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Torsional and Lateral Response of Batter Pile Groups in Sand

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ABSTRACT: *Batter piles are very effective in resisting lateral and torsional forces acting on the structure. Experimental work was carried out in the laboratories on 2 x 2 batter pile groups to investigate the torsional and lateral response of batter pile groups in sand. Lateral and torsional load tests were conducted on pile groups with three different orientations such as vertical pile group, one side battered pile group and two side battered pile group with different batter angle 0^0, 10^0, 20^0, 30^0 and 40^0. It was found that the lateral capacity of batter pile groups increased with increasing the batter angle up to 30 degree. It was also found that torsional capacity of batter pile groups increased with increasing the batter angle up to 30 degree. One side battered pile group shows slightly greater lateral capacity than two side battered pile group, but at the same time, two side battered pile group shows greater torsional capacity than one side battered pile group.*

Keywords*: batter pile group, Lateral loading test, torsional loading test*

INTRODUCTION

Some structures such as tall buildings, offshore platforms, bridge bents, and electric transmission towers are subjected to lateral loads of considerable magnitude due to wind and wave actions, ship impacts, or high-speed vehicles. Significant torsional forces can be transferred to the foundation piles by virtue of eccentric lateral loading. These torsional loads transferred to the foundation of the structure in the form of horizontal loads and moments. Insufficient design of the piles against these loads may result in disastrous consequences. To resist these lateral forces batter piles are used. Batter piles are inclined piles which are driven at an angle with the vertical. Batter piles carry lateral loads primarily in axial compression and/or tension while vertical deep foundations carry lateral loads in shear and bending. When subjected to lateral loading, batter piles will therefore generally have a greater capacity and be subject to smaller deformations than vertical piles of the same dimensions and material. Kong and Zhang (2007) found that a pile group subjected to torsion, the torsional resistances was substantially mobilized at small twist angles, while the lateral resistances kept increasing in the whole range of twist angles. Deepak Kumar et.al., (2016) concluded that the negative batter pile showed more resistance as compared to that of a vertical pile for a constant deflection subjected to lateral loads and similarly positive batter piles showed less resistance as compared to vertical piles.BushraSuhailet. al.,(2014) found that the torsional capacity for pile group increases with increasing the percentage of allowable vertical load and increasing L/D ratio.MandarSanatkumar et.al., (2008) concluded that the negative batter single piles (-10° to -30°) offer 15-25% more resistance and positive batter piles (+10° to +30°) offer 20-30% less resistance than vertical pile. Pile groups (0°, +10°) to (0°, +30°) offer 25-35% less resistance as compared to vertical pile group. Pile groups (-10°, 0°) to (-30°, 0°) and (-10°, +10°) to (-30°, +30°) offer 15-35% more resistance as compared to vertical pile group.

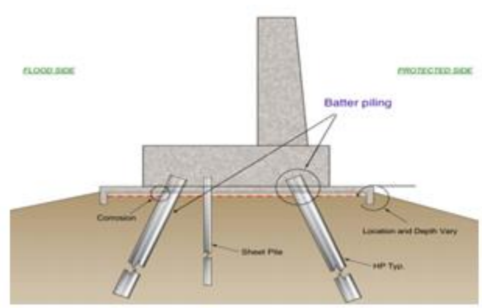

Fig.1: Batter pile group under retaining wall

MATERIALS USED

Locally available dry sand was used to prepare the test bed. Sand has a specific gravity of 2.56 and has an effective mean particle size (D_{10}) of 0.19. It has uniformity coefficient (C_u) of 2.3 and coefficient of curvature (C_c) of 0.79. According to Indian Standard classification systems, sand is classified as Poorly Graded sand (SP). Pile group was made up of mild steel pipe of outer diameter 18.5mm. Pile cap is also made up of mild steel of size 115 mm x 115mm x 15mm. Three different orientations such as vertical pile group, one side battered pile group and two side battered pile groups were fabricated with different batter angle 0^0, 10^0, 20^0, 30^0 and 40^0 with respect to vertical.

Fig. 2: Sand

Fig. 3: Steel pile groups

Properties of sand

Table-1 Index properties of sands

Parameters	**Value**
Specific gravity	2.56
Effective size, D_{10} (mm)	0.19
D_{30} (mm)	0.28
D_{60} (mm)	0.46
Uniformity coefficient, C_u	2.3
Coefficient of curvature, C_c	0.79
Gradation of sand	SP
Maximum dry density, (g/cc)	1.79
Minimum dry density, (g/cc)	1.48
Sand density (35% RD) (g/cc)	1.58
Angle of internal friction (35% RD) (degree)	30^0

EXPERIMENTAL INVESTIGATION

Laboratory model experiments were conducted to investigate the lateral and torsional response of batter pile group. Experiments were done in a test tank of size 850 mm x 850mm x 650 mm, made up of steel sheet of thickness 5mm. sand is filled in the tank in layers. Predetermined quantity of soil is filled in layers with a spacing of 50mm. Each layer was compacted to achieve the desired density. Pile group is placed in desired embedment depth and continue the filling of sand till it reaches 2cm below bottom of pile cap and level the top surface of sand bed. Then lateral load was applied to the pile cap using pneumatic setup. This pneumatic setup includes an air compressor to produce the compressed air, pressure regulator to regulate the pressure of Compressed air, flow control valve to regulate the flow of compressed air, and a pneumatic air cylinder (air actuator) to applying lateral load on pile cap. In lateral loading test, continuous load is applied at the middle of the pile cap. The applied load was measured using proving ring of 2.5Kn capacity which was attached at the end of air actuator rod. During test, the displacement of the pile cap was measured using dial gauge of 25mm capacity which was placed in the opposite side of pile cap. Batter pile groups were fabricated with different batter angles 0^0,10^0,20^0,30^0 and 40^0 in both one side battered pile group and two side battered pile group orientations. Another set of one side battered pile group were fabricated with batter angle 30^0 and varying horizontal angles such as 0^0, 30^0, 45^0, and 60^0 with respect to loading direction to study the effect of horizontal angle on the lateral behavior of batter pile group.

In torsional loading test, torsional load is applied on to the pile cap through the application of a pair of forces on the pile cap

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in two opposite direction through the two steel loading arms welded to the pile cap. For providing torsional load on the pile group, a pneumatic setup was fabricated, which included two pneumatic air actuator, An air compressor, pressure regulator and a flow control valve. Proving ring of 2.5kN capacity was attached at the end of each actuator rods to measure the applied load. Two dial gauges of 25mm capacity were fixed to one side of pile cap to obtain the displacement values at the corners. Using these values angle of twist was calculated by a trigonometric equation. Three different orientations such as vertical pile group, one side battered pile group and two side battered pile group were fabricated with different batter angle 0^0, 10^0, 20^0, 30^0 and 40^0 with respect to vertical to study the effect of orientation and batter angle of pile group on torsional capacity.

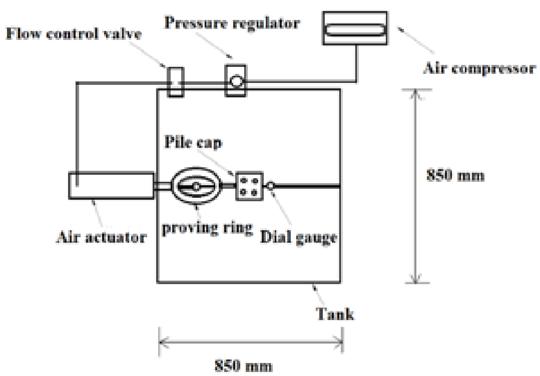

Fig. 4: Schematic diagram of pneumatic setup for lateral loading

Fig. 5: Pneumatic set up for lateral loading.

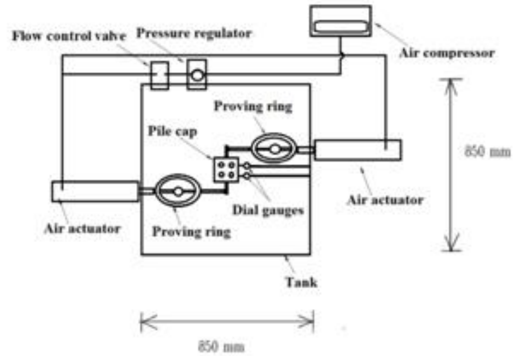

Fig. 6: Schematic diagram of pneumatic setup for torsional loading

Fig. 7: Pneumatic setup for torsional loading

RESULTS AND DISCUSSIONS

Lateral loading test results

Horizontal load is applied at the middle point of pile cap for obtaining lateral behavior of batter pile groups in sand. Batter angle of batter pile group was changed 0^0, 10^0, 20^0, 30^0 and 40^0 to obtain the effect of batter angle on lateral load capacity. Pile groups with three different orientations were tested to understand effect of pile group orientation on lateral capacity. The orientations were varied as vertical pile group, one side battered pile group and two side battered pile group. Horizontal angle of battered pile with respect to the loading direction was also changed 0^0, 30^0, 45^0 and 60^0 to obtain its effect on lateral load capacity.

Effect of batter angle of one side battered pile group in loose fill of sand

Lateral load capacity of one side battered pile group increases with increase in batter angle up to 30^0, and then decreases. The spacing between the pile increases linearly from top to the bottom with pile length, because the piles are inclined with

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vertical. As the batter angle increase the average spacing between the piles also increases. So there is reduction of overlapping of stress zones happen when batter angle increases. Reduction of this shadowing effect is the one of the reason for increasing lateral capacity with increase in batter angle. Increase of lateral resistance is also due to the increase in horizontal component of axial capacity and hence it can take more horizontal loads. When the batter angle increases, embedment depth of batter piles gets decreases. Therefore lateral capacity gets reduced after a certain value of batter angle.

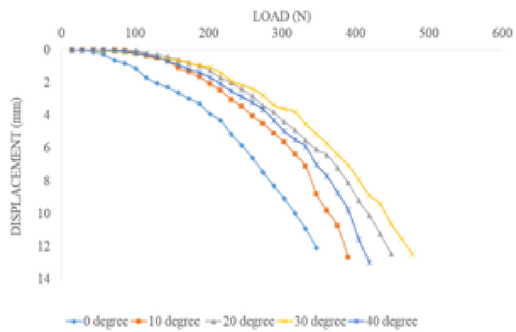

Fig 8: Load-Displacement graph of one side battered pile groups with different batter angles

Effect of batter angle of two side battered pile group in loose fill of sand

Lateral load capacity of two side battered pile group in loose sand increases with increase in batter angle up to 30^0, and then decreases.

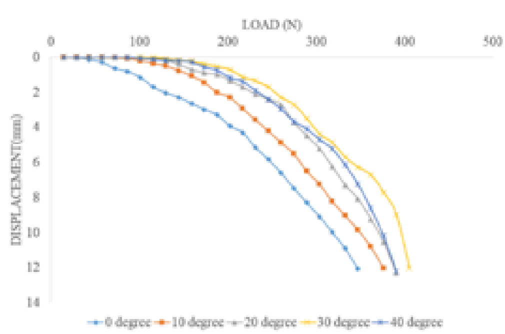

Fig 9: Load-Displacement graph of two side battered pile groups with different batter angles

Reduction of shadowing effect and increase of horizontal component of axial resistance of batter piles are the main reasons for increasing lateral load capacity with increase in batter angle. At higher batter angle, the embedment depth of the piles gets smaller. So after a certain batter angle lateral load capacity decreases.

Ultimate lateral load capacity variation with batter angle

Ultimate lateral load variation of both one side battered and two side battered pile group are represented by bar diagram as show in the fig 10.

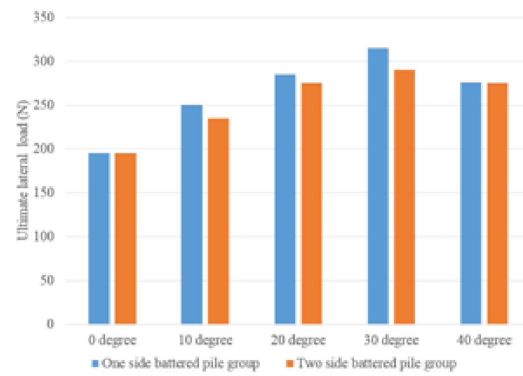

Fig.10: Ultimate lateral load capacity variation of one side battered and two side battered pile groups

Ultimate lateral load capacity values increases with increase in the batter angle up to 30^0, and then decreases for both orientations. Ultimate lateral load capacities of one side battered pile group and two side battered pile group has marginal difference. Two side battered pile group has slightly lesser values than one side battered pile groups due to the presence of positive batter piles in the pile group.

Effect of Horizontal Angle of Battered Pile With Respect to Loading Direction

Lateral load capacity of one side battered pile group with batter angle 30^0 increases with increase in horizontal angle up to 45^0 and then decreases

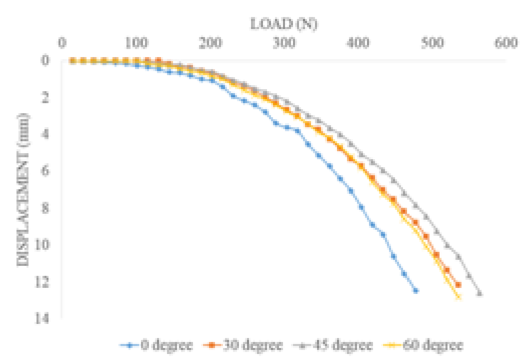

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Fig 11: Load-Displacement graph of one side battered pile groups with varying horizontal angle

.The area of soil in passive zone which mobilize lateral resistance against pile surface is increases up to 45^{0} horizontal angles. So better results obtained up to 45^{0}.

Torsional loading test results

Torsional load is applied on to the pile cap through the application of a pair of forces on the pile cap in two opposite direction. Batter angle of batter pile group was changed 0^{0}, 10^{0}, 20^{0}, 30^{0} and 40^{0} to obtain the effect of batter angle on torsional load capacity. Pile groups with three different orientations were tested to understand effect of pile group orientation on torsional capacity. The orientations were varied as vertical pile group, one side battered pile group and two side battered pile group.

Effect of Batter Angle of One Side Battered Pile Group in Loose Fill

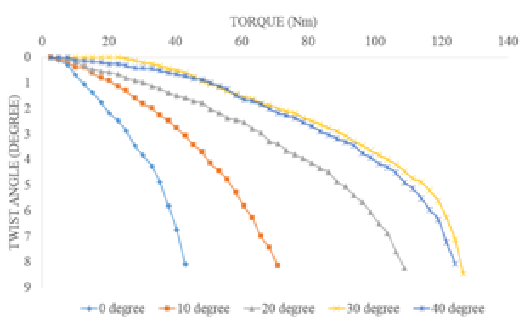

Fig 12: Torque – Twist angle curve for one side battered pile groups with different batter angles

Torsional capacity of one side battered pile group increases as the batter angle is increases up to 30^{0}, and then decreases. Reduction of overlapping of shear zones in the surrounding soil of each pile is the main reason for relatively higher lateral load resistance of batter pile groups when compared to the vertical pile group. As the batter angle increases, lateral load capacity is also increases. This is due to linear increase of distance between two piles with pile length towards the bottom.

Effect of Batter Angle of two side Battered Pile Group in Loose Fill

Torque twist angle curves of two side battered pile group with varying batter angle is shown in fig 4.5.

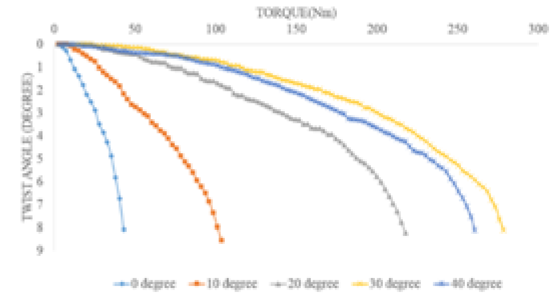

Fig 13: Torque – Twist angle curve for two side battered pile groups with different batter angles

Torsional capacity of two side battered pile group increases with increase in batter angle up to 30^{0}, and then decreases. Reduction of shadowing effect is the main reasons for increasing torsional capacity with increase in batter angle. However, increase batter angle led to decrease in embedment depth of pile group. So after a certain batter angle torsional load capacity gets decreases.

4.2.3 Variation of failure torque with batter angle

Failure torque variation for both one side battered and two side battered pile group are represented by bar diagram as shown in fig 14.

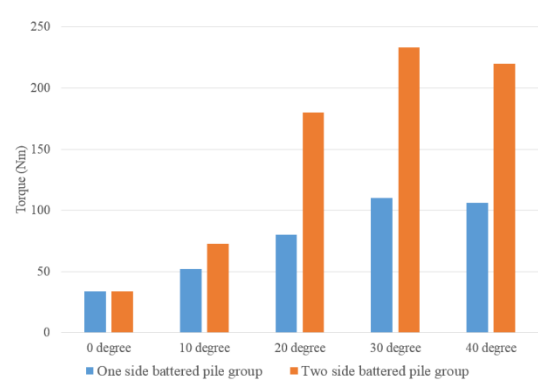

Fig 14: Failure torque variation of one side battered and two side battered pile groups with batter angle

Torsional capacity of both one side battered pile group and two side battered pile group increases with increasing batter angle up to 30^{0} and then decreases. Two side batter pile groups show higher torsional capacity than one side batter pile group. This is because, in two side battered pile group, piles of two sides of pile group are battered in two opposite direction.

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So shadowing effect is much smaller in the case of two side battered pile group.

CONCLUSIONS

- Both one side battered pile group and two side battered pile group configuration has greater lateral load capacity than all vertical pile group configuration.
- Ultimate lateral load capacity of both one side battered pile group and two side battered pile group increases with increasing batter angle up to 30^0 and then decreases.
- Ultimate lateral load capacities of one side battered pile group and two side battered pile group has marginal difference. One side battered pile group has slightly higher values than two side battered pile group.
- Ultimate lateral load capacity increases with increasing horizontal angle of battered pile with respect to loading direction up to $45^0$and then decreases.
- Torsional capacity of both one side battered pile group and two side battered pile group increases with increasing batter angle up to 30^0 and then decreases.
- Two side batter pile groups shows higher torsional capacity than one side battered pile group. Failure torque of 30^0 two side battered pile group is 2.1 times that of one side battered pile group.

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