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# Soil Structure Interaction Study on FRP Strengthened RCC Piles under Lateral Load

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**Abstract:** Pile Foundations are used in areas where the soil strata below the superstructure is found to be weak or highly compressible. Pile foundations are also provided to resist significant lateral forces induced by earthquakes, winds, waves, earth pressures and ship impacts. The performance of RCC pile foundations subjected to lateral load is of considerable importance in Structural practice. Strengthening/retrofitting of such foundation structure is important to resist the increased lateral loads due to changes in the use of the structure, or to address the design or to resist the earthquake or construction errors. In recent years, Fibre Reinforced Polymer (FRP) jacketing has become popular to retrofit/strengthen the existing deficient piles. The lightweight, high strength and corrosion resistance of FRPs made them particularly suitable for repair. In this study, the performance of the FRP strengthened long flexible-free headed piles subjected to lateral loads were analysed. This project was undertaken to investigate the structural behaviour of Cast insitu FRP piles and RCC piles in Sand. The main focus of this research is to determine the potential of FRP strengthening for piles subjected to static lateral loads. To establish confidently the feasibility of using FRP for strengthening of piles, more information and performance data were gathered in critical areas, such as strength and durability of FRP materials, interface behaviour between FRP materials with soil, and soil-pile load transfer interactions. Soil-structure interfaces have a great influence on the load carrying capacity and load-deformation response of geotechnical structures.

**Keywords:** Fiber reinforced polymer, Strengthening, RCC Piles, Pile load tests

## I. INTRODUCTION

The pile foundations are used to transfer the load from the structure to soil when the structure is embedded in poor soil stratum. In an axially loaded pile, the load is transferred to the soil through the skin friction at the soil-pile interface and end bearing offered by the hard soil. Pile foundations are subjected to significant amount of lateral forces in addition to the vertical forces. The lateral forces are due to the wind, wave, earthquake, dredging and impact loads. Studies showed that the influences of vertical load on lateral response are not so important when the vertical load is applied continuously with the lateral load. The recent design practices consider the influence of these two loadings independently and hence pile design are taken out separately for vertical and lateral loads. The effect of vertical loads on the piles are well established through these years whereas studies on piles under lateral loads are limited and are simultaneously to establish a good condition method of analysis considering the effect of all the influencing parameters. The current study focuses on the significant factors affecting the soil. In recent years, Fibre Reinforced Polymer (FRP) jacketing has become popular to strengthen the existing deficient piles. The lightweight, high strength and corrosion resistance of FRPs made them particularly suitable for repair. In this study, the performance of the FRP strengthened long flexible-free headed piles subjected to lateral loads will be analysed. The main focus of this research is to determine the potential of FRP strengthening for piles subjected to lateral loads. To establish confidently the feasibility of using FRP for strengthening of piles. The study of laterally loaded pile requires a proper assessment of soil-structure interaction phenomenon involving the interaction between pile surface and the surrounding soil.

## II. LITERATURE REVIEW

A. Desprez et al (2012) presented a new simplified modeling strategy for reproducing the nonlinear cyclic behaviour of FRP retrofitted RC columns. This can serve as a numerical tool for quick comparative studies on various confinement situations and structure vulnerability before and after FRP retrofitting.

B. Sampath Rao et al (2012) carried out experiments to determine the effect of environmental conditions on the strength aspects of GFRP laminates. The results from the experiments showed that the effect of the environmental condition on the GFRP affects the young's modulus and the flexural modulus of the specimens abruptly.

C. Balasubramanian et al (2012) investigated the effect of the cyclic loading on the characteristics of the retrofitted beam-column joints with FRP materials such as FRP strips, FRP sheets, MS flats and embedded additional reinforcement. This study exclusively depicts the various methods of strengthening RC beam – column joints.

D. Piyush jain (2017) studied the experimental study on retrofitting of RC beam using basalt fibers. The beam was wrapped with basalt fiber sheet in single u-type layering, double u-type layering along the different strength of the beam. The result have been analysed.

E. J. Prakash Arul Jose (2018) studied the experimental study on PFRP confined RC driven piles subjected to vertical loads. To find the performance of PFRP confined RC pile subjected to vertical load. The shear strength at the interface increases with the increase in surface roughness of the specimen.

### III. MATERIAL PROPERTIES

#### A. Concrete

The characteristic compressive strength of concrete used for the study was 30 N/mm<sup>2</sup>. The mix ratio adopted for casting the specimens was 1:1.56:2.67 (Cement: Fine aggregate: Coarse aggregate) with water-cement ratio of 0.4. The compressive strength of cubes after 28 days water curing was 40 N/mm<sup>2</sup>

#### B. FRP

Polypropylene FRP is used. The following properties are determined below.

Thickness = 250gsm  
Type = Woven  
Orientation = Bidirectional  
Tensile strength at wrap = 65kN/m

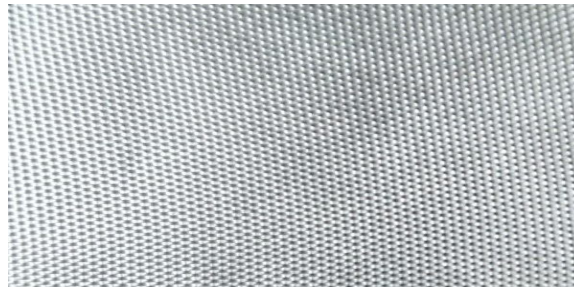


Fig 3.1 Polypropylene FRP

#### C. Reinforcement

The yield strength of steel used for the study was 500 MPa. Six numbers of 8 mm bars were used as longitudinal reinforcement with a cover thickness of 40 mm. Bars of 6 mm diameter at 175 mm spacing were used as lateral reinforcement (ties).

#### D. Adhesive

The adhesive used to wrap the Polypropylene FRP over concrete specimen by Epoxy resin and hardener.

### IV. METHODOLOGY

A. A series of piles of 230 mm diameter (D) and 4 m long (3 m below and 1 m above ground level) bored-cast-in-situ reinforced concrete piles will be casted in the field.

B. The piles will be casted at a spacing of 5 D from each other in a circular manner.

C. A series of 4 piles of 230 mm diameter (D) and 4 m long (3 m below and 1 m above ground level) bored-cast-in-situ reinforced concrete piles were cast in the field. The piles were cast at a spacing of 2.5 D from each other in a straight manner. A spacing of 2.5 D was kept such a way that the interactions between the piles were negligible.

D. Hand Auger equipment will be used for drilling work in bored and cast in-situ pile for depth up to 4m.

E. Pre-fabricated reinforcements will be inserted in the bore holes of pile diameter 230mm and concreting of M30 grade will be adopted.

F. Curing will be done for 28 days after concreting.

G. Soil will be excavated up to depth of 1.5m.

H. Chiseling, plastering and rubbing will be done. Epoxy will be applied over the prepared and cleaned surface.

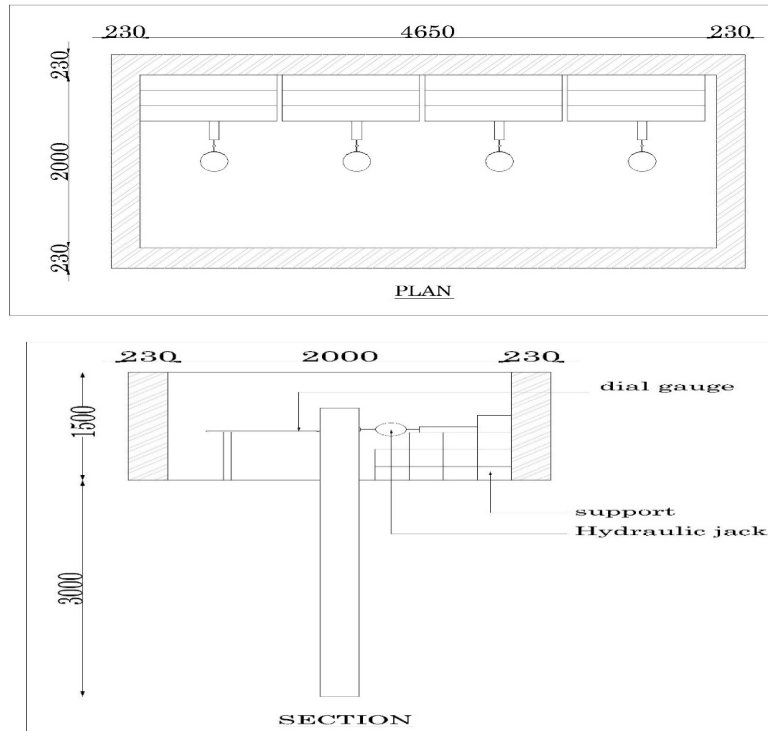
I. Fiber Reinforced Polymer (FRP) wrapping method will be used in this project for strengthening the RC pile under lateral load.

J. Earth filling will be done by filling the soil layer by layer.

K. Installation of dial gauge to measure the horizontal displacement of pile.

L. Lateral load test will be done as per IS 2911.

M. Soil Structure interaction is to be determined from this project.



## V. EXPERIMENTAL INVESTIGATION

### A. Pile Lateral Load Test

The lateral load test was performed in accordance with IS: 2911(Part 4) – 2013. The pile was loaded horizontally at a distance of 0.85 m above ground level. The lateral load to the pile was applied through a hydraulic jack, which was placed between the supporting and testing piles. The reaction was obtained from the supporting beam. The capacity of the jack is 100kN and ram diameter is 75 mm with 150 mm ram travel. The jack is connected to a hydraulic pump. The load applied is displayed on pressure gauge and also measured through proving ring. The dial gauges were installed to measure the lateral displacement of pile. Dial gauges used for these tests were accurate to 0.01 mm. Dial gauges were clamped on specially fabricated steel frame with 30 cm apart from one another. The steel frame was fixed in the ground in such a way that there was no deflection in the steel frame. The loading sequence adopted in the test is in accordance with IS: 2911(Part 4) – 2013. Experimental investigations have been conducted on PFRP confined and unconfined piles. Maintained Load Method was adopted in the test. In this method application of increment of test load and taking of measurement or displacement in each stage of loading was maintained till rate of displacement of the pile either 0.1 mm in first 30 minutes or 0.2 mm in first one hour or till 2 hour whichever occur first. In the static lateral load test, the load was applied in increment of 20% of the working load until it reaches ultimate lateral load. After this stage, the load was released and then brought to 'no load' condition. Each load step was maintained as mentioned above. The pile lateral movement readings were taken at 0 minutes, 15 minutes and 30 minutes after each load step.



Fig 5.1 Test Setup

Table 5.1 Lateral load Test

TYPE	Ultimate Load ( $P_u$ ) (kN)	Load corresponding to 12 mm displacement at GL (kN)	Load corresponding to 5mm displacement at GL (kN)	Safe Load (kN)
Unconfined	26.50	23.30	13.25	11.65
Pile confined with bidirectional PFRP mat	33.70	28.80	17.50	14.40

**B. Soil Behaviour on FRP Strengthened RCC Pile**

In the analysis of soil-pile interaction under lateral load, the behaviour of soil around a pile is an important parameter which has a great influence on the results. It can be observed that there is a cap between pile and soil surface in the loading side of the ground. This cap is extended to some depth below ground level depends on the type of FRP wrapping. It was also noticed that the top surface of the ground around the pile opposite to loading slightly heaved. The maximum horizontal displacement occurs in the ground level and decreases gradually with depth. At greater depths the displacements of soil around the pile are negligible.



Fig 5.2 Soil-Pile interaction

**C. Shear Strains around a Laterally Loaded Pile**

It can be observed that the maximum shear strain occurred at the pile-adjacent to soils near the surface. A triangular strain wedge to the side of the displaced pile is created. It shows that in front of a laterally loaded pile a passive zone is established.

**D. Effects of Pile Stiffness On Soil Deformation**

In flexible piles, the pile stiffness is an effective parameter in lateral load capacity. This parameter significantly influences the deformation of the surrounding soil. From the observation it can be seen that the mobilized depth of the strain wedge was increased and the mobilized angle was decreased with increasing pile stiffness (with PFRP wrapping).

**E. Failure Mode of FRP Strengthened RCC Piles**

The failure of all piles occurred below the ground level, at a distance of about 1.35 to 1.9 times the diameter of the pile. The failure of pile was occurred at some depth below ground level. This is due to the development of high bending moment at this level. Therefore the location of failure can be considered as depth of fixity of the pile.



unconfined pile



PFRP confined pile

Fig 5.3 Failure mode comparison

Table 5.2 Depth of Pile failure

Type	Pile failure (depth from GL in cm)
Unconfined pile	31 (1.35 D)
PFRP confined pile	44 (1.90 D)

### VI.RESULT AND DISCUSSIONS

Load vs Displacement Curve comparison on FRP confined and conventional pile

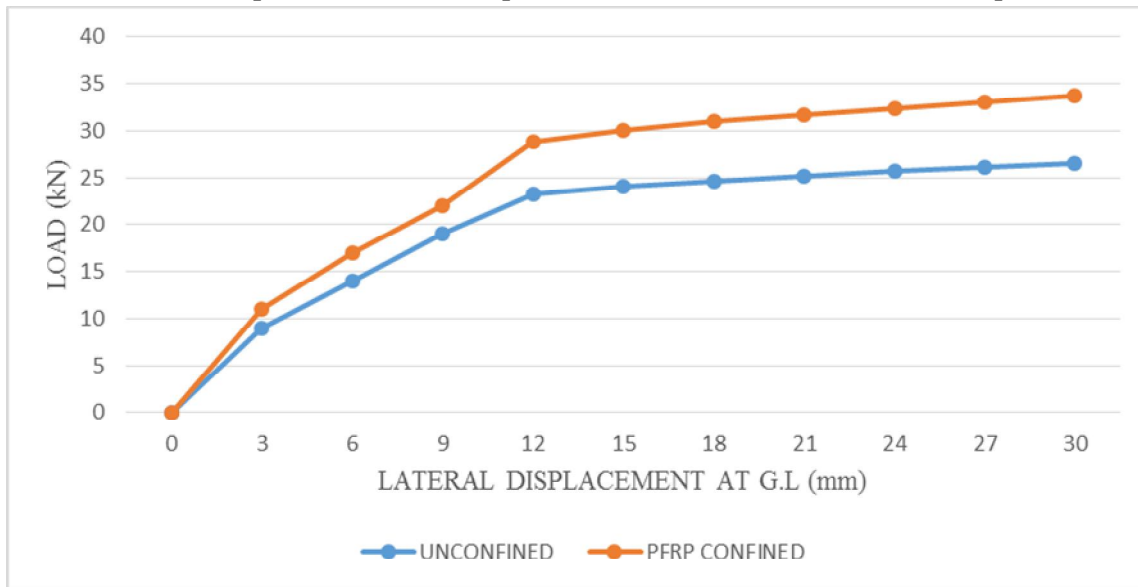


Fig 6.1 Load vs Displacement curve

From the above figure, the lateral strength of PFRP pile strengthened with bidirectional PFRP mat was increased by 27% than that of unconfined pile. This clearly indicates that the PFRP strengthening is an effective method for strengthening of existing piles.

### VII. CONCLUSION

- A. The PFRP wrapped piles lateral capacity is significantly higher than the conventional pile of the same depth and diameter. The PFRP wrapped piles depth of fixity is about 42% higher than conventional concrete piles. It shows that the moment carrying capacity of PFRP wrapped piles are much more than the conventional concrete piles.
- B. The percentage increase in lateral strength of pile strengthened with bidirectional PFRP mat was 27% than unconfined pile. This clearly indicates that the PFRP strengthening is an effective method for strengthening of existing piles.

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