



# Behavioural analysis of vertical and batter pile groups under vertical and lateral loading in sand

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## Abstract

Laboratory model tests were carried out to study the behaviour of vertical piles and batter pile groups under vertical and lateral load. The model pile groups were made up of mild steel rod of 8-mm diameter. Parameters such as degree of batter and different length to diameter ratios of 7.50, 15.00 and 22.50 were considered in this study. The size of the model tank was 1000 mm × 1000 mm × 800 mm. Experiments were performed on 3 × 3 model pile groups with a row of batter piles both positive and negative in addition to vertical pile groups with batter angle 0° in sandy soil subject to vertical and lateral loads. It was observed that the behaviour of vertical pile groups and group of piles with batter piles were similar but it showed substantial variation in the capacity of pile groups. Results indicated that the load–settlement relationships were non-linear for all model pile groups both under vertical and lateral loading. Numerical FEM analysis using ABAQUS/CAE 6.11 was also used to compare and validate the load carrying capacity of pile groups obtained from the experimental model tests.

**Keywords** Batter piles · Vertical load · Lateral load · Load–settlement · FEM

## Introduction

Usually, the tall structures are rested upon pile foundations when the subsoil condition is poor and the hard stratum is not available at a desirable depth. Structures like chimneys, cooling towers, sky scrapers and multi-storied buildings are subjected to lateral loads in addition to vertical loads. The lateral resistance of pile foundations is often significant in the design of offshore structures. These offshore structures are usually subjected to overturning moments due to wind, wave pressure and ship impact. These moments are transferred to the foundation in the form of horizontal and vertical loads. The type of foundation recommended for such loading conditions is the combination of vertical and batter piles (Hirani Anil et al. 2013). Lateral loads are in the order of 10–15% of the vertical loads in the case of onshore structures and can exceed 30% of vertical loads in the case of coastal and offshore structures (Narasimha Rao et al. 1998). Batter piles

are the one which is inclined at an angle to the vertical called the batter angle and are employed in the direction of the lateral loads. As there are different magnitudes of loads on various parts of the structures, the use of the batter piles along with vertical piles in the pile–soil system increase the overall efficiency (Rajashree and Sitharam 2001). Studies were carried out by different authors on the behaviour of piles under independent loadings (Poulos and Davis 1980; Prakash and Sharma 1990; Tomlinson and Woodward 2008). However, in practice, piles are used in groups and are connected by pile cap (Hirani and Verma 2011). In pile group, the main factor is that the group interaction effect (Rollins et al. 2005 and Chandrasekaran et al. 2009) and it becomes more significant when the spacing between the piles decreased. Extensive theoretical and experimental work has been carried out on single pile subjected to lateral loads and on pile groups subjected to lateral loads (Narasimha Rao et al. 1996 and Lv et al. 2011). However, there are limited studies on pile groups with vertical piles and pile groups with row of batter piles subjected to independent vertical and lateral loads. Due to complexity involved in analysing the piles under combined loading, the current practice is to analyse the piles independently for vertical loads and lateral loads, and studies on the interaction effects on piles under combined loads require a systematic and sophisticated analysis (Karthigeyan et al. 2007). This

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