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Effects of Orientation on Basalt Fibres Retrofitted RCC Piles Subjected to Lateral Loads

C. Selvamony[1], R. Anandakumar[2*], A. Seeni[2] and S. Sivakumar[3]

[1]PSN Engineering College, Melathedyoor - 627152, Tirunelveli, Tamil Nadu, India; selvamony_2007@yahoo.com
[2]S. Veerasamy Chettiar College of Enggineering and Technology, Puliangudi - 627855, Tamil Nadu, India; er.seeni@gmail.com
[3] Mahakavi Bharathiyar College of Enggineering. and Technology., Athuval - 627760, Tamil Nadu, India; vssivakumar69@gmail.com, anandakumar.mtech @gmail.com

Abstract

For the past three decades, Fibres are utilized in various fields of Engineering for varying purposes. This study aims at investigating the influence and performance of fibre orientations on Basalt Fibre Reinforced Polymer (BFRP) composite retrofitted RCC piles under lateral loads. The lateral performances of the piles are evaluated based on the load bearing capacity of the piles with same cross sections and reinforcements. M30 grade concrete was designed to cast 27 nos of RCC piles. After 28 days water curing, the piles were scheduled for test based on fibre orientation such as hoop direction 12 nos, vertical direction 12 nos. and without wrapping 3 nos. as conventional elements. BFRP hoop orientation wrapped 12 elements were splitted in to 4 sets; each sets contained 3 nos. pile elements such as 3 nos. as double wrapped elements, 3 nos as 30% preloaded of conventional element ultimate load & retrofitted with BFRP, 3 nos 60% preloaded & retrofitted and remain 3 nos. 90% preloaded & retrofitted elements. Similarly, BFRP vertically wrapped elements (12nos) also splitted for test. The conventional, BFRP double wrapped, retrofitted elements were tested in a loading frame keeping one end fixed and leaving the other free. During Lateral Loading the Deflection, Strain, Cracks were observed, Tabulated and Plotted the Stiffness, Load vs. Deflection curves. Moreover, the performances of the wrapped piles were evaluated by comparing with the conventional ones. It was observed that hoop and vertical wrapping on piles increases the respective load carrying capacity by 0.15 and 1.9 times than the conventional piles.

Keywords: Basalt Fibre, Lateral Load, RCC Pile, Unidirectional Fabric, Wrapping

1. Introduction

Retrofitting means strengthening the damaged or Deteriorated Structures without damage the existing structures and keeps the originality for long service. Retrofitting process indirectly supports in maintain the global sustainability. This paper deals with effects and importance of orientation on basalt fibres retrofitted RCC piles subjected to lateral loads and comparison of the performance with conventional pile elements.

Ahmet Pamuk et al.2004 explained in the paper of Retrofitting of Pile Foundation Systems against Liquefaction about the various physical modelling tests that were conducted to find about the fundamentals of lateral spreading of Pile-Soil Interaction. The paper shows the effective testing of the pile group foundations under the severe effects that are caused mainly due to the Non-Liquefiable shallow soil layer. The tests were conducted with two dynamic centrifuges.

Experiments. Model piles and an inclined laminar box were used to find out the Feasibility of the Retrofitting method that is used to reduce the bending moments in the Pile Group Foundations. The results from the tests showed an effective reduction in the bending moments in the piles for about 60-70% by the use of retrofitting techniques that were more simple and easy to make. It also stated that

** Author for correspondence*

the simplicity of this retrofitting technique can be used for multilayered soil with Non-Liquefiable Shallow layers and for new foundation systems. B. Purushotham Reddy et al. 2009 explained in his paper of Retrofitting of RC piles using GFRP composites with finite element analysis result comparison to study about the behaviour nature of retrofitted RC piles that are strengthened with the help of Glass Fibre Reinforced Polymer (GFRP) composites. The analysis was carried out using commercial software ANSYS. In-order to study the behaviour under various loadings such as Axial, Lateral and Combined were tested after retrofitting with Glass Fibre Reinforced Polymer and compared. The loading effect was made and the corresponding deflection and strain are obtained and compared with experimental plots. The conclusions were made from the result from finite element modelling. 43% of increase in Axial compression is obtained for the retrofitted specimen. Lateral load capacity of the retrofitted specimens is found to be relatively higher than that of the conventional piles. Sadone et al. 2012 used the strengthening configuration of columns subjected to combined axial load simulating gravity load and reverse cyclic lateral load simulating earth quake load were applied on CFRP confined columns with bonded longitudinal CFRP plates. Murugan et al. 2014 explained in the PhD Thesis, the GFRP and CFRP retrofitted pile performance subjected to lateral loads and compared with conventional one. CFRP retrofitted piles possess high strength than GFRP retrofitted and conventional piles. GFRP retrofitted piles withstand more strength than conventional pile. Anandakumar et al. (2014) found that the performance of BFRP retrofitted RCC piles subjected to axial loads. Even 90% preloaded of ultimate strength of conventional element and retrofitted with BFRP in Hoop Orientation was attained more strength than conventional elements. Besides, Anandakumar et al 2015 found the performance of BFRP retrofitted RCC piles subjected to impact loads, in this study the fibre orientation comes along the element that is vertical direction. Similarly, 30%, 60% and 90% preloaded of ultimate impact strength of conventional element attained more strength than conventional elements.

The main objective of this research is to find out the ultimate strength and performance of BFRP double wrapped piles subjected to the lateral loads with fibre orientation in hoop and vertical and to compare with conventional piles.

2. Materials and Methods

For this research the materials like Cement, Fine and Coarse Aggregate, Steel, Potable water, Basalt Fibre, Epoxy were used after testing as per on IS 8112-1989, 383-1970, 1786-1985 and 3025-1964 codes respectively and basalt fibre & epoxy technical data were collected from manufacturers; the test results are presented in Table 1. Based on the materials test results, M30 grade concrete design was designed as per IS 10262-2009 for Specimens and Casting and Testing of elements. Initially specimens such as Cubes, Cylinders and Prisms were Cast and Tested after 28 days of curing with and without BFRP Double wrap. Double wrapped specimens namely Cubes, Cylinders and Prisms Possess 1.5 times, 2.13 times and 2.40 times more characteristic strength

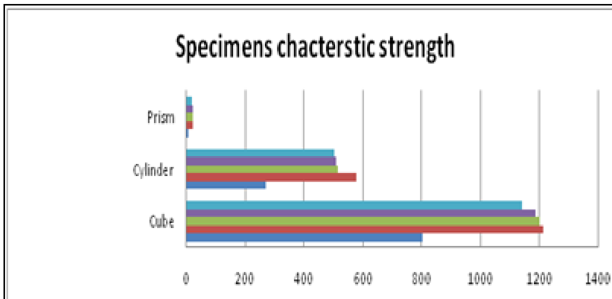
Table 1. Materials and their Properties

Description of Materials	Properties of materials
Cement – OPC 43 Grade	Specific gravity -3.15; fineness -227.8; initial setting time -45 min; Final setting time -585 min; standard consistency -36%.
Fine Aggregate	Good river sand; size - 4.75 mm and down size; specific gravity -2.8; Fineness modulus -3.1; water absorption -0.5%; surface texture –Smooth; particles shape- Angular.
Coarse Aggregate	Specific gravity -2.8; fineness modulus -7.5; Impact value -15.2; water absorption -0.5%; Particle shape –Angular; crushing value -18.6; particles shape- Angular.
Water	Good potable; p^H Value- 7.61; chloride - 420 ppm; sulphite -10ppm; suspended (TDS) - 890 ppm.
Basalt Unidirectional Fabric	Structures waving – UD; weight – 450 gram/m^2; thickness – 0.36 mm; width 600 mm; warp alone.
Epoxy (Hardener)	Aspect (visual) - white viscous paste; viscosity at 25 °C - 70000 - 90000 [mPa s]; density at 25 °C (ISO 1675)- 1.0 [g/cm3]
Epoxy (Resin)	Aspect (visual)- clear, pale yellow liquid; viscosity at 25 °C (ISO 9371B) - 10000 - 12000 [mPa s]; density at 25 °C (ISO 1675) - 1.15 - 1.20 [g/cm3].
Steel – RTS – Fe 415	Yield strength – 469.3 N/MM^2

than conventional specimens respectively. Moreover, for retrofitting processes conventional specimens are preloaded by 30%, 60% and 90% of ultimate load of conventional specimens. Preloaded specimens were retrofitted with BFRP double wrapping in hoop direction for Cubes & Cylinders, and in Vertical Direction for prisms by using Epoxy Adhesive Prior to Testing (Epoxy required 36 to 48 hours for setting), besides that characteristics were given in Figure 1.

Following the same procedure, 27 nos. of RCC end bearing piles were cast by using M30 grade concrete and same reinforcements (Shaft 150 mm dia. and 2250 mm length and 8 mm dia. - 6nos. Vertical Rods and Stirrups 6mm dia. rods 120mm c/c; it is showed in Figure 2. After 28 days of Curing, the piles were tested under lateral loads as scheduled in Table 2. BFRP wrapping is made using Epoxy Adhesive. It requires 36 to 48 hours for setting of Epoxy. For this Experiment, the retrofit pile elements were preloaded with 30%, 60% and 90% of ultimate load of conventional elements. Preloaded piles were retrofitted with BFRP wrapping in hoop orientation or vertical orientation of fibre warp.

The Conventional Elements were cleaned thoroughly by Emery Papering, Scrapping, Water Washing, White Cement Washing etc. for making the elements ready for Grid Marking and BFRP wrapping. After this processes, The Conventional Elements were fixed vertically with plump at 1000 kn capacity loading frame. Then pallets were fixed in the front side (Loading opposite side) at 1/3 rd Span, Mid Span and 2/3 rd Span Spacing from top for observing the deformation readings by strain gauge to find out the Stress and Strain. Dial gauge were fixed on loading side at 1/3 rd span, mid span and 2/3 rd span for measuring the deflection and lateral movements. The Hydraulic jack of 250 kn capacity is mounted at loading frame. Jack loading piston was made in contact with element using 40mm diameter shaft over the element at 75mm from top end as pictured in Figure 3. After completion of the setups (it shows in Figure 3-5), initial readings were noted at free loading conditions. Then the lateral load was applied with increment of 1 kN intervals up to the ultimate load carrying capacity. For every 1 kN intervals, the Readings, Behaviours and Performance were observed and tabulated in Table 3. After analysing the observed values, the graph of Load vs. Deflection is drawn as in Figure 6-10. Similarly, BFRP doubly wrapped in vertically pile elements were tested and their performances were tabulated in Table 3 and Load vs. Deflection curves plotted in Figure 11-15. All the above tests were conducted as per IS: 2911 (part 4) –1985 (Reaffirmed in 2000) and IS 516–1954.



	Cube	Cylinder	Prism
90% Preloaded & Retrofitted3	1141.5	503.3	22.3
60% Preloaded & Retrofitted2	1187	511	23.6
30% Preloaded & Retrofitted	1198	517.65	23.65
BFRP double wrapped	1210	578.9	24.03
Conventional	803.33	270.75	9.9

Compressive load in kN.

Figure 1. Characteristic Strength of Specimens.

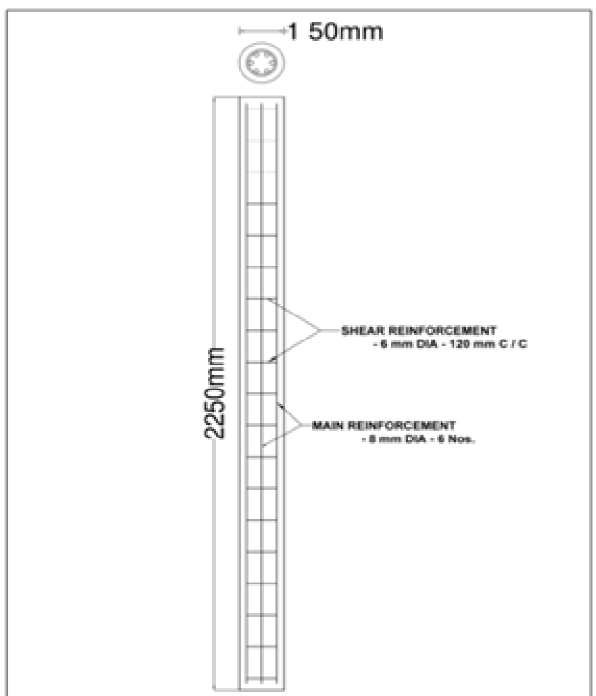


Figure 2. CReinforcement Details of Pile Elements.

Table 2. Experimental Schedule for Element Testing

Faber orientation	Conventional	BFRP double wrapped	30% preloaded and retrofitted	60% preloaded and retrofitted	90% preloaded and retrofitted
Hoop Direction	3	3	3	3	3
Vertical Direction		3	3	3	3

After positioning of the Conventional Elements, the Initial Strain and Dial Gauge readings were taken at free loading condition. Then the serial static lateral load was applied as per IS 2911(Part4)-1985 (Reaffirmed 2000). In this experiment 1 kN, 2 kN, 3 kN, 4 kN range load were applied until ultimate failure occurs. For every 1 kN loading intervals, the Strain and Dial Gauge readings were observed. In this experiment, the first cracks were observed at a load of 6 kN. The Fine Cracks were formed at loading face on the concrete shaft at mid span to bottom fixed point. The same cracks developed as thin cracks at loading condition of 8.5 kN. Under the loading condition of 9 kN, very wide cracks were formed at element shaft from mid span to bottom of the element. Ultimate failure nodes were found out on the loading face portion under the 9.75 kN loading condition at fixed point.

3. Results and discussion

BFRP vertical (90° orientation) Wrapped Pile elements possessed more lateral strength than BFRP Hoop (0° orientation) Directional Wrapped Elements and Conventional Elements. The Conventional and BFRP

Figure 3. CLateral Load Test on Conventional RCC Pile Elements at Free End.

Figure 4. BFRP Wrapping in Hoop Directional (0^0 orientation) and Retrofitted RCC Pile Elements Test.

Figure 5. BFRP Wrapping in Vertical Direction (90^0 orientation) and Retrofitted RCC Pile Elements Test.

Wrapped elements in Hoop Direction withstands 9.75 kN and 11.25 kN of lateral loads respectively while BFRP vertically wrapped elements attained 17.80 kN. Besides, the Maximum and Minimum Stress were determined and given in Table 3. From Table 3, BFRP vertical wrapped elements possessed maximum stress than hoop orientation wrapped elements and conventional elements. Fibre warp orientation along the length direction acts as a reinforcement so it enhances the lateral bearing capacity of retrofitted piles than hoop orientation wrapped elements and conventional ones.

Similarly, 30%, 60% and 90% of preloaded and retrofitted with BFRP double wrapped elements in vertical directions possesses higher lateral bearing capacity than Hoop Directional Retrofitted and Conventional Elements as in Table 3.

Stiffness of BFRP vertical directional wrapped pile element was found as 0.132 kN / mm.it is higher than BFRP Hoop Directional Wrapped and Conventional Pile Elements. BFRP composites enhance the stiffness of basalt fibre wrapped elements during lateral loads but it gets sudden torn during ultimate load. Besides, Retrofitted with BFRP wrapped in vertical (90° orientation) Directional Pile elements possess high strength than BFRP Hoop Directional and Conventional Piles.

Cracks were initially formed just above the fixed

Table 3. Performance of Pile Elements Subjected to the Lateral Loads

Type of element	Load bearing capacity in kN	Stiffness in kN/mm	Maximum stress in N/mm^2	Minimum stress in N/mm^2
Conventional pile	9.75	0.132	59.404	58.300
BFRP wrapped in hoop directional (0° orientation) pile	11.25	0.152	65.829	64.590
30% preloaded & retrofitted with BFRP wrapped in hoop directional (0° orientation) pile	10.90	0.149	63.781	62.580
60% preloaded & retrofitted with BFRP wrapped in hoop directional (0° orientation) pile	10.30	0.140	60.270	59.135
90% preloaded & retrofitted with BFRP wrapped in hoop directional (0° orientation) pile	9.90	0.135	57.929	56.839
BFRP wrapped in vertical (90° orientation) directional pile	17.80	0.289	104.156	102.195
30% preloaded & retrofitted with BFRP wrapped in vertical (90° orientation) directional pile	15.82	0.281	92.542	90.804
60% preloaded & retrofitted with BFRP wrapped in vertical (90° orientation) directional pile	15.50	0.278	90.698	88.990
90% preloaded & retrofitted with BFRP wrapped in vertical (90° orientation) directional pile	15.00	.274	87.889	86.234

end prior to the formation at middle of Conventional Elements. The fine cracks were formed at fixed end above portion due to Lateral Load at 6.00 kN. 100mm intervals fine cracks were formed at mid span in Hoop Direction. Simultaneously the first cracks were developed as thin cracks on 7.25 kN. Thin cracks were developed as aggravated medium cracks at 8.50 kN over midspan areas and fixed end portion of elements. Cracks were developed on ultimate loading of 9.75 kN. The failure of BFRP Hoop Directional (0° orientation) Wrapped elements are quite similar to conventional piles. However, the cracks are not visible as the BFRP wraps hides the concrete shaft. But, in BFRP vertically wrapped pile elements failed at 17.80 kN of ultimate load. No cracks were visible until the wraps gets torn with sound during ultimate loading time.

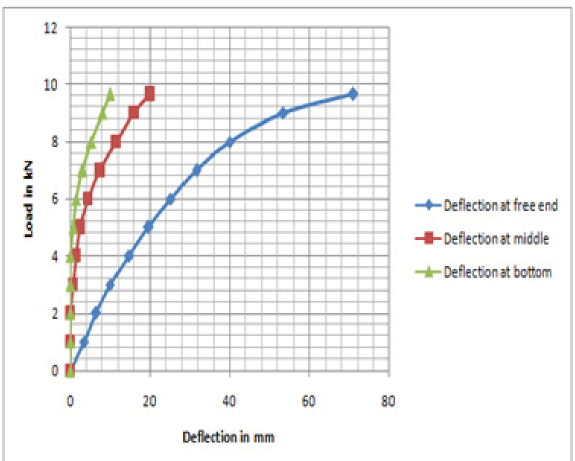


Figure 6. Load vs. Deflection of Conventional Element

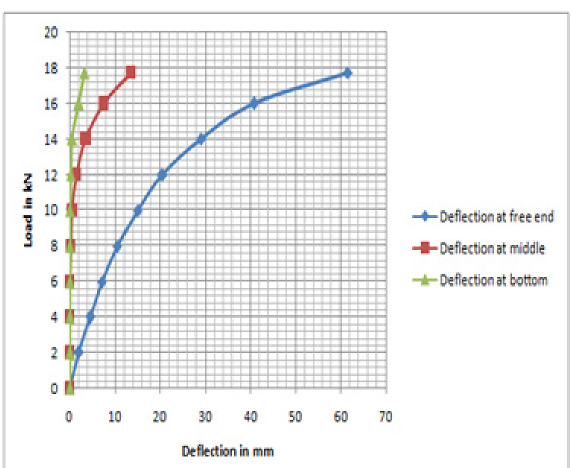


Figure 7. LLoad vs. Deflection of BFRP Vertical (90^0 Orientation) Wrapped Elements.

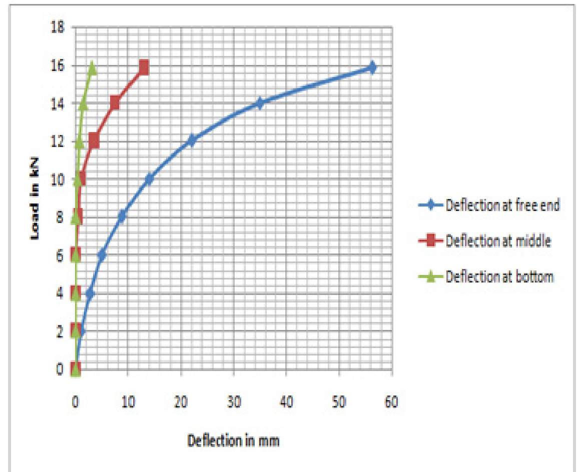


Figure 8. Load vs. Deflection of 30% Preloaded and Retrofitted with BFRP Vertical Wrapped Elements.

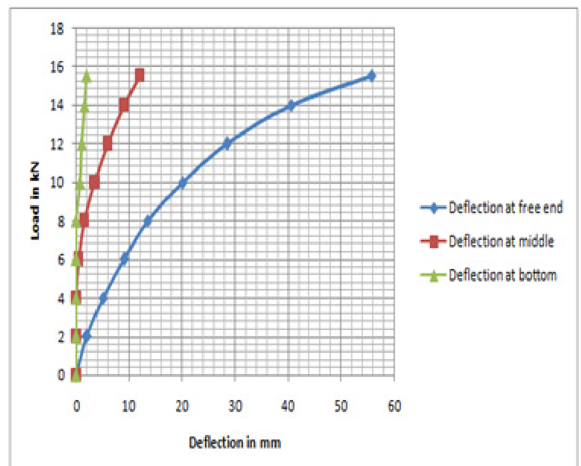


Figure 9. Load vs. Deflection of 60% Preloaded and Retrofitted with BFRP vertical Wrapped Elements.

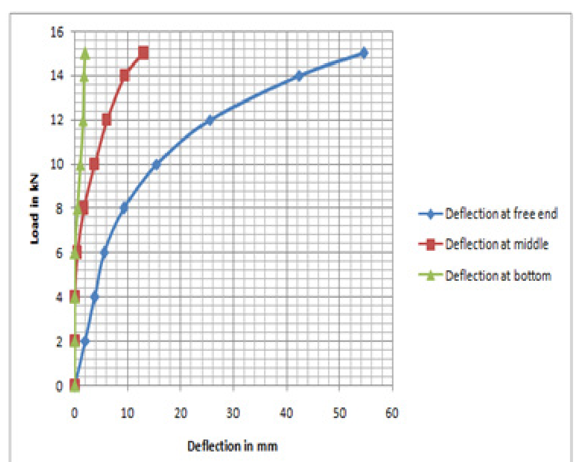


Figure 10. Load vs. Deflection of 90% Preloaded and Retrofitted with BFRP Vertical Wrapped Elements.

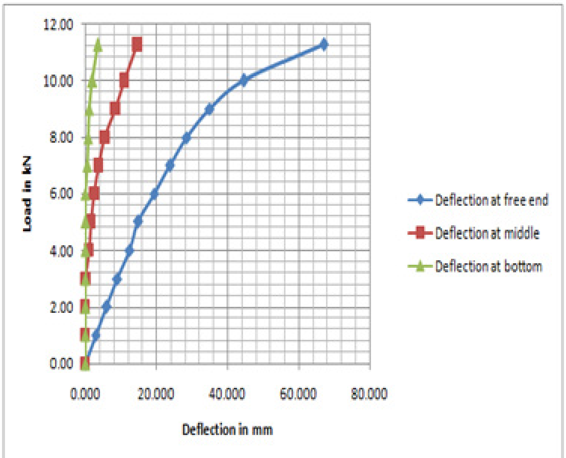


Figure 11. Load vs. Deflection of BFRP Hoop Directional (0^0 orientation) Wrapped Element.

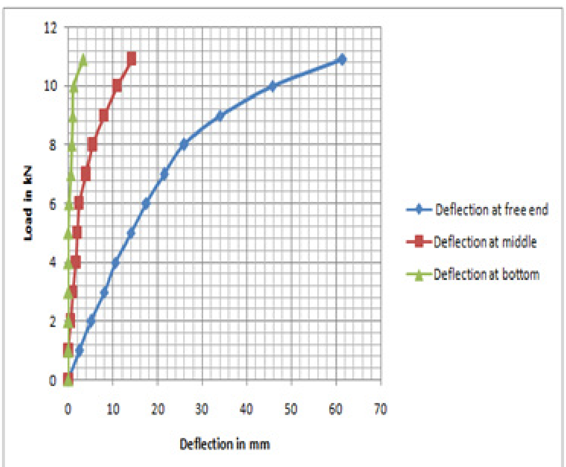


Figure 12. Load vs. Deflection of 30% Preloaded and Retrofitted with BFRP Hoop Directional Wrapped Elements.

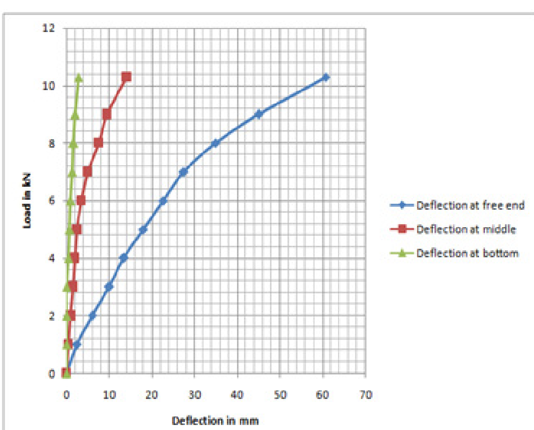


Figure 13. Load vs. Deflection of 60% Preloaded and Retrofitted with BFRP Hoop Directional Wrapped

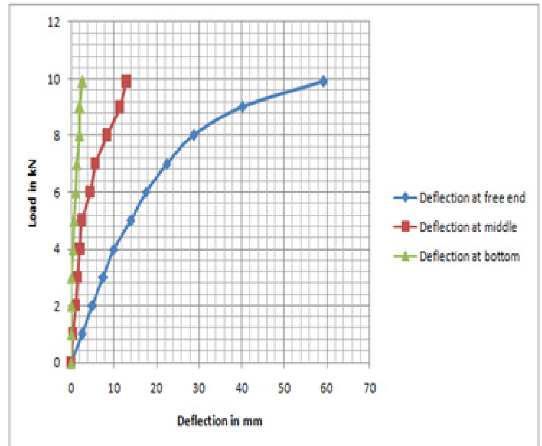


Figure 14. Load vs. Deflection of 60% Preloaded and Retrofitted with BFRP Hoop Directional Wrapped Elements.

Figure 15. Hoop directional Wrapped Elements.

4. Conclusion

It is obvious from the study that the basalt fibre vertically (90° orientation) wrapped elements possessed 158%, 145%, 150% and 151% of higher lateral load bearing capacity than the Hoop Directional Wrapped. Similarly, BFRP vertically wrapped elements were attained 182%,162%, 160% and 154% more lateral strength than the conventional ones. Flexural performance of vertically wrapped elements was higher than Hoop Directional Wrapped and Conventional Elements. The Basalt Fibres possess high tensile strength than steel which tends to increase the lateral load bearing capacity and flexural strength. Vertical Wrapping of Basalt Fibre can be used for retrofitting purpose where tensile loads prevail. Hoop

Directional wrapping is not suitable for locations where tensile and flexural force exists. However the orientation of Fibre Wrapping on pile elements is done depending upon the load conditions. For axial compression condition, hoop orientation is best applicable but in lateral or tensile load conditions, vertical orientation proves to be an effective one. In future, this study can be expanded by using different Fibres and different Elements such as Beams, Columns and Joints etc.

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