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Investigation of Bearing Capacity of Footings Resting on Sloping Ground

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Abstract: Rapid urbanization in the North-Eastern hilly regions, driven by population growth, economic development, and housing shortages, has led to increased construction of residential and commercial buildings on or near slopes. Shallow foundations on slopes have lower bearing capacity compared to flat ground, posing challenges for engineers. Factors like slope excavation, heavy rainfall, and human activities further affect slope stability. This study models soil and structural interactions to analyze slope stability and foundation bearing capacity using software like PLAXIS and ETABS. Results show that larger footings and greater setback distances increase bearing capacity, while steeper slopes reduce it. Ensuring safe foundation design on slopes is crucial for building stability and safety in these regions.

Keywords: Bearing capacity, setback, slopes, combine footing, single footing, footing width, Plaxis.

I.INTRODUCTION

Bearing capacity is an important consideration in foundation engineering because it establishes whether the foundation can sustain the weight of the building or structure it is meant to support, Engineers must carefully evaluate the soil and site conditions when developing a foundation in order to choose the right kind and guarantee that it has enough bearing capacity. The foundation may collapse or settle beneath the weight of the building if the bearing capacity is insufficient, which could cause structural damage or even collapse. Both the physical properties of the footing and the mechanical properties of the soil affect a foundation's final bearing capacity.

Soil testing, computations, and modeling are a few techniques engineers employ to ascertain the projected bearing capacity and plan the foundation appropriately. The allowable bearing pressure of shallow foundations is determined by two factors:

- The settlements under allowable bearing pressures should not exceed tolerable levels, and
- The safety factor against eventual shear failure must be sufficient.

The ability of the soil to support loads applied to the ground is known as bearing capacity. The kind of soil, its shear strength, density, and moisture content are some of the variables that affect bearing capacity. For example, cohesive soils—such as clay—have greater carrying capacity than non-cohesive soils—such as sand. Additionally, it is dependent on the embedment load depth (the higher the bearing capacity, the deeper the embedment). The first thorough theory for assessing the ultimate bearing capacity of a rough, shallow foundation was developed by Terzaghi in 1943. According to Terzaghi's hypothesis, a foundation is referred to as shallow if it is laid at a depth that is equal to or less than its breadth. It is true that the fundamental idea behind footings' carrying capability has changed over time.

There are hills in India's northeastern region. Building construction, both residential and commercial, has surged as a result of the North-East's hilly regions' rapid metropolitan area expansion. As a result, a large number of single- or multi-story buildings are built on or close to the hill. Being aware of the carrying capacity of a foundation built close to a slope is crucial for engineers because it affects how well a structure built close to a slope performs. A foundation near a hill has a lower carrying capacity than one on level ground. For footing placed near to the face of a slope, a reduction in the bearing capacity of the foundation is expected due to the curtailed zone of passive resistance developed towards the slope face (R.Acharyya and A.Dey 2017).

Determining how well strip footings endure near sloping surfaces has piqued the curiosity of researchers. They have investigated this using several techniques. One approach is to use an Artificial Neural Network (ANN) model, which functions similarly to a computer program with learning and prediction capabilities. In 2018 and 2019, researchers Acharyya and Dey investigated this. Experiments are another method. For instance, in 2012, Keskin and Laman conducted model tests in which they constructed scaled-down replicas of strip footings on sand slopes to evaluate their performance. Others have experimented with stabilized sand slopes, such as El Sawwaf in 2009. Then there are research projects that employ intricate computer simulations known as Finite Element Studies. This was done in 2017 by Acharyya and Dey to better understand the behavior of square footings, a new type of foundation, on sloping terrain.

The overall goal of all these investigations is to determine the effectiveness of various foundation types in non-level terrain. It's significant because constructions and buildings are frequently constructed in areas with uneven terrain, such as hills or slopes. This study looks at the bearing capacity (qu) and failure process of a square footing on a dry cohesive less with varying steepness of slope, setback ratios, widths, kinds, and depths of footing as well as angles of internal friction. With the use of sophisticated numerical simulations via the PLAXIS 3D software, the current study intends to investigate in detail the bearing capacity of isolated footings located on sloping ground. It also seeks to comprehend the intricate relationship between footings and sloping terrain, taking into account various locations.

II.ANALYSIS OF SOIL SLOPES

A thorough model was made to examine the stability of a cohesionless soil slope with variable angles of inclination. In the current study, different geotechnical characteristics are taken into consideration to calculate the bearing capacity of an isolated footing and combine footing sitting at the slope's crest using the PLAXIS 3D v AE. 01 software. A finite element program called Plaxis 3D is used for geotechnical analysis and design. It is mostly used to simulate intricate three-dimensional soil structure interaction problems, giving engineers insights into how soil and structures behave under different circumstances such as excavation, tunneling, foundation construction, and slope stability.

Overview of the Model

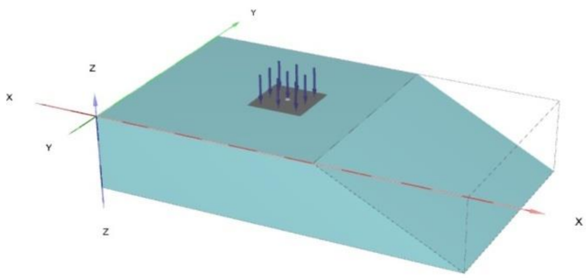

Fig. 1 Representation of footing located at the crest of the slope

As seen in fig. 1, a model for footing sitting on the slope's crest has been designed for the current investigation. Standard fixity conditions have been used in this model. The model's bottom is completely solid and its sides are fixed horizontally, but its slanted side is free to move. A smaller, finite number of 10-noded tetrahedral elements make up the discretized version of the model. There are various mesh schemes available in Plaxis 3D, including extremely coarse, coarse, medium, fine, and very fine. 5.000E-3 medium element size factor, 1.200 global scale factor, and medium element distribution are used in this instance.

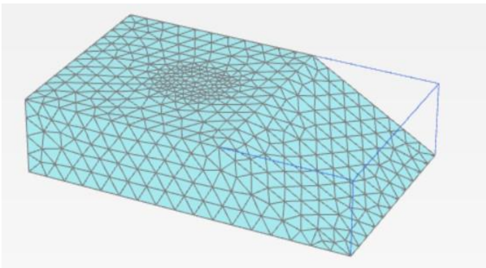

Fig. 2 Representation of meshing used in the model

The Mohr–Coulomb (M–C) model was used to simulate the cohesion-less soil for the foundation. The Mohr Coulomb model comprises three strength parameters cohesion, angle of internal friction, and angle of dilatancy and two elastic parameters elastic stiffness and Poisson's ratio. A key idea in the fields of soil mechanics and geotechnical engineering is the Mohr-Coulomb theory. It offers a foundation for comprehending how soils behave and how strong they are under various circumstances, especially when shear stress is present. The French engineer Charles-Augustin de Coulomb and the German engineer Otto Mohr are honored in the theory's names. In essence, it explains how the normal and shear stresses exerted on a soil element during failure relate to one another.

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Position of the Footing

In order to assess a square footing's bearing capability using a numerical framework, different footing positions have been methodically chosen for in-depth examination. This entails setting the footings at various setback ratios represented by the symbols *b*/*B* on the ground. Here, B is the footing's breadth and b is the setback distance the horizontal distance measured from the slope's edge to the footing's centerline. For this investigation, the particular setback ratios selected are b/B=0, 0.5, 1, 2, and 3.

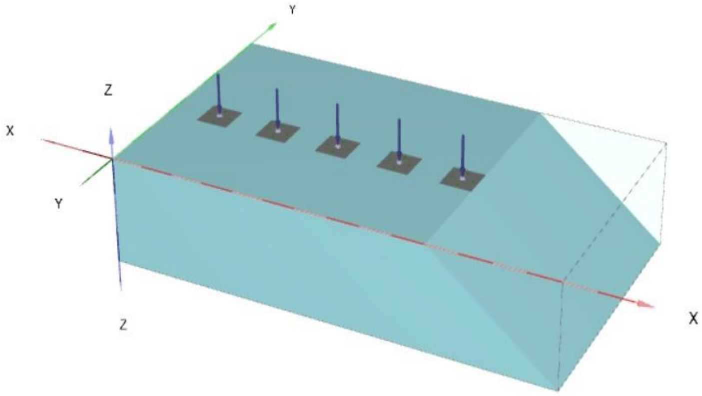

Fig.3 Position of footings on the surface of the soil in different setback

Design and Modeling of building

A prominent tool for structural analysis and design, ETABS software, is used in this study to examine a four-story building consisting of the ground floor and three more floors. 30.4 meters in length and 10 meters in width make up the building's rectangular layout. The building is 12 meters tall overall, with a height of 3 meters for each floor. Response spectrum analysis is used in the structural analysis. This technique evaluates the building's reaction to seismic activity by taking into account the many frequencies at which the structure may vibrate during an earthquake. By using this method, the building can be better understood and designed to withstand seismic forces.

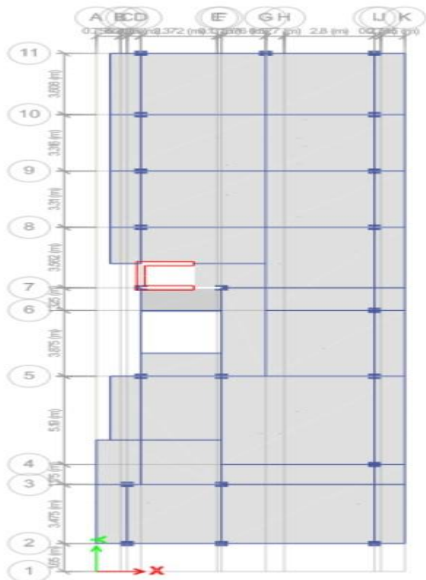

Fig.3 Building Floor plan

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III.RESULT AND DISCUSSION

Validation study

Castelli and Lentini (2012) used a reinforced box with transparent walls to analyze weak foundations on slopes. On sand slopes, they tested square footings in various sizes. Displacement transducers were used to obtain measurements, and settlement data was meticulously documented. The maximum dry density of the sand, which came from Playa Catania in Italy, was 17.50 KN/m³, and its estimated internal friction angle was 38°. To reproduce their findings, a numerical model was created using characteristics for soil stiffness that were taken from relevant studies. In order to precisely replicate soil features, soil cohesion and friction angle were also used from earlier studies. By closely matching experimental settings by using B=0.08m and b=0.12m, the numerical model is intended to be validated and become more applicable to real-world situations.

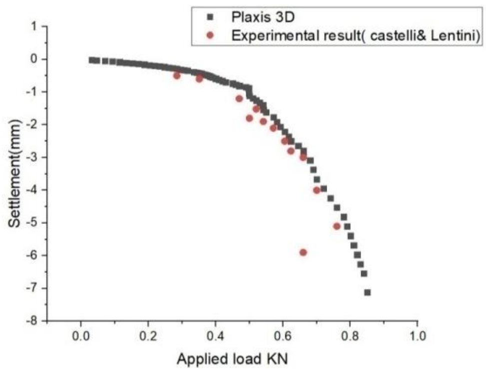

Fig.4 Validation study graph

Parametric study

In order to do a thorough examination of the carrying capacity of isolated and combined footings on sloping terrain, different footing widths B = 1, 1.5, and 2 meters were taken into consideration. A smaller setback ratio raises the risk of failure when footings are situated at the top of a slope. In this study, several setback distances were investigated in order to guarantee the precision and dependability of the findings.

Five different setback ratios for footings lying on sloping terrain were examined: b/D = 0, 0.5, 1, 2, and 3. These ratios, as illustrated in figure 3.4, demonstrate the relationship between the footing's depth and the edge of the slope based on research conducted in 2017 by R. Acharyya and A. Dey. The study attempts to give a thorough understanding of how the footing's position in relation to the slope affects its stability and bearing capacity by utilizing these different setback ratios.

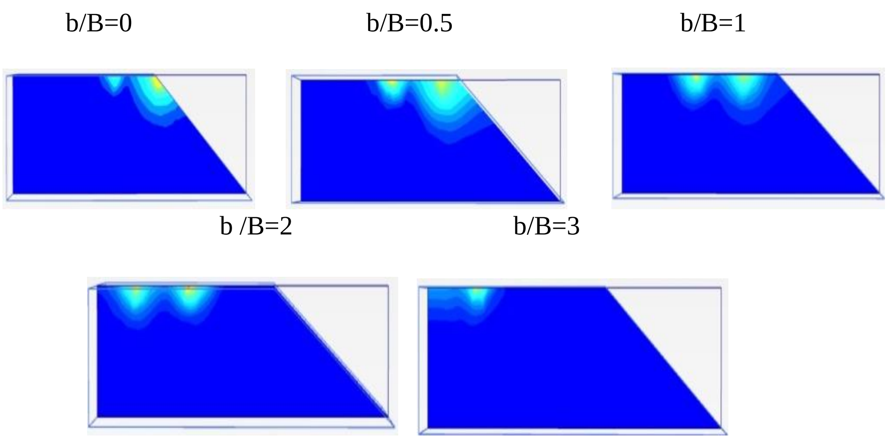

Fig.5 Formation of passive zones beneath the footing in different setback ratio for single footing

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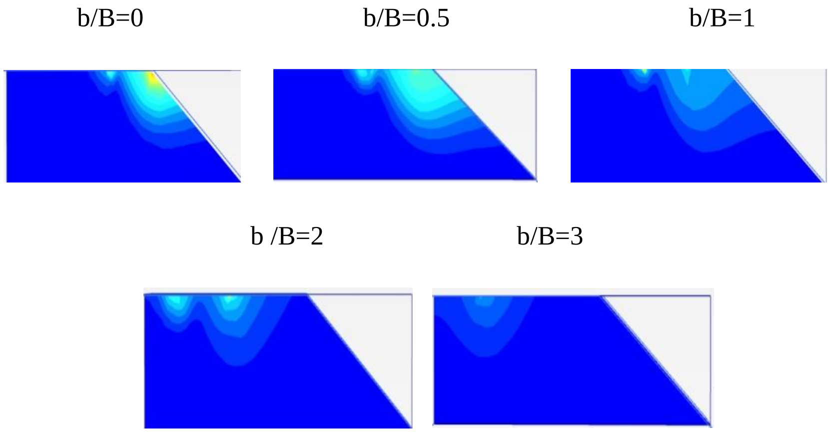

Fig.6 Formation of passive zones beneath the footing in different setback ratio for combined footing

For soil-structure interaction and foundation stability, the soil beneath a footing must resist lateral movement brought on by the load from the structure above. The active zone is created when soil directly beneath the footing is compressed by an applied force. Past this point, passive zones form when soil is forced upward and outward to prevent shear failure and lateral spread. Passive zone formation is influenced by number of elements, including loading conditions, footing depth, footing design and size, and soil qualities. The breadth and form of the passive zones are determined by the type, density, and strength of the soil; larger footings provide more expansive zones. Increased weights and deeper footings result in larger passive zones, which improve stability. Comprehending passive zones is essential for designing foundations since they enhance bearing capacity and maintain structural integrity by resisting lateral and vertical displacements.

Angle of Internal Variation

It is clear that a sizable variation in the angle of internal friction causes an equivalent variation in the result. The following results are obtained from this experiment by measuring four different internal friction angles: 30, 32, 35, 38, and 40. The graph below shows how the bearing capacity of the soil increase as the angle of internal friction increases.

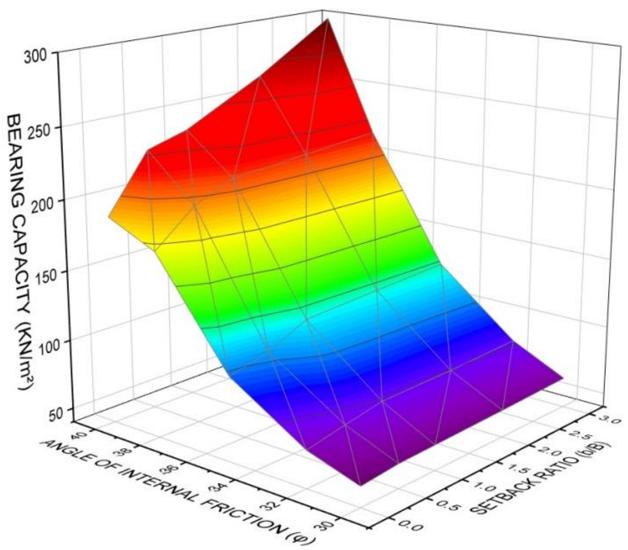

Fig.7 Variation of angle of internal friction with setback ratio and bearing capacity

Slope Angle Variation

Variations in the slope angle can have a big effect on the soil's capacity to support weight. As mentioned in the method, the footings are placed at different setback ratios; a footing near the slope's crest has a lower bearing capacity than a footing farther from the crest. In this experiment, four different slope angles—30°, 35°, 40°, 45°, and 50°—are

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measured. As Figure 4.3 shows, the soil's carrying capacity increases with a larger setback ratio and, on the other hand, declines with an increase in slope angle.

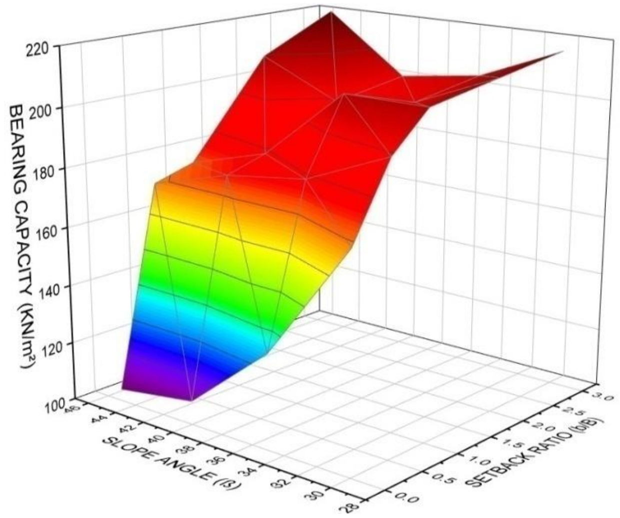

Fig.9 Variation of slope angles with setback ratio and bearing capacity for single footing

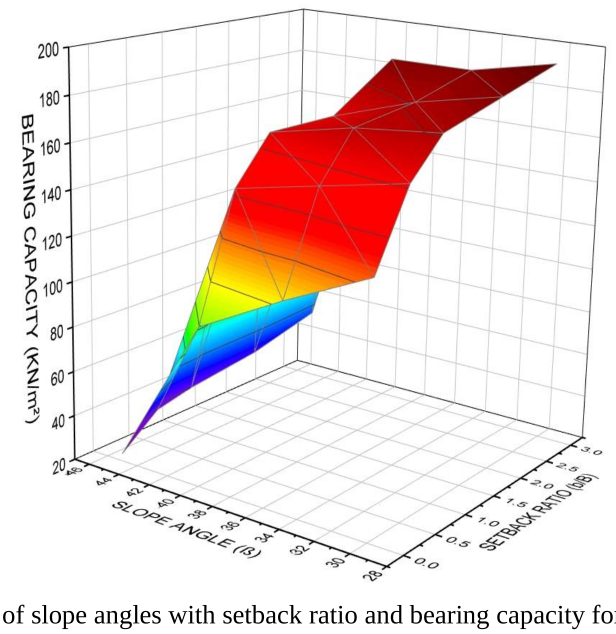

Fig.10 Variation of slope angles with setback ratio and bearing capacity for combined footing

Variation of Footing Width

Three distinct footing width types—B=1, 1.5, and 2 meters—have been used for modeling in this work. As the footing width rises, bearing capacity also increases, as seen in figure 4.4.

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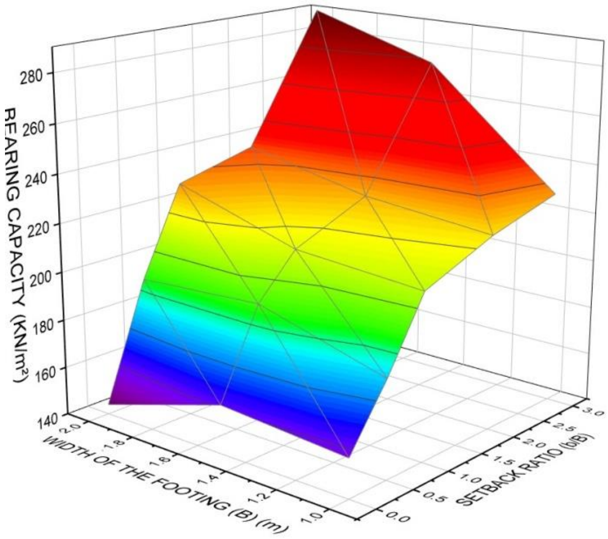

Fig.11 Variation of bearing capacity with width of footing and setback ratio for single footing

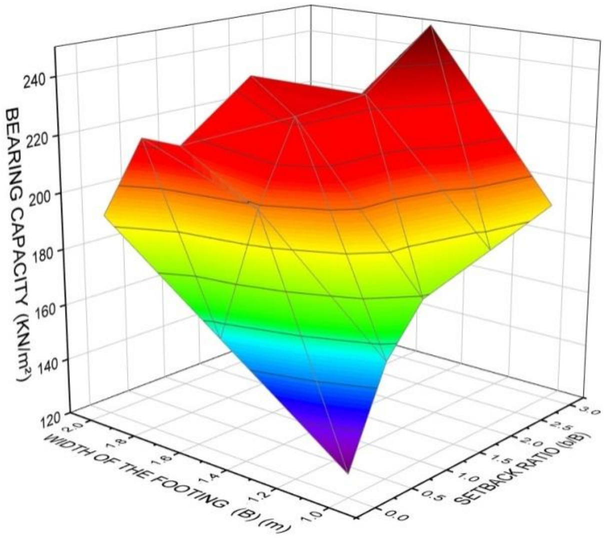

Fig.12 Variation of bearing capacity with width of footing and setback ratio for combined footing

Analysis of soil Data using Column Load

In this study the highest column loaf from the building modeled in ETABS is added to the soil i.e. 2307 KN. From table 4.1 and figure 4.7 below it can be observed that the bearing capacity of the soil increases with an increase in setback ratio.

Table 1 Values obtained after applying the column load to the building

Name	0 Setback	0.5 Setback	1 Setback	2 Setback	3 Setback
Ultimate Bearing Capacity	275	345	355	360	385
Factor of safety against shear failure	2.5	2.5	2.5	2.5	2.5

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Bearing Capacity for shear failure	110	138	142	144	154
Corresponding limiting pressure	150	175	150	175	185

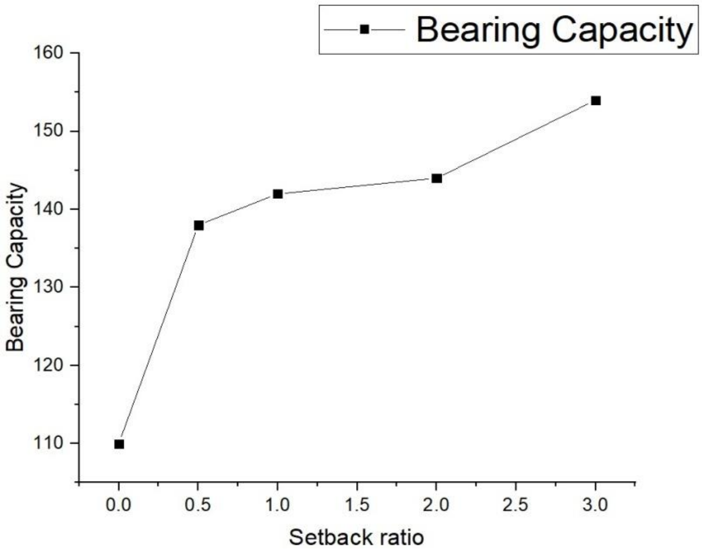

Fig.13 A plot graph obtained by applying a column load to the footing.

IV.CONCLUSION

A numerical analysis was performed to determine the soil's bearing capability. The setback ratio, foundation width, and angle of internal friction were found to have a considerable impact on the carrying capacity of footings on sloping ground. The following presents the findings from the investigation of footings' carrying capability on sloping terrain.

- The soil's carrying capacity is increased when footing size increases because the load is dispersed across a greater area.
- The distance between the load and the footing's edge increases as the setback ratio rises, improvinSg bearing capacity and stability.
- The soil's resistance to shearing increases with an increase in the angle of internal friction, which raises the bearing capacity.
- The soil's carrying capacity decreases as the slope angle rises because of a loss in soil stability.
- The column load transmitted from the building to the soil stays within safe bounds regardless of the setback ratio. The degree to which soil stability and bearing capacity are maintained by the design criteria is demonstrated by the safety of the column load throughout a range of setback ratios.
- For setback ratios of 0, 0.5, 1, 2, and 3, the various design bearing pressures for the maximum column load of 2307 KN are 110 KN/m², 138 KN/m², 142 KN/m², 144 KN/m², and 154 KN/m², respectively. These setback ratios also show a tendency to rise.

REFERENCES

[1]. Acharyya, R., & Dey, A. (2017). Finite element investigation of the bearing capacity of square footings resting on sloping ground. *INAE Letters*, *2*, 97-105.
[2]. Acharyya, R., & Dey, A. (2019). Suitability of the typology of shallow foundations on hill-slopes. *Indian Geotechnical Journal*, *49*(6), 635-649.
[3]. Acharyya, R., & Dey, A. (2018). Importance of dilatancy on the evolution of failure mechanism of a strip Footing resting on horizontal ground. *INAE Letters*, *3*(3), 131-142.

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[4]. Acharyya, R., & Dey, A. (2019). Assessment of bearing capacity for strip footing located near sloping surface considering ANN model. *Neural Computing and Applications*, *31*(11), 8087-8100.
[5]. Acharyya, R., & Dey, A. (018). Assessment of bearing capacity and failure mechanism of single and interfering strip footings on sloping ground. *International Journal of Geotechnical Engineering*.
[6]. Acharyya, R., & Dey, A. (2020). Assessment of interaction mechanism and bearing capacity of strip footings located on slope face. *Sādhanā*, *45*(1), 89.
[7]. Azzam, W. R., &ElWakil, A. Z. (2016). Experimental and numerical studies of circular footing resting on confined granular subgrade adjacent to slope. *International Journal of Geomechanics*, *16*(1), 04015028.
[8]. Castelli Francesco and Lentini Valentina (2012) "Evaluation of bearing capacity of footing on slopes". *International Journal of Physical Modelling in Geotechnics*
[9]. Chakraborty, D., & Kumar, J. (2013). Bearing capacity of foundations on slopes. *Geomechanics and Geoengineering*, *8*(4), 274-285.
[10]. Choudhury, D., & Subba Rao, K. S. (2006). Seismic bearing capacity of shallow strip footings embedded in slope. *International Journal of Geomechanics*, *6*(3), 176-184.
[11]. El Sawwaf, M. (2010). Experimental and numerical study of strip footing supported on stabilized sand slope. *Geotechnical and Geological Engineering*, *28*, 311-323.
[12]. El Sawwaf, M. A. (2005). Strip footing behavior on pile and sheet pile-stabilized sand slope. *Journal of Geotechnical and Geoenvironmental Engineering*, *131*(6), 705-715.
[13]. Naderi, E., & Hataf, N. (2014). Model testing and numerical investigation of interference effect of closely spaced ring and circular footings on reinforced sand. *Geotextiles and Geomembranes*, *42*(3), 191-200.
[14]. Salih Keskin, M., & Laman, M. (2013). Model studies of bearing capacity of strip footing on sand slope. *KSCE Journal of Civil Engineering*, *17*, 699-711.
[15]. Standard, I. (1893). Criteria for earthquake resistant design of structures. *Bureau of Indian Standards, Part*, *1*.
[16]. Standard, I. (1987). Code of practice for design loads (other than earthquake) for buildings and structures. *Part II, Imposed loads (second revision), IS-875-1987*.