A Review on Finned Pile Foundation

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doi: https://doi.org/10.21467/proceedings.112.16

ABSTRACT

Foundation is that part of the structure which supports and transfers the loads from the structure to the soil. Pile foundations are subjected to both axial and lateral loads especially in quay walls, harbour structures, offshore structures, earth-retaining structures, bridges, power stations, lock structures, tall chimneys, and high-rise buildings. Foundations for offshore structures are subjected to environmental loads from waves, currents and wind giving rise to lateral loads that could be up to one third of the vertical loads. In order to enhance the lateral capacity of pile of such structures finned pile can be used. Experimental and numerical analysis of finned pile in sandy and clayey soil is studied by various researches and they concluded that the lateral capacity can be improved compared to that of regular piles. This paper discusses the various parameters of finned pile that influence the lateral capacity of pile foundation. The various parameters discussed are position, number, inclination, shape and dimensions of fin. From the literatures it was found that rectangular fins show better lateral resistance than triangular fins and also as the length and width of the fin increases the lateral capacity of pile also increases in both sandy and clayey soil under lateral loads.

Keywords: Finned pile, Lateral load, lateral resistance.

1 INTRODUCTION

Piles are generally used in high rise structures, power transmission line foundations, wind farms and offshore structures to support vertical loads, horizontal loads and their combined effect. The foundations of such structures are designed to carry the large vertical loads. But in the case of offshore structures the horizontal loads acting due to wind and waves are significantly large which can be upto three times the vertical load acting on them. Therefore, the pile for such structures has to be designed to resist the large lateral loads. Researchers have come up with various methods to improve the lateral capacity of pile which are subjected to large lateral loads. The lateral capacity of pile can be enhanced by modifying the upper part of the soil or the pile near the ground. The various techniques used include the jet grouting of the upper soil section, increasing the diameter of the pile and use of screw piles. But all these methods require special equipment for installation and extra costs in the manufacture and transportation stages. Hence researchers came with the idea of finned pile.

Finned piles are simply conventional piles modified by attaching plates to the curved surface of the pile. These piles are generally manufactured in steel as well as concrete. The researchers have studied the behaviour of finned pile under lateral loads. Numerous experimental and numerical studies have been conducted over the years to analyse the lateral resistance of finned pile. A review on the various studies performed on finned piles to understand their lateral behaviour is discussed in this paper.

2 FINNED PILE

Finned piles are simply conventional piles modified by attaching plates to the curved surface of the pile. The addition of fins increases the passive soil area that resists the lateral loads thereby improving the lateral resistance

Proceedings DOI: 10.21467/proceedings.112; Series: AIJR Proceedings; ISSN: 2582-3922; ISBN: 978-81-947843-3-3

of the pile and decrease the horizontal movement. Several experimental and numerical studies were carried out to investigate the behaviour of pile modified with fins. The parameters studied include the shape of the fin, position of the fin, dimensions and orientation of the fin. Figure 2.1 shows the schematic representation of a pile with two rectangular fins attached at the head of the pile at right angle to the curved surface and diametrically opposite. Studies show that the lateral capacity of pile considerably increases on the addition of fins to the pile. According to the study by Albusoda et al.(2018) on finned piles embedded in sandy soil, the lateral load carrying capacity increases by 76% compared to that of regular pile.

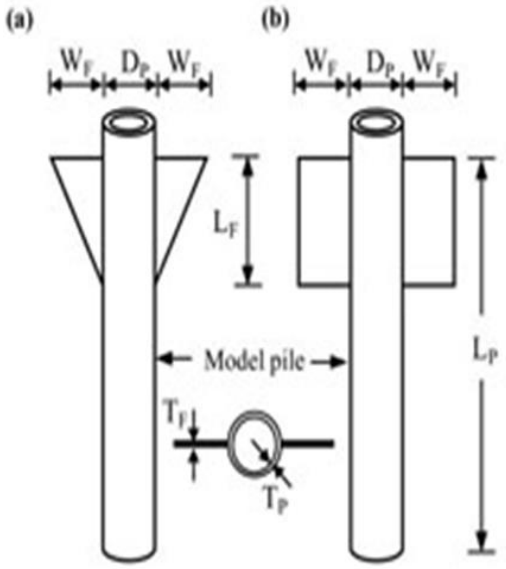

Fig.1. Schematic representation of finned piles with triangular and rectangular fin (Nasr, 2014)

Hazzar et al. (2013) conducted numerical study to understand the factors that influence the lateral capacity of pile. According to them the ultimate lateral resistance increases with increase in diameter and the length of the pile. The addition of fins have already proved to increase the lateral resistance of pile, so the length of the pile can be reduced if finned piles are used to improve the lateral capacity. According to the study conducted by Peng et al. (2010) the length of the finned pile can be decreased upto 12.5% to get the same lateral resistance as that of regular piles. Their results also show that for a monopole to show the same lateral resistance as that of finned pile the core diameter of the pile has to be more than that of finned pile. Thus the material used in the manufacture of pile can be reduced to 60% if finned piles are used, thus making the finned pile more economical than regular pile.

3 PARAMETERS THAT INFLUENCE LATERAL CAPACITY

3.1 Position of fin

The lateral load resistance of the piles can be improved by the addition of fins on the curved surface of the pile. The addition of fins increases the stiffness of the pile thereby increasing the lateral resistance. Hence the addition of fins at any length of the pile can improve the lateral resistance. Babu and Viswanadham (2018) studied the effect on position of the fin by placing the fins on top, middle and bottom of the pile. They observed that the pile with fins attached at the top show greater lateral resistance and the lateral resistance increased by 20%, 15% and 10% when the fins were attached at the top, middle and bottom in comparison to regular piles.

Proceedings DOI: 10.21467/proceedings.112
ISBN: 978-81-947843-3-3

Series: AIJR Proceedings
ISSN: 2582-3922

This is because of the increase in the pile stiffness and increase in the area of soil resisting the lateral load. These results were similar to that observed by Peng et al. (2010).

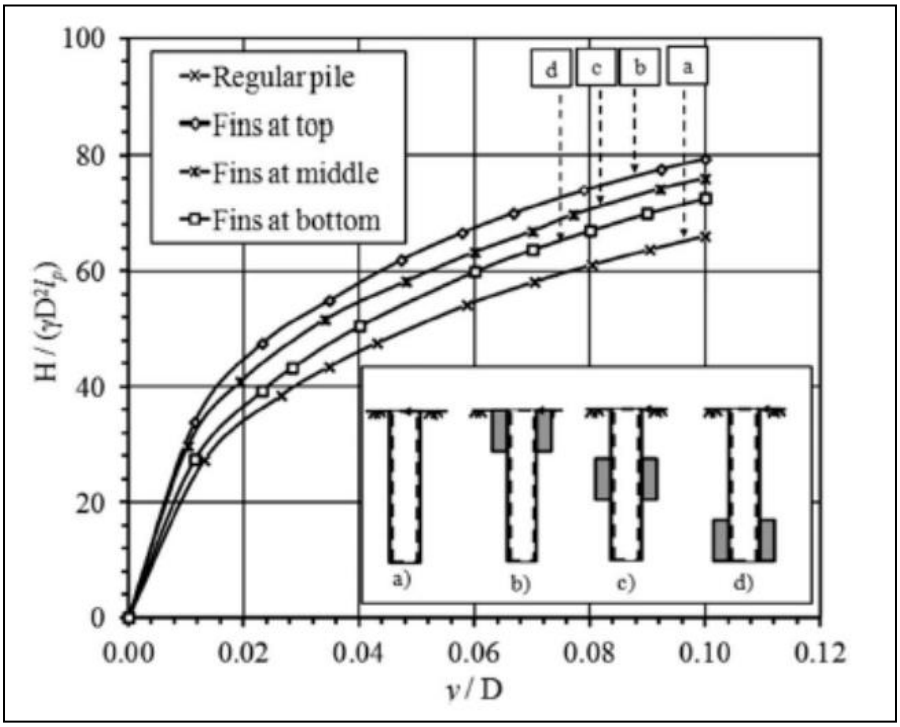

Fig.2. Lateral load deflection curves of fin piles for different fin locations (Babu and Viswanadham, 2018)

Pile foundations are used in structures like bridge abutments, marine dolphins, tower foundations, submerged platforms, and dock-fendering systems which are subjected to tension loads. Inorder to increase the uplift capacity screw piles are generally used but these pile create additional cost. Azzam and Elwakil (2016) conducted studies on the use of finned pile with fins attached at the end of the pile on sandy soil and they observed that the uplift capacity has significantly increased compared to regular piles. Thus pile foundations with fins attached at the bottom can be used to increase both the lateral and uplift capacity.

3.2 Effect of number of fins

Sakr et al. (2020) conducted experimental analysis on finned piles in clayey soil to study the impact of the number of fins on the lateral resistance of piles. The lateral load deflection curves obtained in their study is shown in figure 3 and it demonstrates that when the direction of loading is along the largest reaction surface, as the number of fins increases lateral capacity of pile also increase and also the structural stiffness of fin in the direction of lateral load has major effect on the lateral resistance.

In actual condition, lateral load may operate in any direction hence it is recommended to have more than two numbers of fin to resist lateral loads. A schematic representation of the soil resistance provided by the regular pile and finned pile is shown in figure 4. It is seen that area of the soil that resists the lateral load is larger in case of finned pile compared to that of the regular pile due to the presence of fins. It is also seen that the piles subjected to lateral load along the larger surface with three fins show greater lateral load capacity than two finned pile because of the large passive area of soil in front of the fins and the increase in pile rigidity due to three fins.

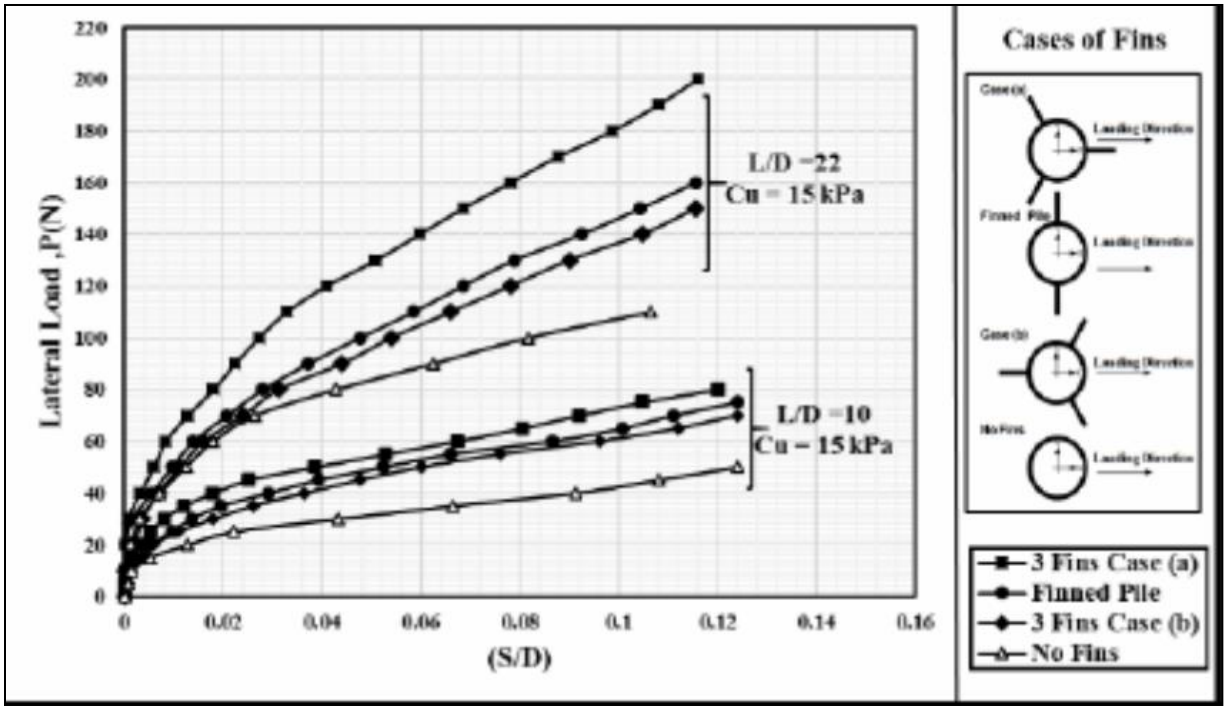

Fig.3. Lateral load deflection curve for different number of fins (Sakr et al, 2020)

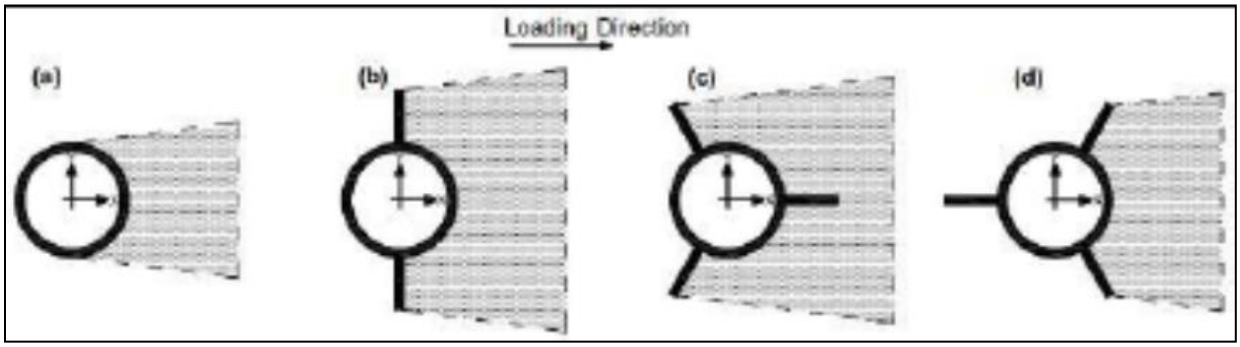

Fig.4. Schematic diagram of soil resistance provided by fins under lateral loading

3.3 Effect of shape of fin

Nasr (2014) studied the effect of the shape of the fin by considering rectangular and triangular fins. According to his observations pile with both rectangular and triangular fins show increased lateral resistance than regular piles and improvement in ultimate lateral load was upto 64% and 86% respectively. It is seen that pile with rectangular fins show greater lateral resistance compared to pile with triangular fins and this is due to the increase in the passive area of soil that resist the lateral load is more in pile with rectangular fins.

Proceedings DOI: 10.21467/proceedings.112
ISBN: 978-81-947843-3-3

Series: AIJR Proceedings
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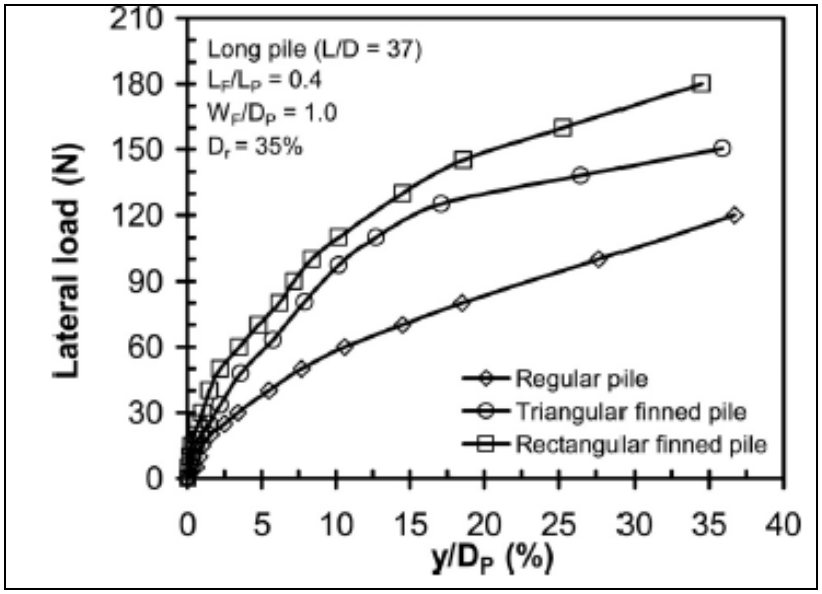

Fig.5. Lateral load–deflection curves piles with different shapes of fin. (Nasr, 2014)

3.4 Effect of Fin orientation

Babu and Viswanadham (2018) performed numerical analysis and Sakr et al.,(2020) conducted experimental analysis on the finned pile. They considered straight and diagonal fin orientations and observed that diagonal fin configuration show greater lateral resistance than straight fin configuration. This is because the area of soil that resist the lateral load is greater in diagonal fin configuration. In case of piles with diagonal fin configuration the soil in between the fins and pile act as a block and resist the lateral load. In actual condition the lateral load can operate in any direction, hence it is always better to adopt diagonal configuration of fins for better results.

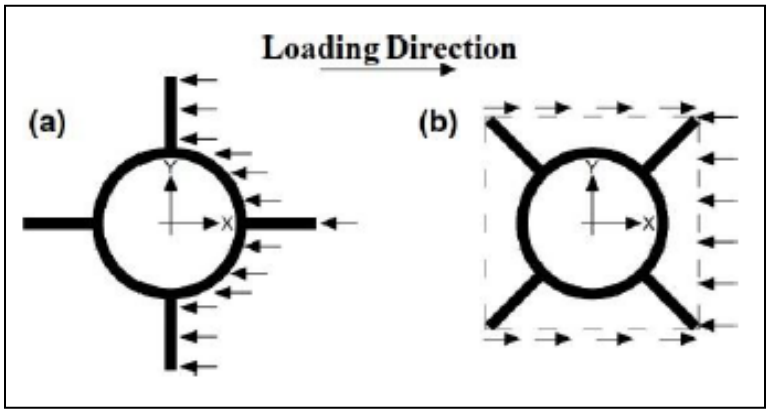

Fig.6. Representation of soil resistance of various fin orientations under lateral load (Sakr et al., 2020)

3.5 Effect of soil property

Most of the studies on finned pile were conducted on sandy soils. Babu and Viswanadham (2018) studied the influence of soil density by conducting numerical analysis on piles embedded in sand at various densities. It was observed that lateral load-carrying capacity of piles is more than twice in dense sand as in loose sand. This is due to the development of high confining stresses around the fins and piles. Sakr (2020) conducted experimental study on finned pile embedded in very soft and soft clayey soil and observed that as the undrained shear strength.of the soil increases ultimate lateral load capacity of regular and finned pile also increases. The

ultimate lateral load increases because, as the soil cohesiveness increases the shear strength and stiffness of clay increases.

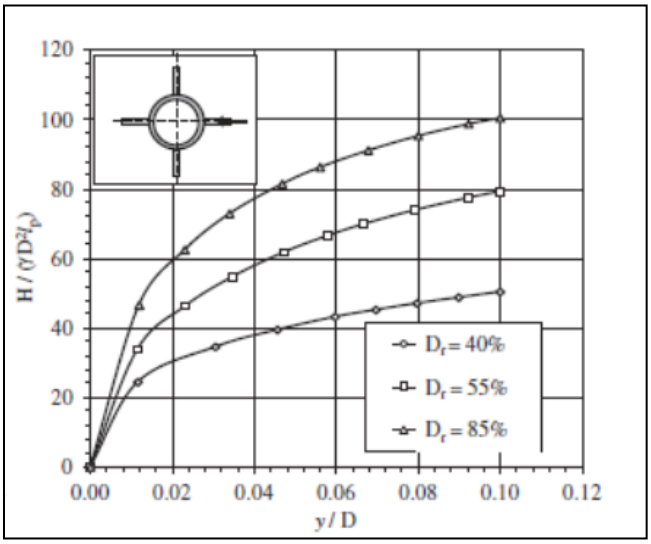

Fig.7. Lateral load deflection curves for fin piles embedded in various densities of sand (Babu and Viswanadham, 2018)

3.6 Effect of fin length

Fin length is an important parameter that influences the lateral capacity of pile. As the length of the fin increases, the lateral stiffness of pile and the passive area of soil resisting the lateral load increases thereby increasing the lateral capacity of the pile. Nasr (2014) conducted experimental and numerical analyses on finned pile embedded in sandy soil and observed that the ultimate lateral load carrying capacity of finned pile increases with increase in fin length and the improvement increases significantly upto the ratio of fin length to fin width equal to 0.4 and on increasing the fin length beyond, the increase in lateral resistance decreases. Sakr (2020) conducted experimental study on the influence of fin length on lateral capacity of pile embedded in clayey soil and similar pattern of results were obtained.

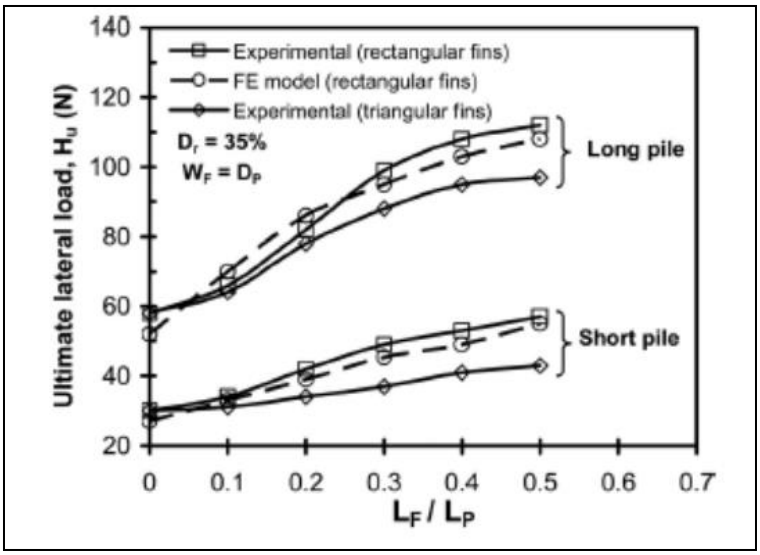

Fig.8. Ultimate lateral load for various fin lengths (Nasr(2014))

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3.7 Effect of Fin Width

Another important parameter which influences the lateral capacity of finned pile is the fin width. As fin width increases the lateral deflection of pile decreases. In regular pile due to the lateral load soil flow surround the outer pile surface whereas when piles are attached with fins the passive area of soil resisting the lateral load increases which is equivalent to three times the diameter of regular pile.

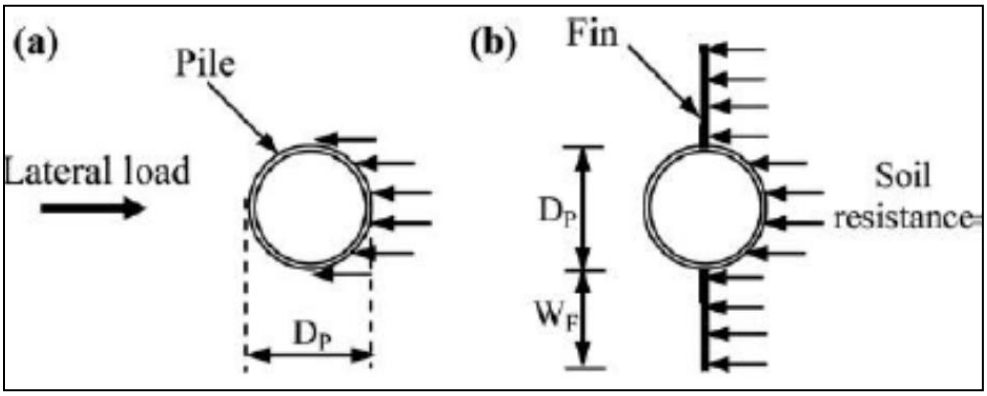

Fig.9. Area of soil resistance in regular and finned pile under lateral load (Albusoda (2017))

Studies show that the lateral resistance offered by finned pile increases with increase in width of the fin. The rate of increase in the lateral capacity of pile is maximum when the width of the fin is equal to the diameter of the pile and on further increasing the width increase in lateral resistance is low. According to Stewart (1999), the area that resists lateral loads around the pile is a three-dimensional inverted cone shape formed near the soil surface and centered on the pile. The lateral resistance of the pile depends significantly on the deformation of soil within the inverted cone shape. When the ratio of fin width to pile diameter is less than 1, the fin width is located within the range of the inverted cone shape. On increasing the fin width beyond the zone of soil resistance the improvement shown is reduced. Also, as the width of the fin increases the rigidity decreases, hence to maintain the required stiffness the thickness of the fin has to be increased. This will increase the cost and thereby reduces the benefit of finned pile. Therefore, the fin width equal to pile diameter can be considered the best fin width.

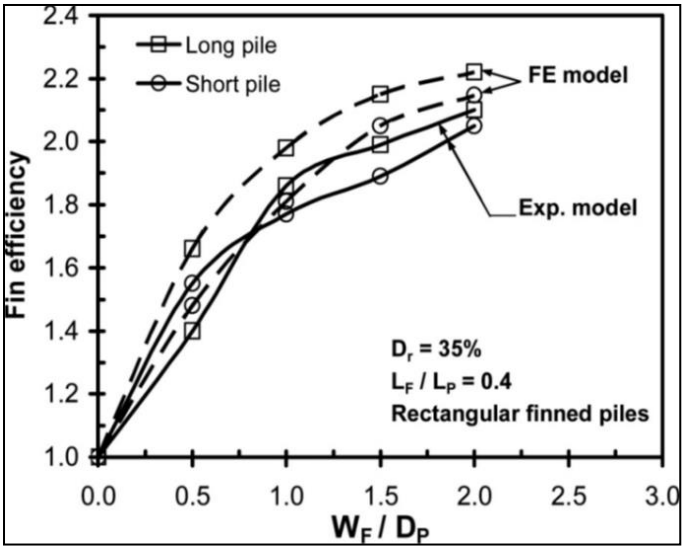

Fig.10. Variation of fin efficiency with fin width (Nasr, 2014)

4 CONCLUSION

Finned pile is a modified pile foundation which can improve the lateral load capacity. Finned pile requires lesser diameter and length to provide lateral resistance compared to regular pile, therefore the use of finned pile is economical. The various parameters that influence the lateral capacity are dimensions of the fin, position shape and orientation of fin. In order to increase the lateral capacity of piles it is recommended to place the fins on the head of the pile near the ground surface. Piles with fins attached at the base of the pile are used under tension load. The lateral capacity of pile increases as the width and length of the fin attached to the pile increases. Similar results were obtained in sandy and clayey soil. The efficient dimensions of the fin can be taken as length of the fin equal to 0.4 times the length of the pile and width of the fin equal to the diameter of the pile. On comparing the lateral capacity of pile with rectangular and triangular fins, rectangular fins show greater improvement in lateral capacity than triangular fins. Studies also show that diagonal fins and more than two numbers of fins show better lateral resistance.

How to Cite this Article:

Chandni, S., & Ambi, R. (2021). A Review on Finned Pile Foundation. *AIJR Proceedings*, 129-136.

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