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Behaviour of Single Pile in Reinforced Slope Subjected to Inclined Load

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ABSTRACT
Deep foundations, including driven piles, are used to support vertical loads of structures and lateral forces. Typical structures subjected to lateral loads include bridge abutments, transmission tower, sand offshore platforms. Traffic, wind, wave, and seismic forces are common types of lateral loads subjected to pile foundations. The present work is focused on understanding the lateral load capacity of vertical piles located near crest of the slope and subjected to the lateral and inclined loads. The experimental investigation was carried out to study the effect of reinforcing an earth slope on the inclined loading behavior of a single vertical pile located near the slope. Layers of geogrid were used to reinforce a sandy slope of 1V:2H. The parametric studies were performed by varying the length of pile(L), angle of inclination of load (θ), number of geogrid reinforcement (Nr) and crest distance. It was observed that the lateral load capacity of pile depends upon these parameters. The lateral load capacity of pile increases with increase in inclination of load, length of pile(L), number of geogrid reinforcement (Nr) and crest distance.
Keywords: Lateral deflection, Lateral load test, Pile, Reinforced slope, Ultimate lateral load.

I. INTRODUCTION

The civil engineering developments are continuing all over the world. Land on the earth has becoming finite for the construction. Structures like, bridge abutment on steep river slope, open type berthing structure, electric / telephone poles on high way/ railway embankment and approach to water intake tower in river /sea are constructed in sloping ground and this structures are subjected to lateral load due to the lateral soil movement of unstable slope. Lateral movement of these unstable slope results in large lateral force on pile supported structures. Due to such lateral loads and the no availability of good construction sites, engineers are often required to place footings at crest or near slopes.

These lateral forces are sometimes much greater than the weight of the structure itself. Therefore, the foundation systems must be designed to resist both axial forces and lateral forces. Under lateral loads, the piles may induce slope failure, particularly at shallow depths, as well as may undergo severe reduction in its lateral capacity. Lateral loads applied to deep foundations are transferred into the surrounding soil, and the interaction between the soil-pile systems resists lateral movement of the foundation.

Various methods to stabilize slopes include soil nailing, reinforcing with layers of geogrid, and installation of piles or vertical sheet piles. Stabilizing earth slope has a significant effect on the overall stability of the slope and on improving the bearing capacity supported on/near a reinforced ground slope. There exists a lack of knowledge concerning pile behavior and the effects of these reinforcements on the pile lateral bearing load. Therefore, the aim of this research was to define more clearly the response of pile located near sandy slopes reinforced with layers of geogrid.

Therefore, the aim of this project is to investigate the response of pile located near sandy slopes reinforced with layers of geogrid layers and to determine optimum number geogrid reinforcements Also, the investigation is carried out to find out the pile response for location of pile relative to slope crest, the effect of inclined loading and the embedded length of pile. Initially, in this paper, the results of model tests of long pile subjected to lateral loading and inclined loading in homogeneous sand with 1V:2H reinforced slope are compared. Angle of inclined loading is varied as 0°, 15° and 30°.

The objectives are formulated for this experimental investigation as:

- To conduct experimental investigation of laterally loaded piles in reinforced slope
- To investigate and establish the relationship between the pile response and number of geogrid layers and to determine optimum number geogrid reinforcements.

To determine the effect of the embedded length of short pile and long pile when pile is placed away from the slope crest To investigate the effect of inclined loading

II. MATERIALS & PROPERTIES

2.1. Test Materials

2.1.1. Test Sand

For the model tests, cohesionless, dry and clean Kanhan sand was used as the foundation soil. This sand is available in Nagpur region of Vidharabha, Maharashtra, India. The properties of sand used are as shown in Table 1.

Table1: Properties of Sand Used

Sr.	Properties	Values
1	Type of soil	Sandy soil
2	Specific gravity	2.57
2	γ_{max}	17.67 kN/m³
3	γ_{min}	16.94 kN/m³
4	Angle of internal friction, Ø	27.5°
5	Average grain size (D60)	1.10
6	Effective grain size (D10)	0.45
7	Coefficient of uniformity	2.44
8	Coefficient of curvature (Cc)	1.03
9	I. S. Classification	Medium sand, SP

2.1.2. Model Piles

The model piles for experimental investigation were made from M.S. rods. The piles were 100 mm and 200 mm in length and the corresponding length to diameter ratios of piles were 10 and 20. The piles were provided with threads at one end for attachment of pile cap for ease of applying lateral load.

There are several factors that affect the lateral resistance of a pile but the dominant one is the pile stiffness, which determines whether the pile behaves rigidly or as flexible pile. Laterally loaded pile behaves as a rigid pile based on the value of the stiffness factor *T*. In cohesionless soils, this factor is calculated as,

$$T = \sqrt[5]{\frac{E_P I_P}{n_h}}$$

where,

E_P = Modulus of elasticity of the pile material (21.4 x 10^7 kN/m^2);

I_P = Moment of inertia of the pile cross section (4.91 x 10^{-10} m^4); and

n_h = Constant of subgrade reaction at pile tip.

Broms suggested that the embedment depth of the pile has to be less than 2*T* to be considered as a short rigid pile and greater than 2*T* for behavior as a long elastic pile. Possible values suggested for n_h are 13500 kN/m^3 for medium-dense sand. The estimated value of 2*T* for different relative densities is 0.189.

2.1.3. Geogrid Reinforcement

Biaxial Geogrid was used to reinforce sand bed in the model tests. The size of biaxial geogrid reinforcement used was fifty times the diameter of the pile (50D). The vertical spacing between Geogrid reinforcing layers was 2.5D. The topmost geogrid layer was placed at depth of 2.5 D from top surface of sand bed.

2.2. Experimental Set Up (Test Tank and Loading Frame)

The test tank was made of 4 mm thick M.S. sheets having internal dimensions 700 mm × 400 mm in plan and 500 mm high. One of the side of the tank was made of thick glass, to observe the mode of failure of pile. The loading frame used for applying lateral as well as inclined load on the pile consisted of a rectangular horizontal base frame of channel section. The loading frame had provision to vary the heights of the pulley so as to apply the load either laterally or in any inclined direction in the elevation at 15^0 and 30^0. Laboratory setup of test tank is shown in Fig.1

Figure 1: Laboratory Setup of Test Tank

2.3. Experimental Test Procedure

2.3.1. Preparation of Sand Bed

The test tank was filled by using sand raining technique. The height of fall to achieve the desired relative density was determined prior by performing a series of trials with different height of fall. The sand was poured in the tank by sand rainfall technique keeping the height of fall as 35 cm to maintain the constant relative density 41% corresponding bulk density16.60 kN/m^3 throughout the test.

Minimum depth of sand below the base of the model pile was 100 mm > (5D) to minimize the influence of tank base. The test tank was filled with the sand for a depth of 20 cm by using the sand rainfall technique. Then sand was deposited up to the desired location of the layer of reinforcement i.e. 2.5D, 5D, 7.5D and 10D from surface. The front face of the band bed was then cut to form a sloping face with a slope of 1V:2H.

2.3.2. Laying of Geogrid Reinforcement

After formation of sand bed up to the desired location of the layer of Geogrid reinforcement, the top surface of the sand was levelled and geogrid reinforcement was placed in position. Reinforcement layer was placed in desired position over sand bed and preparation of sand bed was then continued further.

2.3.3. Placing Pile in Position

The sand bed was prepared in the test tank and the pile was then positioned over the prepared sand bed and pushed into the sand for 2.5 times diameter of pile (2.5D) by displacement method till the pile was inserted in the sand bed. Great care was taken to level the slope face using special rulers so that the relative density of the top surface was not affected. After pile was pushed in the sand bed, surface was levelled using sharpened straight steel plate and the test tank was filled up to top layer of sand bed.

2.3.4. Lateral Load Test

The lateral load tests were conducted on model pile as per the procedure recommended by IS:2911 (Part 4) -1985, to evaluate ultimate lateral load and lateral deflection. Dial gauge was placed against the flange welded to the pile to measure the lateral deflection. The static lateral loads were applied in increments by adding dead weights through the loading arrangement. Each load increment was approximately equal to 1/10th of the expected ultimate lateral load and kept constant for 1/2 hour. The ultimate lateral load was selected for 5 mm pile head deflection. However, the loads were applied until pile fails or lateral deflection of pile head reaches up to 8 mm.

2.4. Test Program

The tests was conducted on model pile and the parameters varied were number of geogrid layers, crest distance, length of pile, angle of inclination of loading. Pile diameter, relative density and type of soil were kept constant in all the tests. Detail programme of tests procedures is given in Table 2

Table2: Details of Parametric Study in Experimental Investigation

Sr. No.	Parameters	Details of parameter
1	No. of piles	1
2	Location of pile	2.5D, 5D & 7.5D
3	Dia. of pile (D)	10 mm
4	No. of geogrid layers (N_r)	0, 1, 2, 3, 4
5	Length of pile	10D & 20D
6	Loading condition	Inclined
7	Slope	1V : 2H
8	Spacing of geogrid layers	S/D = 2.5
9	Inclination angle of load	0°, 15° & 30°

III. RESULTS

3.1 Load Deflection Behavior of Long Pile

3.1.1 Load Deflection Behavior of Long Pile with Lateral Load

The tests were conducted on long pile of length 20 cm (L/D = 20) on prepared unreinforced slope and reinforced slope. Number of geogrid layers (N_r) was varied as 1, 2, 3, 4. The angle of loading direction was kept to be 0° and pile location is varied as 2.5D, 5D and 7.5D away from the slope crest. The corresponding load deflection curves are shown in Fig. 2, 3 and 4. Ultimate lateral load capacities determined from these curves are tabulated in Table 3.

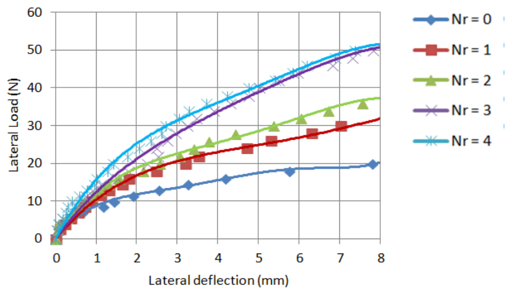

Fig. 2: Load Deflection Curve for Long Pile at b=2.5D and θ=0°

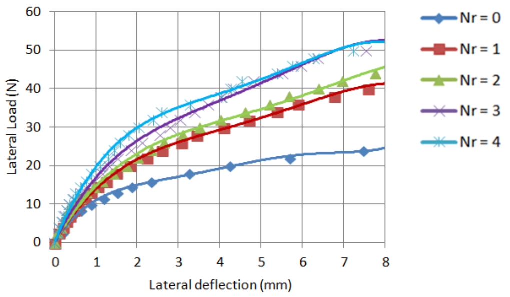

Fig. 3: Load Deflection Curve for Long Pile at b=5D and θ=0°

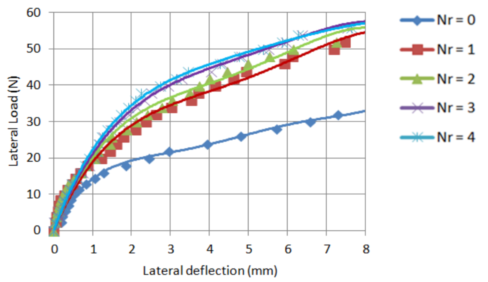

Fig. 4: Load Deflection Curve for Long Pile at b=7.5D and θ=0°

3.1.2 Load Deflection Behavior of Long Pile with Inclined Load(15°)

The tests were conducted on long pile of length 20 cm (L/D = 20) on prepared unreinforced slope and reinforced slope. Number of geogrid layers (N_r) was varied as 1, 2, 3, 4. The angle of loading direction was kept to be 15° and pile location is varied as 2.5D, 5D and 7.5D away from the slope crest. The corresponding load deflection curves are shown in Fig. 5, 6 and 7. Ultimate lateral load capacities determined from these curves are tabulated in Table 3.

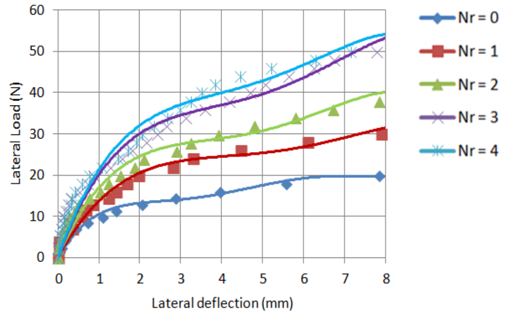

Fig. 5: Load Deflection Curve for Long Pile at b=2.5D and θ=15°

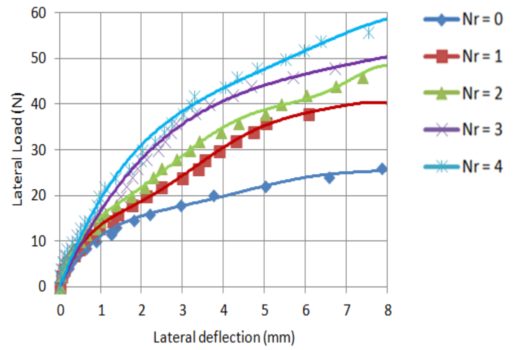

Fig. 6: Load Deflection Curve for Long Pile at b=5D and θ=15°

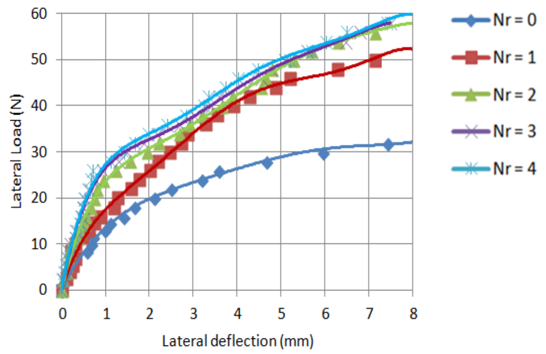

Fig. 7: Load Deflection Curve for Long Pile at b=7.5D and θ=15°

3.1.3 Load Deflection Behavior of Long Pile with Inclined Load(30°)

The tests were conducted on long pile of length 20 cm (L/D = 20) on prepared unreinforced slope and reinforced slope. Number of geogrid layers (N_r) was varied as 1, 2, 3, 4. The angle of loading direction was kept to be 30° and pile location is varied as 2.5D, 5D and 7.5D away from the slope crest. The corresponding load deflection curves are shown in Fig. 8, 9 and 10. Ultimate lateral load capacities determined from these curves are tabulated in Table 3.

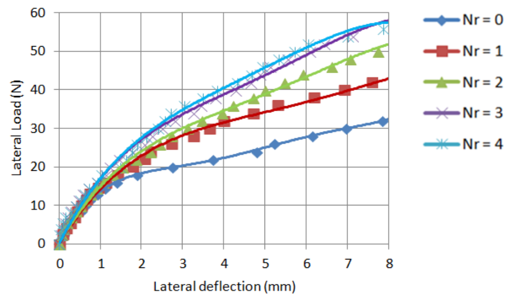

Fig. 8: Load Deflection Curve for Long Pile at b=2.5D and θ=30°

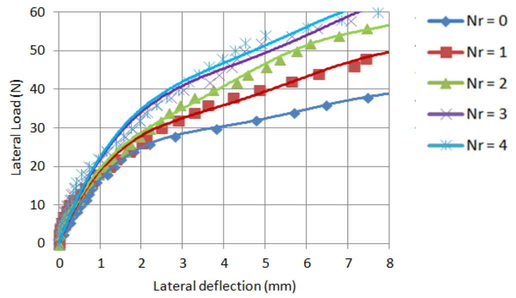

Fig. 9: Load Deflection Curve for Long Pile at b=5D and θ=30°

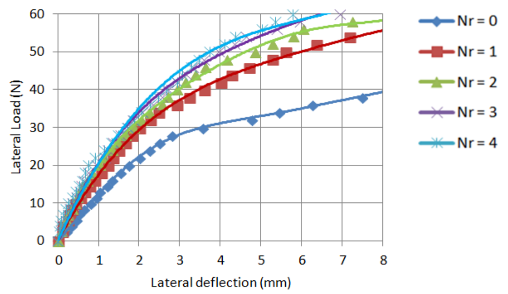

Fig. 10: Load Deflection Curve for Long Pile at b=7.5D and θ=30°

Table 3: Ultimate Lateral Load of Long Pile(N)

Crest Distance	N=0	N=1	N=2	N=3	N=4
For 0° Inclination					
2.5D	17.5	25.5	28	40	41
5D	22	33	35	42	43
7.5D	27.5	42	46	48	48
For 15° Inclination					
2.5D	19	27	32	43	44
5D	23	36	37.5	46	48
7.5D	29.5	45	49	49.5	50
For 30° Inclination					
2.5D	24	34	40	45	46.5
5D	32	39.5	46	50	52
7.5D	36	48	52	55	57

3.2 Load Deflection Behavior of Short Pile

3.2.1 Load Deflection Behavior of Short Pile with Lateral Load

The tests were conducted on Short pile of length 10 cm (L/D = 10) on prepared unreinforced slope and reinforced slope. Number of geogrid layers (N_r) was varied as 1, 2, 3, 4. The angle of loading direction was kept to be 0° and pile location is varied as 2.5D, 5D and 7.5D away from the slope crest. The corresponding load deflection curves are shown in Fig. 10, 11 and 12. Ultimate lateral load capacities determined from these curves are tabulated in Table 4.

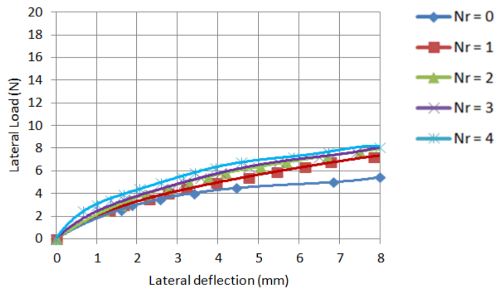

Fig. 11: Load Deflection Curve for Short Pile at b=2.5D and θ=0°

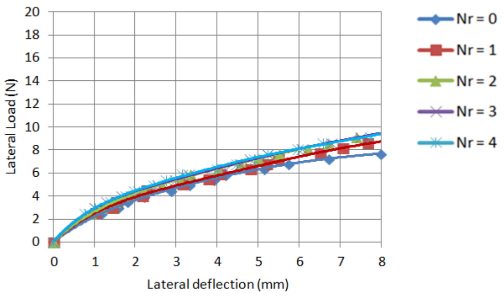

Fig. 12: Load Deflection Curve for Short Pile at b=5D and θ=0°

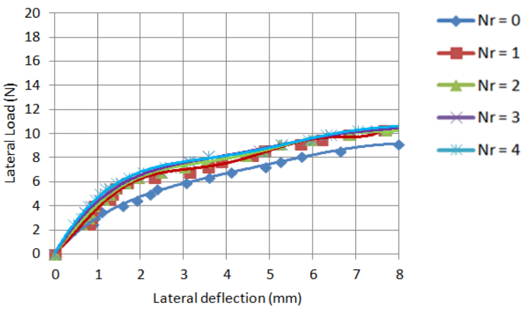

Fig. 13: Load Deflection Curve for Short Pile at b=7.5D and θ=0°

3.2.2 Load Deflection Behavior of Short Pile with Inclined Load (15°)

The tests were conducted on Short pile of length 10 cm (L/D = 10) on prepared unreinforced slope and reinforced slope. Number of geogrid layers (N_r) was varied as 1, 2, 3, 4. The angle of loading direction was kept to be 15° and pile location is varied as 2.5D, 5D and 7.5D away from the slope crest. The corresponding load deflection curves are shown in Fig. 14, 15 and 16. Ultimate lateral load capacities determined from these curves are tabulated in Table 4.

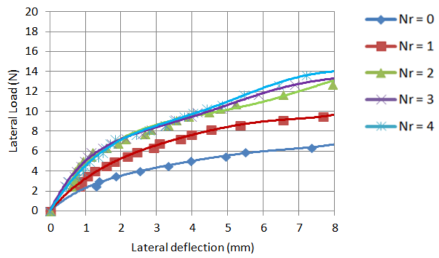

Fig. 14: Load Deflection Curve for Short Pile at b=2.5D and θ=15°

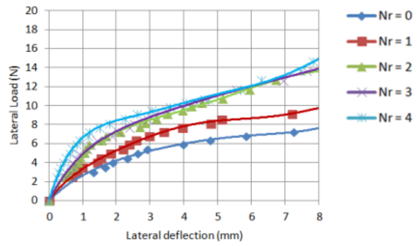

Fig. 15: Load Deflection Curve for Short Pile at b=5D and θ=15°

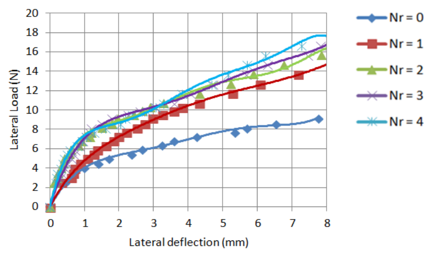

Fig. 16: Load Deflection Curve for Short Pile at b=7.5D and θ=15°

3.2.3 Load Deflection Behavior of Short Pile with Inclined Load (30°)

The tests were conducted on Short pile of length 10 cm (L/D = 10) on prepared unreinforced slope and reinforced slope. Number of geogrid layers (N_r) was varied as 1, 2, 3, 4. The angle of loading direction was kept to be 30° and pile location is varied as 2.5D, 5D and 7.5D away from the slope crest. The corresponding load deflection curves are shown in Fig. 17, 18 and 19. Ultimate lateral load capacities determined from these curves are tabulated in Table 4.

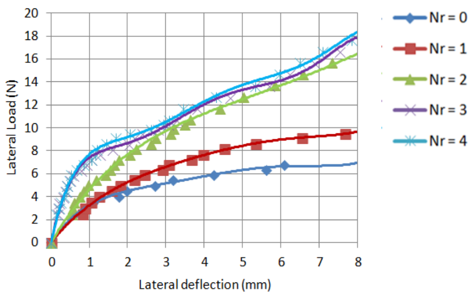

Fig. 17: Load Deflection Curve for Short Pile at b=2.5D and θ=30°

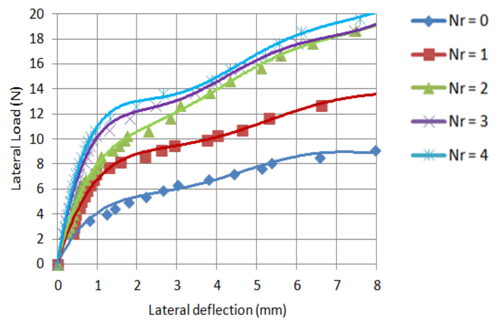

Fig. 18: Load Deflection Curve for Short Pile at b=5D and θ=30°

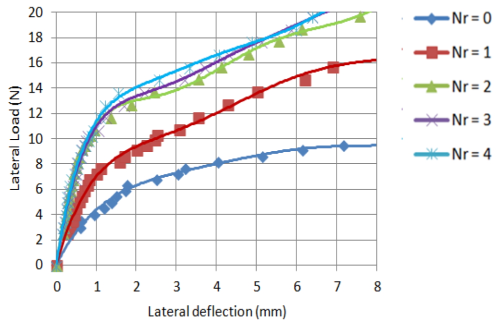

Fig. 19: Load Deflection Curve for Short Pile at b=7.5D and θ=30°

Table 4 : Ultimate Lateral Load of Short Pile

Crest Distance	N=0	N=1	N=2	N=3	N=4
For 0° Inclination					
2.5D	4.8	5.6	6.3	6.4	6.4
5D	6.2	6.7	7.25	7.3	7.4
7.5D	7.5	8.7	8.8	8.9	9.0
For 15° Inclination					
2.5D	5.5	7	10.2	10.4	10.5
5D	6.5	8.4	10.5	10.8	11.0
7.5D	7.7	11.2	12.5	12.8	13
For 30° Inclination					
2.5D	6.3	8.1	12.7	13	13.5
5D	7.6	11	15.5	16.3	16.8
7.5D	8.5	13.7	17.0	17.2	17.4

IV. DISCUSSION

The model tests results obtained from laboratory tests are analyzed and discussed in this section. The ultimate lateral load was selected for 5mm pile head deflection. In this work, loading was continued till the pile deflection reached 8 mm. In this laboratory study, the influence of pile resting on reinforced and unreinforced slope was investigated for different piles(short pile and long pile), number of reinforcement layers, pile placement away from the slope and loading direction. The ultimate lateral load was determined from load deflection curve. The effect of various parameters are discussed in this section.

4.1 Effect of Number of Geogrid Layers

It is seen that there is increase in ULL with increasing the number of geogrid layers. However, in case of short piles, the increase in ULL is marginal for no. of geogrid layer greater than 2. Wherever in case of long piles, the increase is marginal for geogrid layer greater than 3. Thus, optimum no. of geogrid reinforcing layer may be considered as 2 for short pile and 3 for long piles. The max. percentage increase in ULL obtained is **104%** for optimum number of geogrid layer (N_r = 2) for short pile and **129%** for optimum number of geogrid layer (N_r = 3) for long pile.

4.2 Effect of Crest Distance

From the results of experimental investigation, it is seen that the ULL significantly increases with the increasing the crest distance. The figures clearly indicate that there is no optimum crest distance. The max. percentage increase in ULL obtained is **69%** for short pile, and **67%** for long pile when pile is placed at crest distance, b = 7.5D.

4.3 Effect of Angle of Inclination Load

From the results of experimental investigation, the ULL improvement is observed with the increase in the angle of loading from 0° to 30°. The max. percentage increase for short pile in ULL obtained is **64 %** for (15°) and **127% for** (30°). The max. percentage increase for long pile in ULL obtained is **14%** for (15°) and **43 %** for (30°).

V. CONCLUSION

This report has presented experimental results of laboratory lateral load test on piles in slope, to investigate the load deflection behavior of the pile, corresponding to various parameter. From the results of this study, the following broad conclusions are drawn:

1) Reinforcing the earth slope using geogrid has a significant effect on improving the ULL (Ultimate Lateral Load) of single pile located near the slope crest.
2) The improvement in ULL is dependent on the location of pile, the embedded length of pile and number of geogrid layers.
3) For short pile, two layers of geogrid reinforcement are found optimum and for long pile three layers of geogrid reinforcement are found optimum.
4) The max. percentage increase in ULL is **104%** for optimum number of geogrid layer (N=2) for short pile and **129%** for optimum number of geogrid layer (N=3) for long pile.
5) The ULL increases as the crest distance increases.

6) The max. percentage increase in ULL is **69%** for short pile and **67%** for long pile, when pile is placed at crest distance, b=7.5D.
7) The ULL improves with the increase in inclination angle of loading from 0° to 30°.
8) The max. percentage increase in ULL for short pile for 15° inclination is **64%** and for 30° inclination is **127%**. The max. percentage increase in ULL for long pile for 15° inclination is **14%** and for 30° inclination is **43%**.

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