigation is necessary to estimate the extent to which each one of the above factors contribute to the higher resistance exhibited by the bent with batter piles.

Conclusion

The following conclusions concerning batter piles and pile bents in clays are drawn based on the study reported.

(1) Piles with negative batter offer more resistance and those with positive batter offer less resistance than vertical piles when loaded individually.

(2) Bents with either positive batter pile or negative batter pile offer more resistance than the bents with vertical piles only.

(3) Bents with negative better piles offer more resistance than those with positive batter pilet.

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