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Performance of Strip Footing on Slope Stabilized with Inclined Piles and Sheet Piles

A. I. Dhatrak[1], S. S. Somwanshi[2], S. W. Thakare [3]
[1]*Dean Academics, Department of Civil Engineering, Government College of Engineering, Amravati, Maharashtra, India*
[2]*PG Scholar, Department of Civil Engineering, Government College of Engineering, Amravati, Maharashtra, India*
[3]*Associate Professor, Department of Civil Engineering, Government College of Engineering, Amravati, Maharashtra, India*

Abstract: This paper is the study of effect of inclusion of inclined piles and sheet piles along the slope on performance of strip footing placed near slope crest. The parameters such as number of rows of inclined piles/sheet piles, angle of inclination of piles with vertical and location of inclined piles/sheet piles rows are varied. Length of piles, diameter of piles, height of sheet piles, thickness of sheet piles and setback distance of strip footing from slope crest were kept constant. This is the extension of work done on number of rows of vertical piles at various locations, which is previously published. The model plate load tests were carried out on stabilized and unstabilized sand slopes and the results obtained were then analyzed to study the effect of each varied parameter. The study revealed that provision of rows of inclined piles have a significant effect on bearing capacity of strip footing. This increase was only observed in case of two and three rows of inclined piles. Inclusion of sheet piles rows also enhances the performance of strip footing. The bearing capacity increases as the number of rows of inclined piles/sheet piles increases. This improvement in bearing capacity was observed when sheet pile rows were placed near the slope crest.
Keywords- BCR, Bearing Capacity, Inclined piles, Sheet piles, Slope stabilization.

I. INTRODUCTION

In many situations engineers are forced to construct footings on sloping surfaces like hills, such as footings for bridge abutments. This results in decrease in bearing capacity of footing, depending on the location of the footing with respect to the slope crest. Therefore, shallow foundations are avoided, and if it is not possible then provision to stabilize the slope has to be done.

Stability of slope can be increased by using various solutions such as injection of bacterial solutions in soil, soil reinforcement, or installation of continuous or discrete walls. These type of solution not only increases the bearing capacity of footing but also affects the settlement of footing. An often used method of in-situ reinforcement has been the use of piles to stabilize slopes. Use of inclined piles and sheet piles for stabilizing slopes is another approach. In case of stabilizing inclined piles or sheet piles these goals are achieved by the lateral resistance provided by sheet piles against the movement of soil mass.

Most of the previous studies were concentrated on the analysis of slope stability itself or slope stabilized with vertical piles only, very few literature is available for experimental work on slope stabilizing sheet piles and none for inclined piles. Therefore, this study aims to study the changes in bearing capacity of strip footing placed near slope crest stabilized with number of rows of inclined piles and sheet piles. The main objective is to determine the optimum angle of inclination of piles with vertical and the optimum location of rows of sheet piles along the slope. The inclined piles were inserted at the optimum locations for one, two and three rows which was referred from study of A. I. Dhatrak (2017). Number of model plate load tests were carried out for different combinations of varying parameters and the results obtained are presented and discussed below.

II. LITERATURE REVIEW

A. Experimental Studies of Pile Stabilized Slopes

A. Dhatrak *et al.* (2017) studied the performance of strip footing on slope stabilized with piles. The parameters varied were number of rows of piles and locations of piles. They concluded that for single row of piles optimum location was at slope crest. For two rows of piles provided for reinforcing the slope, the optimum location for the first row of piles is at distance of 0.25 times the horizontal projection of slope from the crest and for the second row of piles is at a spacing of 0.25 times the horizontal projection of slope from the first row of piles along the slope. For three rows of piles provided for reinforcing the slope, the optimum location for the first row of piles is at a distance of 0.25 times the horizontal projection of slope from crest and second and third rows of piles at spacing of 0.25 times the horizontal projection of slope and 0.5 times the horizontal projection of slope respectively from first row

of piles along the slope.
A. Mostafa *et al.* (2005) studied the behaviour of strip footing on pile and sheet pile stabilized sand slope. The parameters studied were pile diameter, pile length, ratio of c/c spacing and footing width, pile diameter footing width, height of sheet pile, location of sheet pile, ratio of length to width of pile. It was observed that the bearing capacity was found maximum when pile spacing was minimum and pile length was maximum. The pile spacing had greater significance than pile length or diameter. The optimal location of pile for maximum bearing capacity ratio was pile crest. However sheet pile stabilized slope shows better results as compared to pile stabilized slope.
L.Wang *et al.* (2013) conducted centrifuge testing and observed the behaviour of pile in cohesive soil slopes with varying inclination of slope, pile distance from crest and pile end as fixed and free. They observed that the stability level of the slope was increased by compression and shear effect provided by pile.
P. Induja *et al.* (2015) studied the effectiveness of providing micropile as foundation support to resist dynamic loads. The parameters varied were footing edge distance from crest, micropile depth and slope inclination. Coefficient of elastic uniform compression (Cu) was determined from cyclic load test conducted and it was found that the value of Cu for reinforced case shows an increase by about 2.5 times that of the value obtained for unreinforced case indicating an increase in stiffness of soil. They also concluded that it is safe to place the footing at a setback distance of two times the width of the footing for safe behaviour.

B. Numerical Studies on Pile Stabilized Slopes

R. Rowe *et al.* (1979) proposed a finite element technique for the analysis of undrained behaviour of soil slopes reinforced by pile groups by varying the pile boundary conditions and concluded that the best arrangement is when there is no lateral displacement at top and bottom end is pinned.
F. Cai *et al.* (2000) analysed the slope reinforced with piles using the finite element method with varying parameters such as ratio of centre to centre distance between piles to that of diameter of pile (0-8), ratio of distance of pile from toe to that of slope length (0-l) and pile head conditions as free, hinged, unrotated and fixed. It was concluded that the maximum safety factor for the slope can be achieved when the piles are located in the middle of the slope and the pile head restrained.
S. Jeong *et al.* (2003) proposed a simplified numerical approach for analysing the slope/pile system subjected to lateral soil movements with varying parameters such as ratio of spacing to diameter of pile (0-8), ratio of distance of pile from toe to that of slope length (0-1) and pile head conditions as free, hinged, unrotated and fixed. It was concluded that the pile top should be restrained when piles are used to stabilize the slopes.
J. Won *et al.* (2005) presented the numerical comparison of predictions by limit equilibrium analysis and 3D numerical analysis for a slope pile system with varying parameters such as ratio of spacing to diameter of pile (2-4.5), ratio of distance of pile from toe to that of slope length (0-l) and pile head conditions as free and fixed. They concluded that for stability to be improved optimally, the piles should be installed in the middle of the slope and with restrained pile head and should have optimum S/D ratio as 2.5.
W. Wei *et al.* (2009) analysed the slope reinforced with one row of pile with varying parameters such as spacing between piles (2D-8D), pile location from toe, critical slip surface through different section. It was concluded that when spacing is low. The critical slip surface is shallow and divided into two parts and optimum location is middle of the slope with pile and middle of the critical slip surface with no pile.
S. Yang *et al.* (2011) studied the effect of embedded length of piles for slope reinforced with piles by varying parameters such as pile head condition viz. free, fixed, hinged and nonrotated head, embedded pile length (5-20) m, spacing (2D-6D). It was concluded that a restrained (fixed or hinged) pile head is recommended and free head should be avoided to stabilize the slope.
D. Mujah *et al.* (2013) analysed the multi-row arrangement of small diameter steel piles for landslide prevention using PLAXIS 2D software. The parameters considered as ratio of spacing to diameter of pile (0-8), density of soil (30%-80%). pile size (3-l 0) mm and pile end as hinged and free. It was concluded that greater amount of earth pressure is yielded in a denser ground condition and resistance to both lateral and axial forces is significantly enhanced by small diameter steel piles. The materials EI value plays a significant role in ensuring the overall reinforcement capacity of pile.
S. Pusadkar *et al.* (2015) studied the performance of slope reinforced with piles using PLAXIS 2D. The parameters studied were width of footing, width of load, location of pile from crest, no. of rows of pile, inclination of piles and inclination of load. They concluded that for single row of pile the best pile location was at crest of slope. For two rows of pile the best location was, one pile at crest and other pile at 0.4 times horizontal projection of slope. For three rows of piles the best location was, one pile at crest, one at 0.4 and other at 0.8 times the horizontal projection of slope. Also, for two and three rows of piles inclination of 20^0 is most

effective.

C. Analytical Studies of Pile Stabilized Slopes

T. Ito *et al.* (1981) analysed the stabilizing piles against landslide using one row of piles with varying parameters as ratio of clear distance between piles to the centre to centre distance between them (0.4-0.9), pile head as free. hinged, unrotated and fixed, diameter of pile (0.6- 1.0). It was concluded that safety factor of the pile stability decreases with increase in pile length while safety factor for slope stability increases. The improvement in the safety factor for pile and slope stability with rnulti-row to single row, pile was observed.

H. Poulos *et al.* (1995) described an approach for the design of piles to reinforce slope by varying pile lengths, spacing between piles. He demonstrated that centre to centre spacing required typically ranges between 2 to 4 times the diameters.

E. Ausilio *et al.* (2001) proposed a approach of limit analysis to analyse the stability of earth slopes reinforced with piles by varying the slope angle. The results concluded that optimal location of piles within the slope was near the toe of the slope.

M. Ashour *et al.* (2011) analysed the slopes based on soil-pile interaction with effect of ratio of distance of pile from toe to that of slope length (0.2-1.0) & Spacing to diameter ratio (1-5). The results showed that the position of the pile into the slope, the depth of the failure surface at the pile position, soil type, pile diameter and pile spacing have a combined effect on the maximum driving force that the pile can transfer down to the stable soil.

III. EXPERIMENTAL SET UP

A. Test Set Up

To study the load settlement characteristics of the footings for various parameters, the plate load tests were conducted. The laboratory set-up consisted of a tank, a reaction frame, a model footing, and screw jack, proving ring, dial gauges and model sheet piles as reinforcement.

For the model tests, cohesion-less, dry, clean and washed Kanhan sand was used as a filling material for slope. The particle size of sand used for the test was passing through 2 mm IS sieve and retaining on 1 mm IS sieve. The strip footing with dimension 80 mm x 580 mm and 10 mm thick was used. Footing had a little groove at the centre to facilitate the application of load. The model piles of the circular section were fabricated by using mild steel rods of diameter 6.0 mm and length 120 mm. The sheet piles were 1.0 mm in thickness and made of aluminium with 120 mm height. Total 3 number of sheet piles were used.

he test tank used for experimental investigation was made of 3 mm thick mild steel sheet having dimensions 1000mm x 600mm in plan and 650mm high. The minimum tank size required is 5 times the width or breadth of footing whichever is more. The bulging effect counteracts by providing sufficient horizontal and vertical bracings at sufficient intervals. The load was applied on the model footing with the help of a 25 Ton capacity screw jack. The screw jack was fixed at the centre of horizontal member of reaction frame. For laboratory plate load test, proving ring of 50 kN capacity was used. All the constant parameters are tabulated in Table I and varying parameters for inclined piles and sheet piles are tabulated in Table II and III respectively.

B. Slope Preparation and Inclined Piles/Sheet Pile Insertion

In the present experimental investigations, the relative density of sand slope was maintained by using sand rainfall technique. The height of fall to achieve the desire relative density was determined as a priory by performing a series of trials with different height of fall. In the present investigation the height of fall was selected as 40 cm in rainfall technique and the corresponding relative density was maintained at 40% and corresponding density was 16.56 kN/m^3. The height of slope was maintained as 360 mm. Slope was prepared in layers of 5 cm and face of slope was smoothened with trowel to obtain the slope of 1:1.5 (V:H). Geometric parameters of inclined piles and sheet piles are shown in Fig. 1 and 2 respectively.

Once the setup of sand slope was completed, a row of model piles was installed using an assembly of steel plates which held the piles in required inclinations during the installation. The guide system was initially placed in the tank on the slope coinciding accurately with the markings of inclinations on tank and then the piles were pushed manually at the predecided location and inclinations along the slope with required spacing. The spacing of piles was kept constant as 80 mm centre to centre of piles. A row of model sheet piles was installed by displacement method by pushing the sheet pile vertically manually at desired locations. No visible movement in the sand slope was observed during the installation process. The difference in the relative density of the sand, which occurs during inclined piles/sheet piles installation due to the difference in the pile length and sheet pile height, was considered to be small and neglected.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

TABLE I.
DETAILS OF CONSTANT PARAMETERS

Sr. No.	Constant Parameter	Value
1	Diameter of Pile (D)	6 mm
2	Length of Pile (L)	120 mm
3	c/c Spacing of Pile (s)	80 mm (1B)
4	Thickness of Sheet Pile	1 mm
5	Height of Sheet Pile (h)	120 mm
6	Width of footing (B)	80 mm
7	Slope Inclination	1:1.5
8	Height of slope (H)	360 mm.
9	Setback Distance (b)	160 mm (2B)

TABLE II.
DETAILS OF VARYING PARAMETERS FOR INCLINED PILES

Sr. No.	Varying Parameter	Value
1	Location of Pile from crest (d)	
	i. For 1 Row	0X,
	ii. For 2 Rows	0.25X & 0.5X,
	iii. For 3 Rows	0.25X & 0.5X & 0.75X,
2	No of row	1, 2, 3.
3	Inclination of pile	0, 10^o, 20^o, 30^o

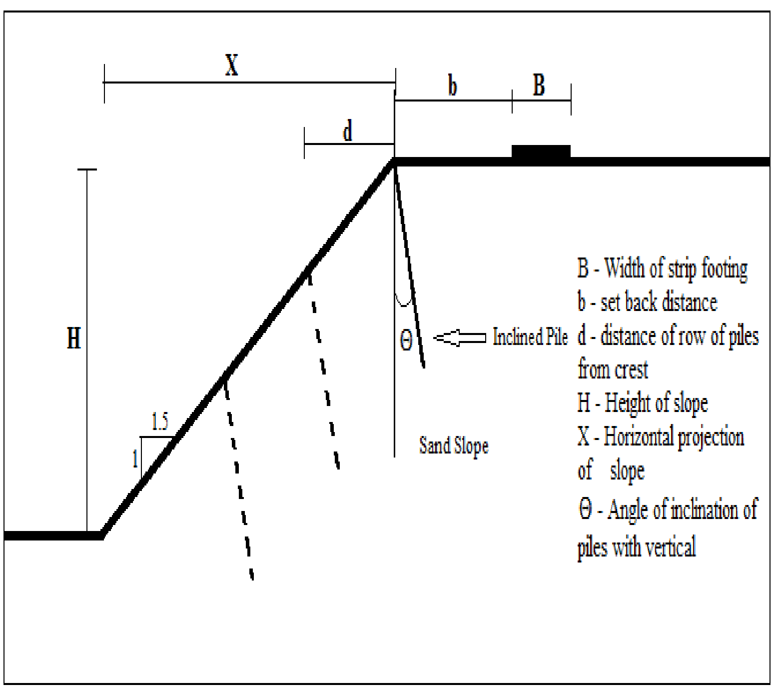

Fig. 1 Geometric parameters of inclined pile -stabilized sand slope model

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

TABLE III.
DETAILS OF VARYING PARAMETERS FOR SHEET PILE

Sr. No.	**Varying Parameter**	**Value**
1	Location of Sheet Pile from crest (d)	
	i. For 1 Row	0X, 0.25X, 0.5X, 0.75X, 1X
	ii. For 2 Rows	0X & 0.25X, 0.25X & 0.5X, 0.5X & 0.75X, 0.75X & 1X
	iii. For 3 Rows	0X & 0.25X & 0.5X, 0.25X & 0.5X & 0.75X, 0.5X & 0.75X & 1X

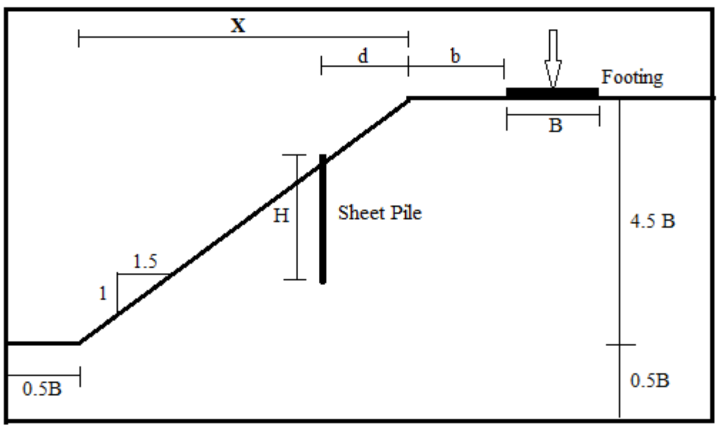

Fig. 2 Geometric parameters of sheet pile -stabilized sand slope model

C. Laboratory plate load test

For the experimental investigations, the model plate load tests were conducted in accordance with IS: 1888-1982 to evaluate the bearing capacity and settlement. The tests were performed on stabilized sand slope as per following procedure.

1) The test sand slope was prepared as discussed above. The footing was placed carefully without disturbing the sand slope at distance 2B from crest.
2) The dial gauges were carefully placed on model strip footing. The loading unit was then lowered through proving ring so that the bottom plunger attached to the proving ring just touches the centre groove on the footing.
3) The load was then applied on footing in increments. Each load increment was approximately equal to one fifth of the ultimate bearing capacity of the strip footing. The final dial gauge readings were noted when the rate of settlement became less than 0.02 mm/hour.
4) After the failure occurred, the load on the footing was released. The footing and piles were removed and the test sand slope was again prepared and next tests were then performed.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

A. Load Settlement Behaviour of Strip Footing on Unstabilized Slope

The sand slope was prepared and model plate load tests were conducted on model strip footing of size 580 mm x 80 mm on prepared unreinforced sand slope. The load settlement curve for unreinforced slope is shown in Fig. 3.

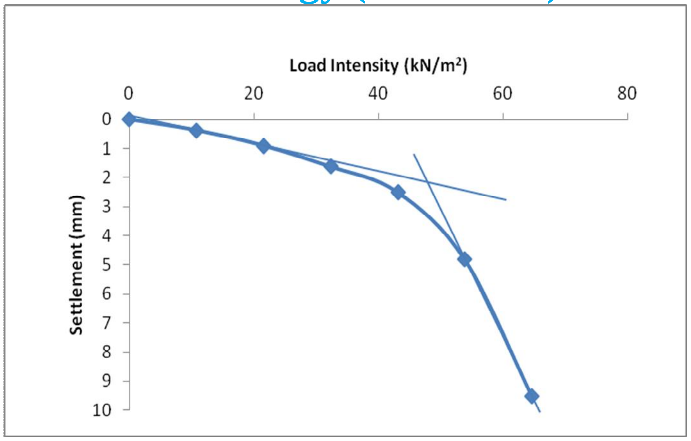

Fig. 3 Load settlement curve for strip footing on unreinforced slope

The ultimate bearing capacity for unreinforced slope was found to be 47.0 kN/m^2.

B. Load Settlement Behaviour of Strip Footing on Slope Stabilized with Rows of Inclined Piles

For optimum locations of rows of vertical piles obtained from tests carried out; the model plate load tests were carried out on strip footing on slope stabilized with rows of inclined piles. The pile inclination was varied from 0 to 30 degree with vertical to study the effect of inclined pile on performance of strip footing on slope.

1) For single row of inclined piles at optimum location: The single row of piles was inserted at an inclination of 10^o, 20^o, 30^o at optimum location of single pile row i.e. 0*X* which was obtained from previous tests. Tests were carried out to study effect of piles inclined at 10^o, 20^o, 30^o on bearing capacity improvement of strip footing. The load settlement curves for the tests with single rows of piles inclined at 0, 10^o, 20^o and 30^o with vertical are shown in Fig. 4.

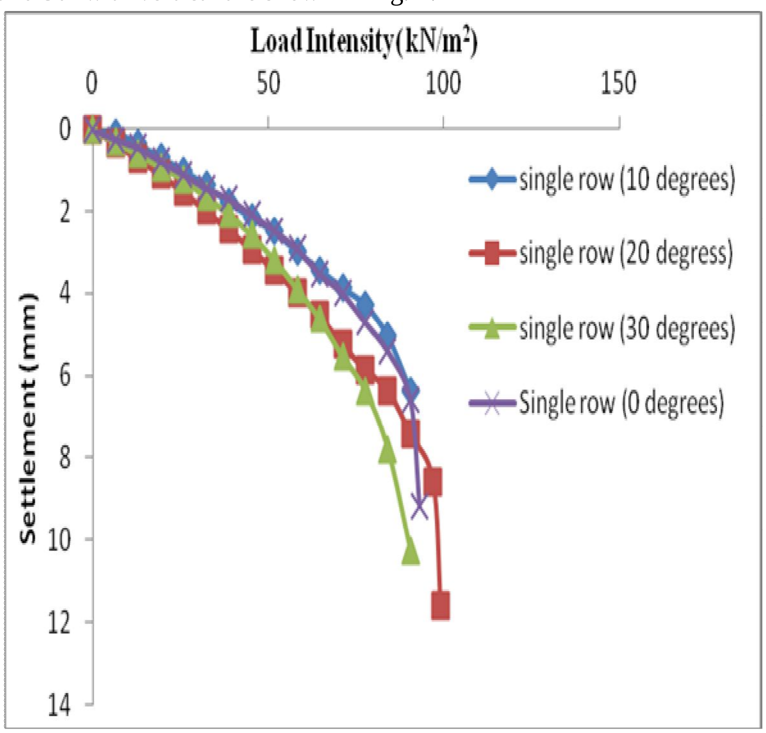

Fig. 4 Load Settlement Curves for Strip Footing Corresponding to Various Inclinations of Single Row of Inclined Piles

The Fig. 4, shows variations of BCR with pile inclination for single row of inclined piles at various inclinations.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

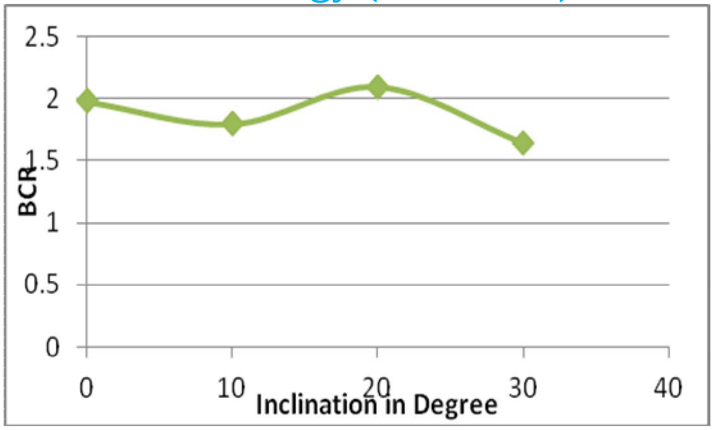

Fig. 5 Variations of BCR with Pile Inclination for Single Row of Inclined Piles (Inclination- 10^o, 20^o, 30^o)

The corresponding values of UBC and the values of bearing capacity ratio for inclination of 0^o, 10^o, 20^o and 30^o are tabulated in Table IV.

TABLE IV.
BCR AT VARIOUS LOCATIONS FROM CREST FOR SINGLE ROW OF INCLINED PILES

Sr. No.	Inclination in degree	UBC (kN/m^2)	BCR
1	0	93.5	1.98
2	10	85	1.8
3	20	99	2.1
4	30	77.5	1.65

From Fig. 5 it is observed that, there is no increase in bearing capacity of strip footing after inserting the piles at an inclination of 10^o and 30^o. In fact bearing capacity of footing is decreased. Thus provision of inclined single pile row is not suitable.

2) For Two rows of inclined piles at optimum location: Two rows of piles were inserted at an inclination of 10^o, 20^o and 30^o at optimum location of pile rows i.e. first row of piles was placed at 0.25X from crest and second pile row placed at a spacing of 0.25X from first row of piles which was obtained from previous tests and tests were carried out to study effect of pile inclination on bearing capacity improvement of strip footing. The load settlement curves for the tests with two rows of piles inclined at 0, 10^o, 20^o and 30^o with vertical are shown Fig. 6.

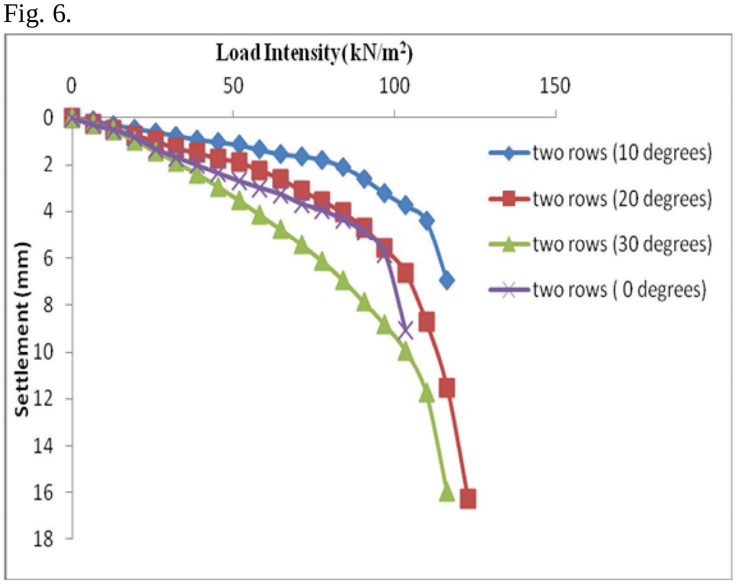

Fig. 6 Load Settlement Curves for Strip Footing Corresponding to Various Inclinations of Two Rows of Inclined Piles

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The values of UBC and bearing capacity ratio for inclination of 0°, 10°, 20° and 30° are tabulated in Table V.

TABLE V.
BCR AT VARIOUS LOCATIONS FROM CREST FOR TWO ROWS OF INCLINED PILES

Sr. No.	Inclination (degrees)	UBC (kN/m^2)	BCR
1	0	102	2.17
2	10	108	2.29
3	20	120	2.55
4	30	101	2.14

The Fig. 7, shows variations of BCR with pile inclination for two rows of inclined piles at various inclinations.

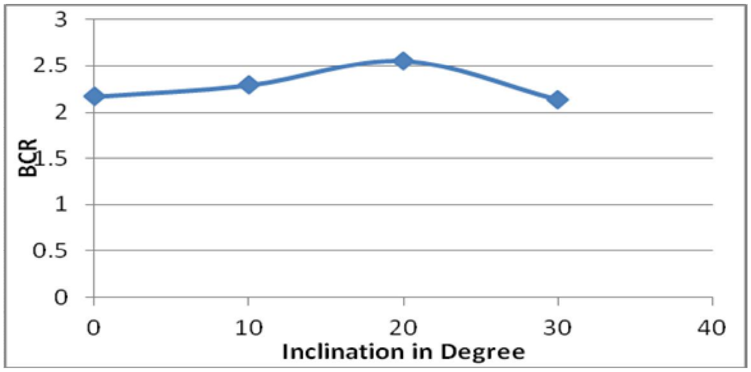

Fig. 7 Variations of BCR for Two Rows of Inclined Piles (Inclination- 10°,20°, 30°)

From Fig. 7 it can be seen that, there is increase in bearing capacity of strip footing up to 20° inclination and after that the bearing capacity decreases. BCR ratio for footing is maximum at 20° for two rows of piles. Thus, two rows of piles inclined at 20° at optimum location are suitable.

3) For Three rows of inclined piles at optimum location: Three rows of piles were inserted at an inclination of 10°, 20° and 30° at optimum location of pile rows i.e. first row at 0.25*X* and second and third rows at a spacing of 0.25*X* and 0.5*X* respectively from first row of piles which was obtained from previous tests and tests were carried out to study effect of pile inclination on bearing capacity improvement of strip footing. The load settlement curves for the tests with three rows of piles inclined at 0, 10°, 20° and 30° with vertical are shown Fig. 8.

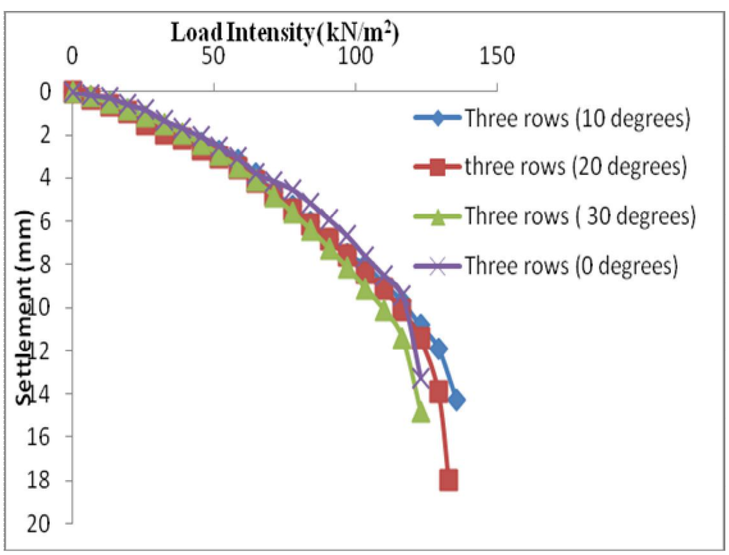

Fig. 8 Load Settlement Curves for Strip Footing Corresponding to Various Inclinations of Three Rows of Inclined Piles

Fig. 9, shows the variations of BCR with various inclinations of pile rows for three rows of inclined piles.

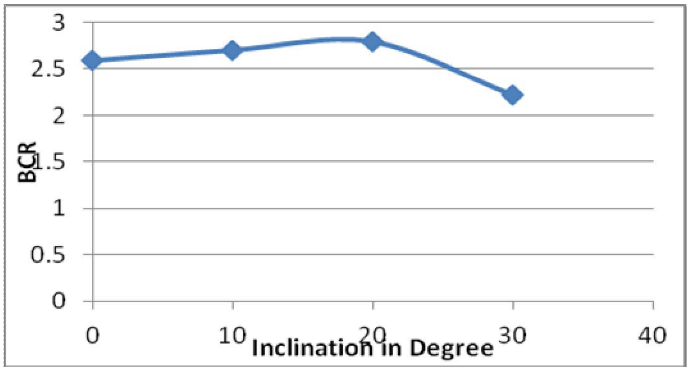

Fig. 9 Variations of BCR with Inclination of Piles for Three Rows of Inclined Piles (Inclination- 10^o,20^o, 30^o)

The corresponding values of UBC and the values of bearing capacity ratio for inclination of 0^o, 10^o, 20^o and 30^o are tabulated in Table VI.

TABLE VI.
BCR AT VARIOUS LOCATIONS FROM CREST FOR THREE ROWS OF INCLINED PILES

Sr. No.	Inclination (degrees)	UBC (kN/m^2)	BCR
1	0	122	2.59
2	10	127	2.7
3	20	131	2.79
4	30	104.5	2.22

From Fig. 9 it is seen that, there is increase in bearing capacity of strip footing up to 20^o inclination and after that the bearing capacity decreases. BCR ratio for footing is maximum at 20^o for three rows of piles. Thus, three rows of piles inclined at 20^o at optimum location are suitable.

C. Load Settlement Behaviour of Strip Footing on Slope Stabilized with Rows of Sheet Piles

For understanding the behavior of strip footing on slope stabilized with sheet piles 12 tests were carried out. The results are discussed below.

1) Load Settlement Behaviour of Strip Footing on Slope Stabilized with One Row of Sheet Pile

A single row of sheet pile was placed at various distances viz., 0*X*, 0.25*X*, 0.5*X*, 0.75*X* and 1*X* along the slope to study the effect of location of sheet pile row on improvement in bearing capacity of strip footing on slope. The load settlement curve of footing corresponding to various locations of single row of sheet pile are as shown in Fig. 10.

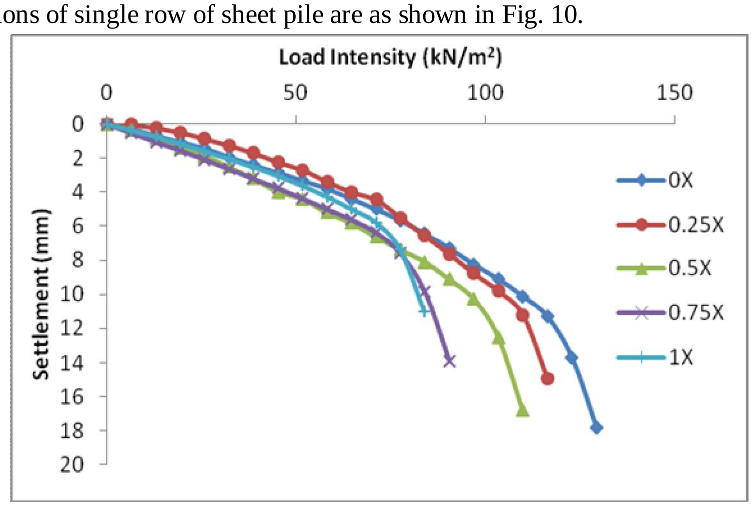

Fig. 10 Load settlement curve for strip footing on slope for various locations of single row of sheet pile

Volume 5 Issue VI, June 2017
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International Journal for Research in Applied Science & Engineering Technology (IJRASET)

The variations of BCR for single row of sheet pile at various sheet pile row location are shown in Fig. 11.

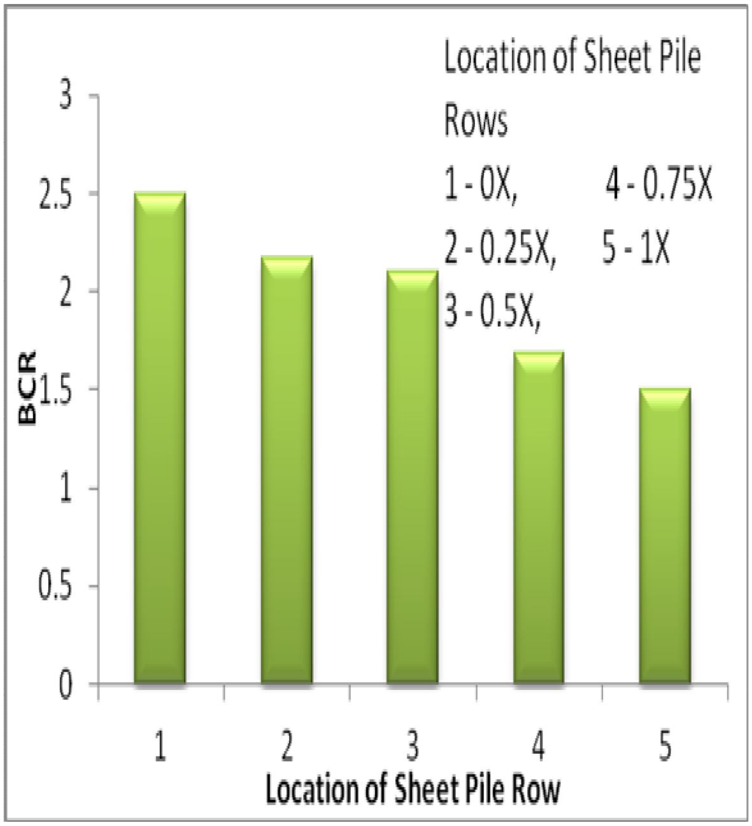

Fig. 11 Variations of BCR with location of sheet pile row for single row of sheet pile

From Fig. 11, the ultimate bearing capacity of strip footing on slope for different locations of single row of sheet pile were determined. The corresponding values of UBC and the values of bearing capacity ratio for various location of single row of sheet pile are tabulated in Table VII.

TABLE VII.
BCR AT VARIOUS LOCATIONS FROM CREST FOR SINGLE ROW OF SHEET PILE

Sr. No.	**Crest Distance of Sheet Pile Row**	**UBC (kN/m^2)**	**BCR**
1	0*X*	117	2.489
2	0.25*X*	102	2.17
3	0.5*X*	99	2.1
4	0.75*X*	79.5	1.69
5	1*X*	73	1.5

It is seen that the sheet pile row placed closer to the slope crest, gives higher bearing capacity with maximum improvement in UBC when the sheet pile row is placed at the crest of slope. Thus, optimum location for single row of sheet piles may be considered at the slope crest.

*2) Load Settlement Behaviour of Strip Footing on Slope Stabilized with Two Rows of Sheet Piles:*Two rows of sheet piles were placed with first row of sheet pile at various crest distances viz., 0*X*, 0.25*X*, 0.5*X*, 0.75*X* and 1*X* along the slope and the second row of sheet piles at a horizontal distance of 0.25*X* from first rows to study the effect of location of sheet piles rows on improvement in bearing capacity of strip footing on slope. The load settlement curve of footing corresponding to various locations of two rows of sheet piles are as shown in Fig. 12.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

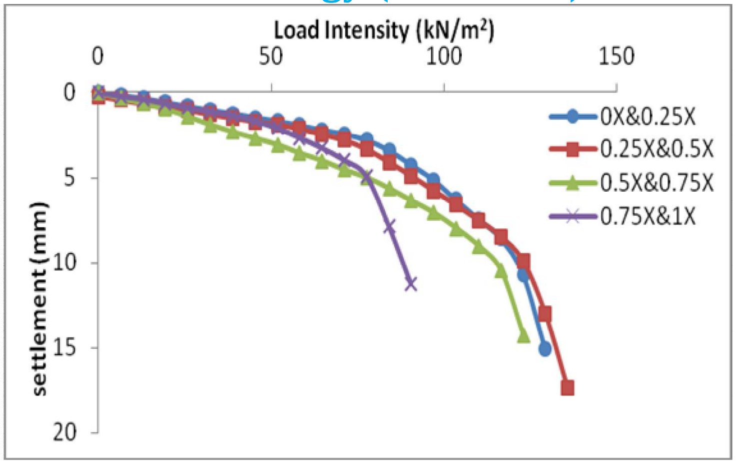

Fig. 12 Load settlement curve for strip footing on slope for various locations of two rows of sheet piles

The variations of BCR for two rows of sheet piles at various sheet pile row location are shown in Fig. 13.

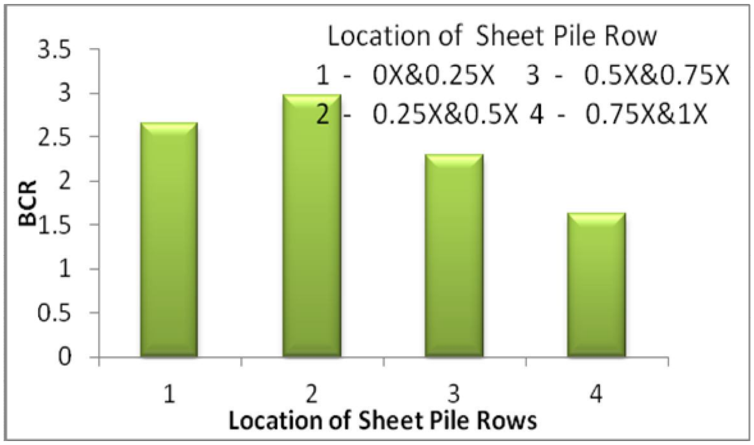

Fig. 13 Variations of BCR location of sheet pile rows for two rows of sheet piles

From Fig. 13, the ultimate bearing capacity of strip footing on slope for different locations of two rows of sheet piles were determined. The corresponding values of UBC and the values of bearing capacity ratio for various location of two rows of sheet piles are tabulated in Table VIII.

TABLE VIII.
BCR AT VARIOUS LOCATIONS FROM CREST FOR TWO ROWS OF SHEET PILE

Sr. No.	Crest Distance of Sheet Pile Rows	UBC (kN/m^2)	BCR
1	0*X* & 0.25*X*	124.5	2.65
2	0.25*X* & 0.5*X*	139.5	2.97
3	0.5*X* & 0.75*X*	108	2.29
4	0.75*X* & 1*X*	76	1.62

From the Fig. 13 it is observed that the optimum location for two rows of sheet piles is 0.25*X* for first row of sheet pile and second row of sheet pile at a spacing of 0.25*X* from first row of sheet pile. It is also seen that the performance of strip footing is better when rows of sheet piles are provided in upper half of the slope as compared to lower half.

3) Load Settlement Behaviour of Strip Footing on Slope Stabilized with Three Rows of Sheet Pile: Three rows of sheet piles were provided with first row of sheet pile at a horizontal distance of 0*X*, 0.25*X*, 0.5*X*, 0.75*X* and 1*X* from the crest and second and third rows of sheet piles at a horizontal distance of 0.25*X* and 0.5*X* from the first row respectively along the slope to study the effect of location of sheet piles rows on improvement in bearing capacity of strip footing on slope. The load settlement curves of footing corresponding to various locations of three rows of sheet piles are as shown in Fig. 14.

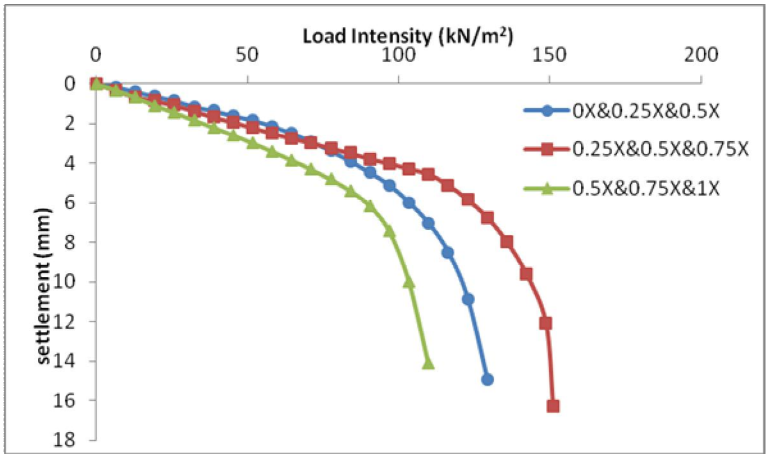

Fig. 14 The Load Settlement Curves for Strip Footing for Various Locations of Three Rows of Sheet Piles

The variations of BCR for three rows of sheet piles at various sheet pile row locations are shown in Fig. 15.

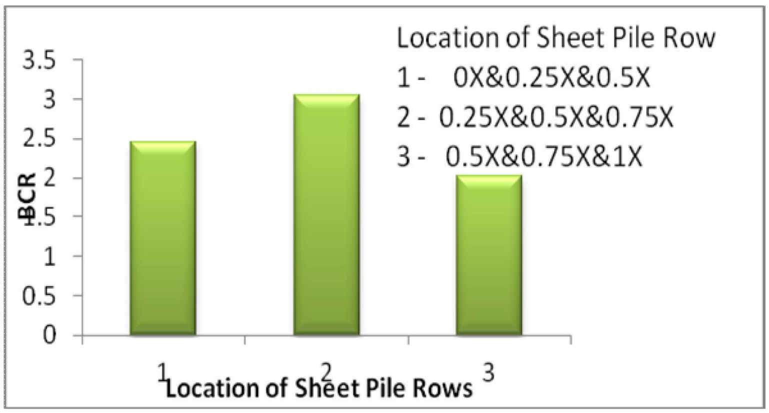

Fig. 15 Variations of BCR with Location of Sheet Pile Rows for Three Rows of Sheet Piles

From Fig. 14, the ultimate bearing capacity of strip footing on slope for different locations of three rows of sheet piles were determined. The corresponding values of UBC and the values of bearing capacity ratio for various location of three rows of sheet piles tabulated in Table IX.

TABLE IX.
BCR AT VARIOUS LOCATIONS FROM CREST FOR THREE ROWS OF SHEET PILE

Sr. No.	**Crest Distance of Sheet Pile Rows**	**UBC (kN/m^2)**	**BCR**
1	0*X* & 0.25*X* & 0.5*X*	115	2.45
2	0.25*X* & 0.5*X* & 0.75*X*	143.5	3.05
3	0.5*X* & 0.75*X* & 1*X*	95	2.02

From the Fig. 15, it is observed that the optimum location for three rows of sheet piles is 0.25*X* from crest for first row of sheet piles with second and third rows at a spacing of 0.25*X* and 0.5*X* respectively from first row of sheet pile.

V. CONCLUSIONS

Based on the experimental results, the following conclusions can be drawn.

A. Pile/Sheet pile reinforced slope shows the better performance as compared to natural slopes.

B. Higher the number of pile/sheet pile rows, better is the performance of strip footing on slope.

C. For sheet pile row the optimum location for reinforcing the slope is at the crest of slope when single row of sheet pile is provided.

D. The optimum sheet pile row locations for two rows of sheet piles provided for reinforcing the slope is when first row of sheet piles is placed at distance of 0.25 times the horizontal projection of slope from crest and second row of sheet piles is at spacing of 0.25 times the horizontal projection of slope from first row of sheet pile along the slope.

E. The optimum sheet pile row locations for three rows of sheet piles is when first row of sheet piles is placed at a distance of 0.25 times the horizontal projection of slope from crest and second and third rows of sheet piles at spacing of 0.25 times the horizontal projection of slope and 0.5 times the horizontal projection of slope respectively from first row of sheet pile along the slope.

F. The provision of single row of inclined piles is not suitable.

G. For two and three rows of inclined piles at the optimum location, inclination of 20^o is most suitable.

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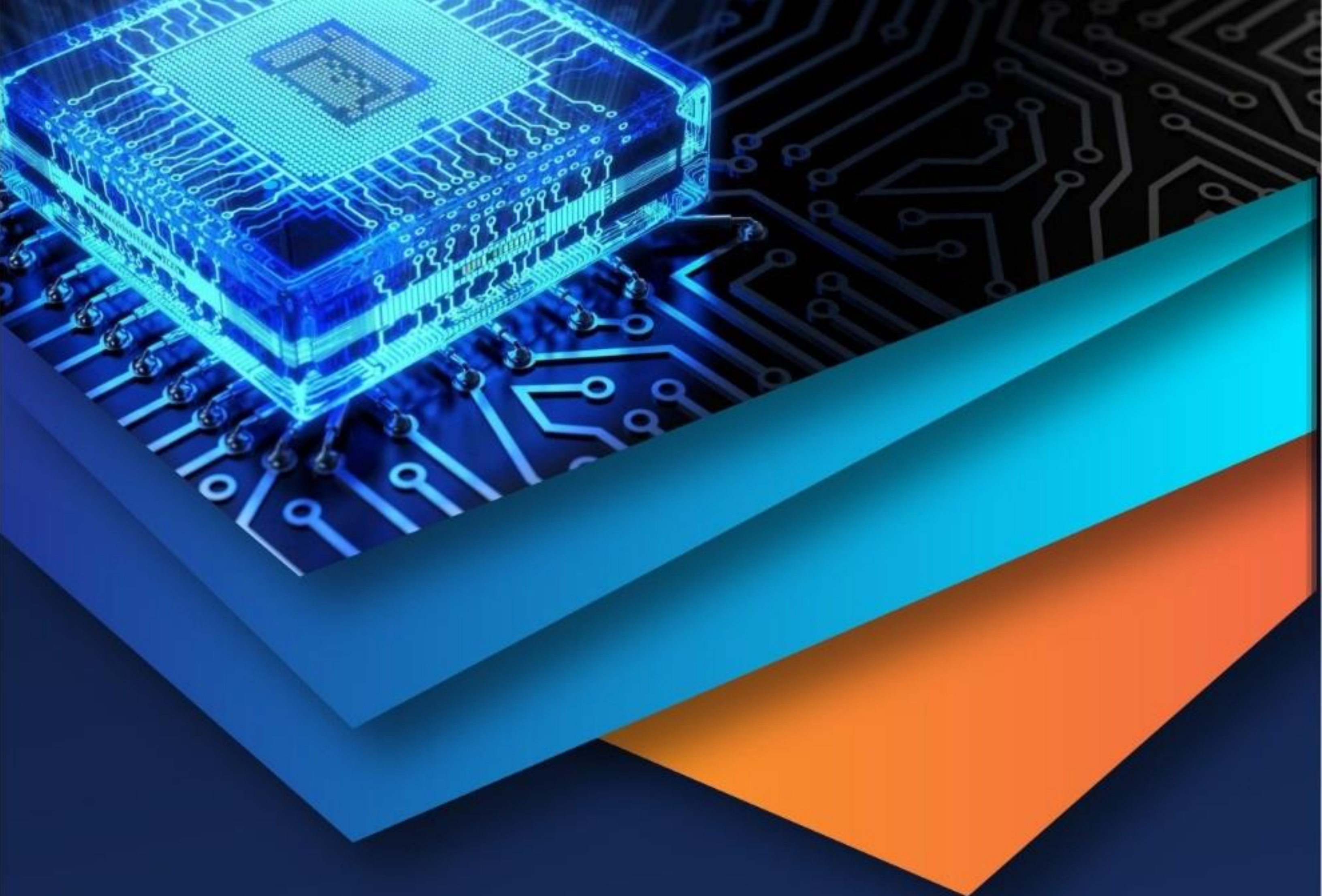

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