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Effect of Placement of Footing on Stability of Slope

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***Abstract** - Due to land limitations and increase in population, peoples are utilizing slopes (natural or manmade) for construction purpose. In such situation, when construction is carried out on slope without analyzing the stability and bearing capacity, slope may result in failure. The present scenario at Uttarakhand in India is one of the examples of slope failure. Many people lost their lives and property in Uttarakhand disaster. Footings of bridges abutments, foundations near to excavations, retaining walls and electric transmission towers built on mountain slopes are the obvious examples of footing on slope. In this paper focus is made on analyzing the slope for different locations of footing, and loading conditions. Analysis indicated that any stable slope may become unstable if new construction activity was carried out near as well as on the slope. The slopes were found to be stable for given soil condition and slope up to certain load, beyond which it becomes unstable. The stability of slope was found to be maximum when load was placed at middle of slope.*

Keywords -- stability of slope, footings, PLAXIS 2D, udl, crest

I. INTRODUCTION

When the foundation is constructed on slope, the bearing capacity is found to be much lesser than that of plain ground. Similarly, the stability of slope due to placement of new footing or increase in existing load may also affect. Many times, people construct the structure on slope without analyzing the stability of slope. In recent years, number of structures on slopes increases rapidly. These structures viz. buildings and road structures can be observed in hilly regions. When a shallow foundation is placed on top of slope and subjected to axial load, the reduced bearing capacity is usually considered. Even then sometimes failure occurs. Fig. 1.1 shows failure of slope during Uttarakhand 2013 disaster.

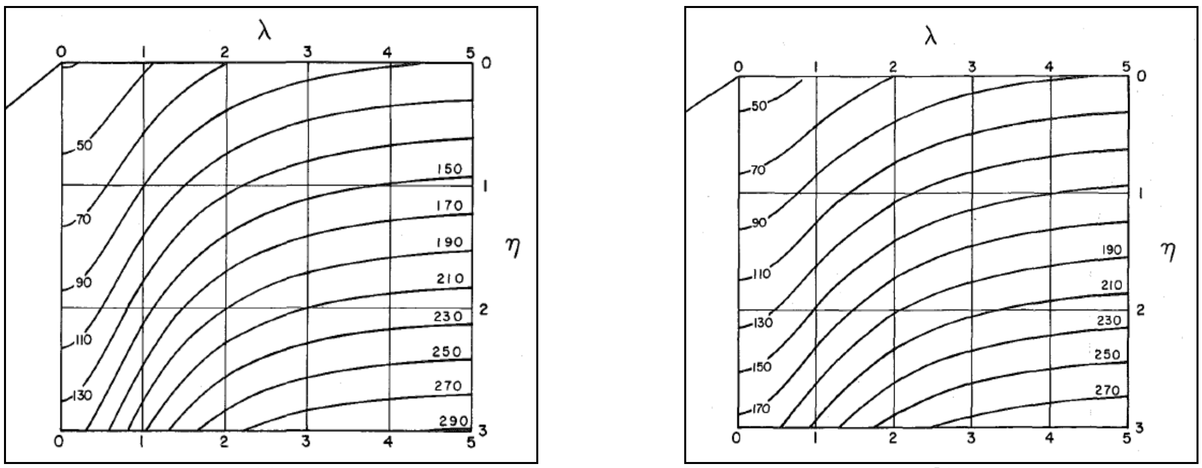
Fig 1.1: Failure of Structure on Slope

The structures constructed near river slope may need more attention. The failure may be due to inadequate study of slopes stability. The slope stability may get affected due to provision of footings on slope during its life time. Therefore, it is necessary to understand the phenomenon of slope stability from the point of provision of external structures at any level on slopes. The investigations includes determining the safe location of footing on slope, determining amount of safe load to be placed on existing footing and effect of distribution of load on slope stability.

II. LITERATURE REVIEW

Meyerhof (1957) studied the problem of ultimate bearing capacity of foundation on slope. The full formation of shear zones under ultimate loading condition were not possible on the sides which were closed to the slope, and therefore supporting capacity of soil on that side get considerably reduced. The bearing capacity of foundation on or near the slope was found to be lesser than that of plain ground. The ultimate bearing capacity equation on or near the slope and design charts shows that bearing capacity depends upon distance of foundation from top of the slope, angle of slope, angle of shearing resistance of soil and depth to width ratio of the foundation.

Gemperline (1988) reported the results of 215 centrifuge tests on model footings located at the top of a slope of cohesionless sand. Based on these experiments evidence, he proposed an equation that would enable foundation engineers to determine the bearing capacity factor which found to be useful in calculation bearing capacity for footings of different size and shapes, located anywhere in the region at the top of the slope. He also provided contours for 1:1.5 and 1:2 slopes as shown in Fig 2.1 which gave the percentage bearing capacity based on the location of footing with respect to footing dimensions and edge distance.



(a) ***(b)***

Fig 2.1: Bearing Capacity Contours in Percentage for 1:2 (a) and 1:1.5(b) Slopes

Bowels (1997) studied the problem of ultimate bearing capacity of foundation on and adjacent to slope and recommends that, the bearing capacity was depending upon angle of shearing resistance, slope inclination, depth of foundation and location of foundation which was adjacent to slope. He also recommended a classical ultimate bearing capacity equation for calculating bearing capacity on slope.

Kumar and Ilamparuthi (2003) studied the response of footing on sand slope. They carried out investigations for three different slope angles and three different edge distances and concluded that the load-settlement behavior and bearing capacity can be improved by inclusion of geosynthetic reinforcement under the footing. Further the bearing capacity decreases with increase in slope angle and decrease in edge distance both in reinforced and unreinforced slopes.

Shiau *et. al* (2011) studied undrained stability of footings on slopes to obtained solutions for the ultimate bearing capacity of footings on purely cohesive slopes by applying finite element upper and lower bound methods. In a footing on slope system, the ultimate bearing capacity of the footing may be governed by either foundation failure or global slope failure. Fig 2.2 presents typical upper and lower bound results for a vertical slope.

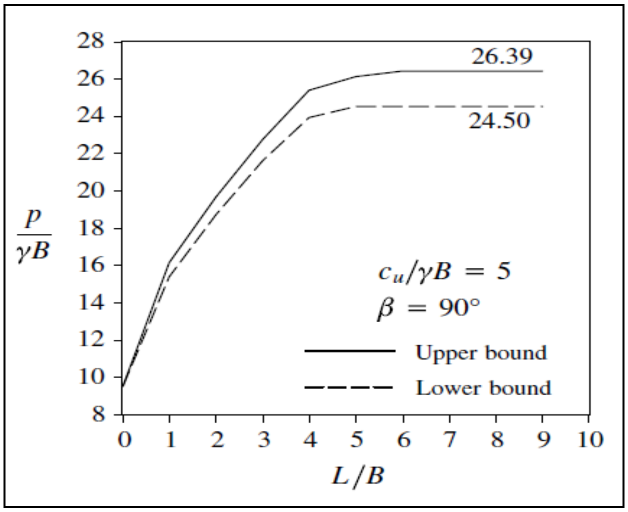


Fig 2.2 Typical Upper and Lower Bound Results

The combination of these two factors makes the problem difficult to solve by using traditional methods. Design charts were presented for a wide range of parameters. They also suggested the procedure for estimation of bearing capacity on purely cohesive slope.

Zhan and Liu (2012) studied the undrained bearing capacity of footings on slopes and investigated the combined bearing capacity behavior of strip footings on the top of undrained soil slopes under vertical load and overturning moment, as well as purely vertical bearing capacity for footings adjacent to slopes, by using the finite element analysis method. Typical vertical load-displacement curves obtained from the finite elements analyses for different slope angles is illustrate in Fig 2.3 below.

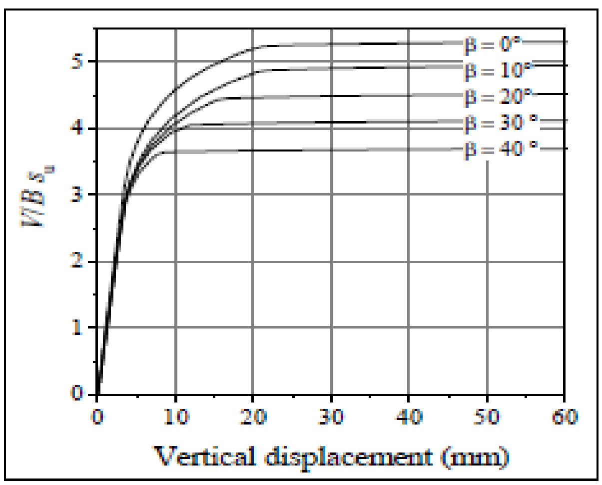


Fig 2.3: Load Displacement Curve (Zhan and Liu)

Factors, such as soil properties, slope angle, slope height, footing location from edge of slope, which affect the bearing capacity behavior of foundations, were analyzed. Base on the study, they concluded that slope had little effect on the bearing capacity of footings on the toe, but the failure mechanism was very different from that of footings on level ground. Fig 2.4 presents the bearing capacity for various footing locations on a weightless vertical cut. Numerical upper and lower bounds are compared with those analytically derived by Davis and Booker (1973).

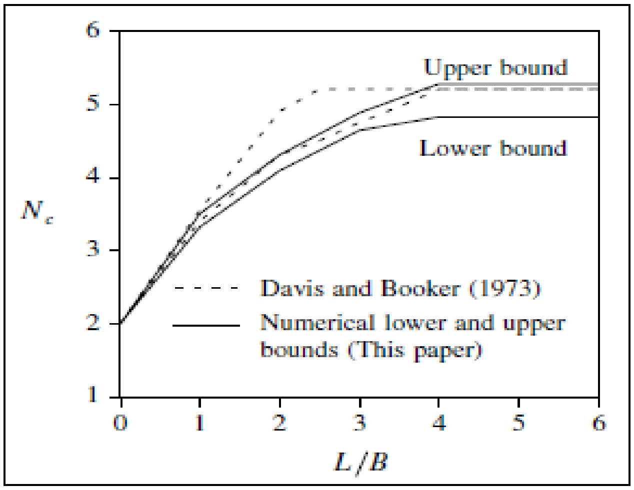


Fig 2.4: Lower and Upper Bound Bearing Capacity for Slopes

The bearing capacity decreases significantly when footings resting on the surface of slopes. Even though all studies are addressing to bearing capacity and constructions on slope are going on with this aspect, the failure of slope with structure is of concern. What happened to stability of slope when footing is placed on it? The placement of footing on slope may result in destabilizing the slope. Hence, to get the answer to few questions, this work was planned. This paper discusses the effect of location of footing, load and slope on the stability of slope.

III. NUMERICAL MODELING

The stability analysis on slope was carried out for footing located at crest, and at vertical distance of 2.5m, 5m 10m and 15m from crest. The slopes considered for the present study were varied from 1:1 to 1:3. The loading on footing was varied from 0 kN/m^2 to $1000 kN/m^2$ or failure load. The soil used for the present study was cohesive soil and the slope height was 20m constant for all cases. Table 1 shows the soil properties used for the study.

Table 1: Soil Properties Used for Study

Parameters	Value
Type of soil	Clay
Youngs modulus (kN/m^2)	1000
Cohesion, (kN/m^2)	200
Angle of friction , ^{o}	0
Unit weight (kN/m^3)	20

The stability analysis was carried out for footing of 2m width. The factor of safety of slope without and with load was determined using PLAXIS 2D. The slopes were analyzed for factor of safety with load varying from 0 to 1000 kN/m^2. Then location of footing was changed and the process was repeated. Fig 3.1, 3.2 and 3.3 shows geometrical model along with the mesh generation during analysis and deformed shape in PLAXIS 2D software. The process was repeated for all slopes and loads. The factor of safety determined for all the cases are discussed.

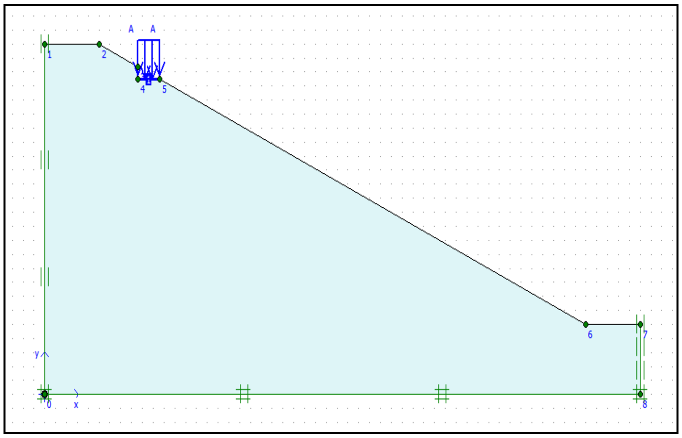


Fig 3.1: Geometry Input

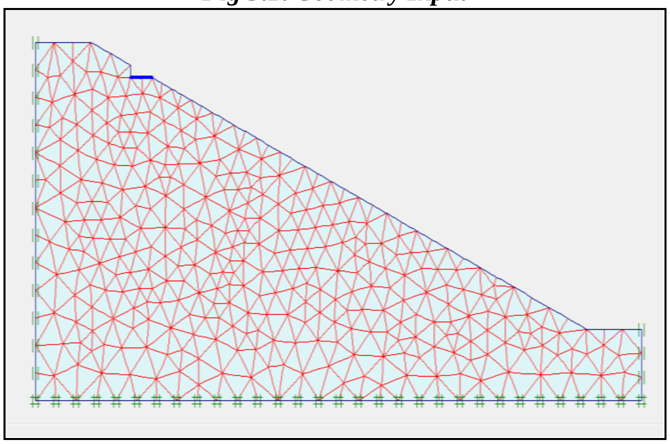


Fig 3.2: Mesh Generation

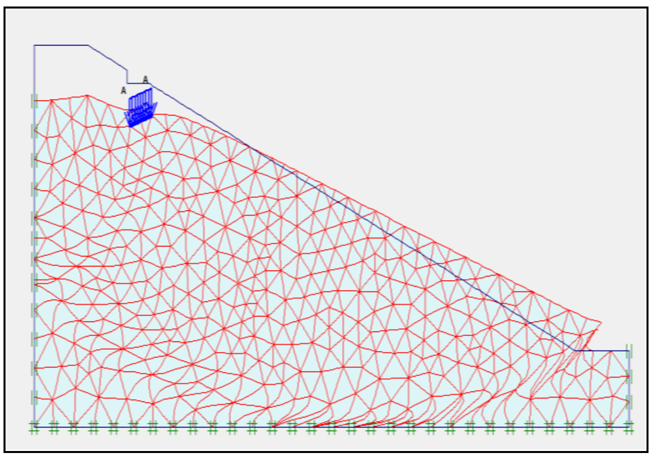


Fig 3.3: Deformed Shape

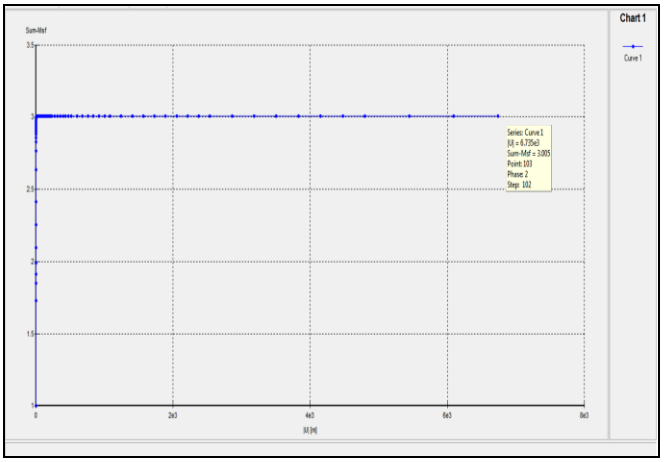


Fig 3.4: Factor of safety curve

IV. RESULTS

The factor of safety was calculated for footing of width 2m, located at crest, 2.5m, 5m, 10m, and at 15m from crest. Fig 4.1 to Fig. 4.5 shows the factor of safety for different load with location of footing at crest 2.5m, 5m, 10m, and at 15m from crest respectively.

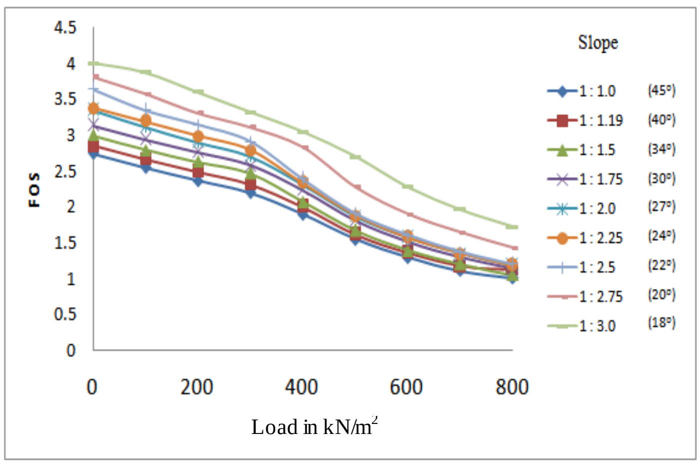


Fig 4.1: Variation of Factors of Safety with Load at Crest of Slope

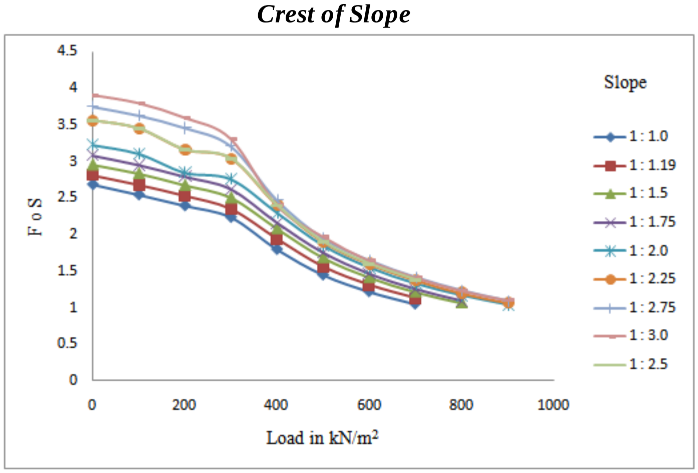


Fig 4.2: Variation of Factors of Safety with Load at 2.5m from Crest of Slope

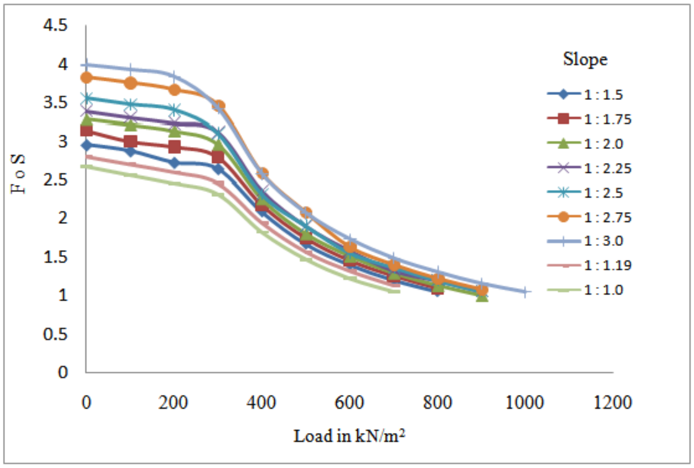


Fig 4.3: Variation of Factors of Safety with Load at 5m from Crest of Slop

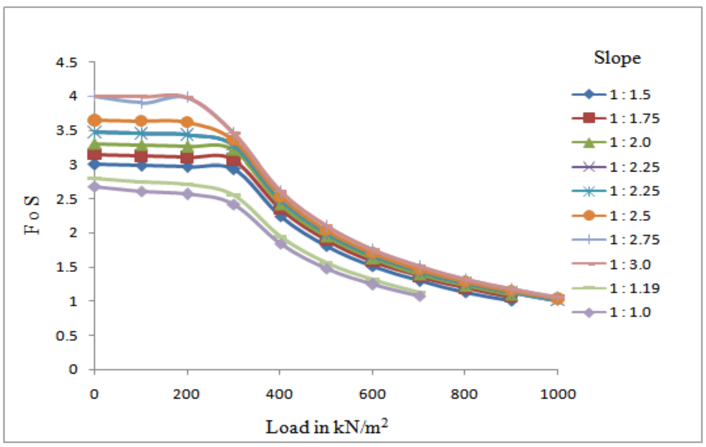


Fig 4.4: Variation of Factors of Safety with Load at 10m Crest of Slope

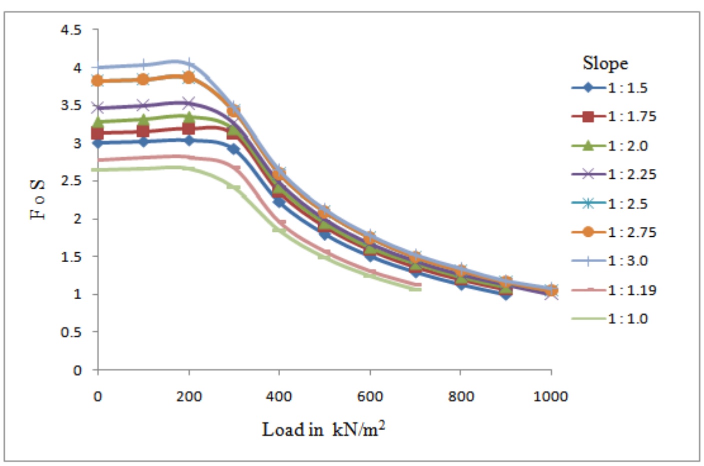


Fig 4.5: Variation of Factors of Safety with Load at 15m Crest of Slope

V. DISCUSSION

From the above result, it can be observed that the factor of safety was gradually reduces for load up to 300kN/m^2. When footing load increases beyond 300kN/m^2 that factor of safety is reduces sharply with load. The percentage reduction factor of safety was calculated by using equation (1). Fig 5.1 to Fig. 5.5 shows the percentage reduction in factors of safety with location of footings for 1:1, 1:1.5, 1:2, 1:2.5 and 1:3 slope.

$$\% \text{ Reduction in } F o S = \frac{Fi - Fo}{Fi} \text{ x } 100 \quad (1)$$

where,

Fi is factor of safety for no load condition

Fo is factor of safety for particular load condition

It is observed that for any slope and any location of footing on slope, the factor of safety is reduced by 20% when load on structure is 300kN/m^2. The reduction in factor of safety is constant for falter slope 1:1 when the load is more than 300kN/m^2. However, for steeper slope, reduction in factor of safety increases with load moving from crest towards toe. But, for all slopes and location of load, the factor of safety reduction increases with increase in load on the slope.

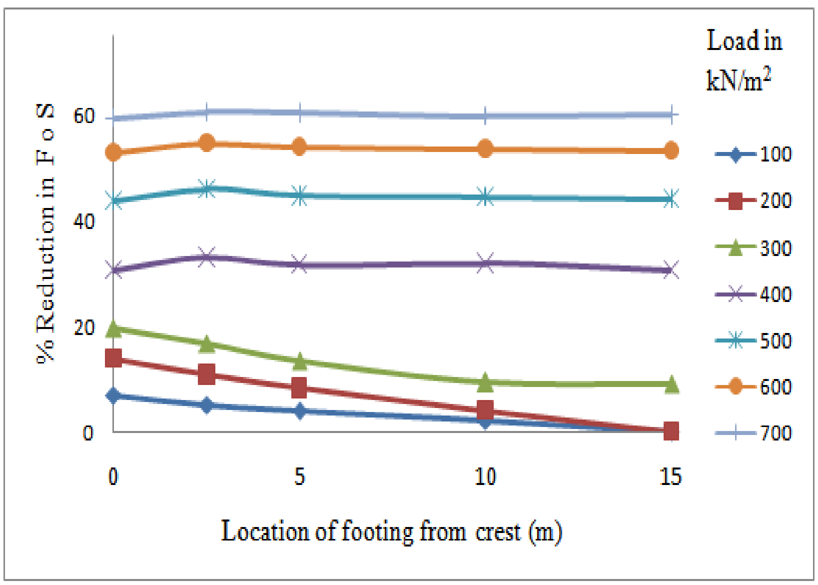


Fig 5.1: Percentage Reduction in Factors of Safety with Location of Footings for (1:1) Slope

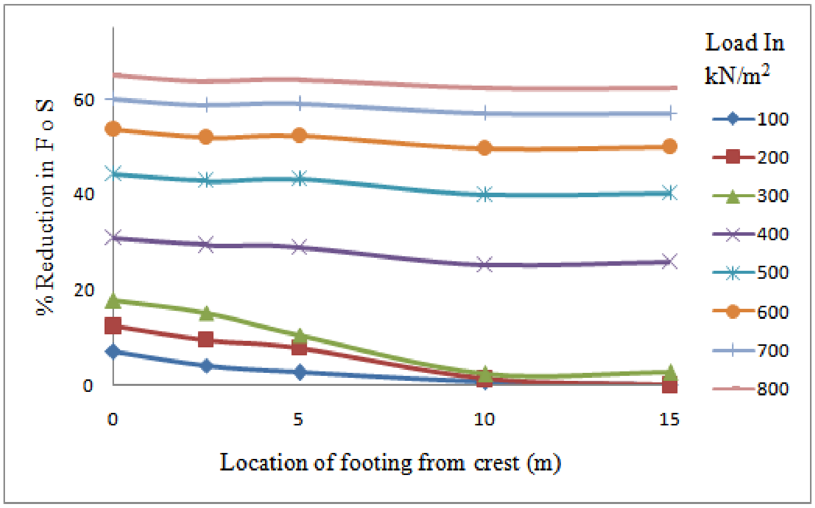


Fig 5.2: Percentage Reduction in Factors of Safety with Location of Footings for (1:1.5) Slope

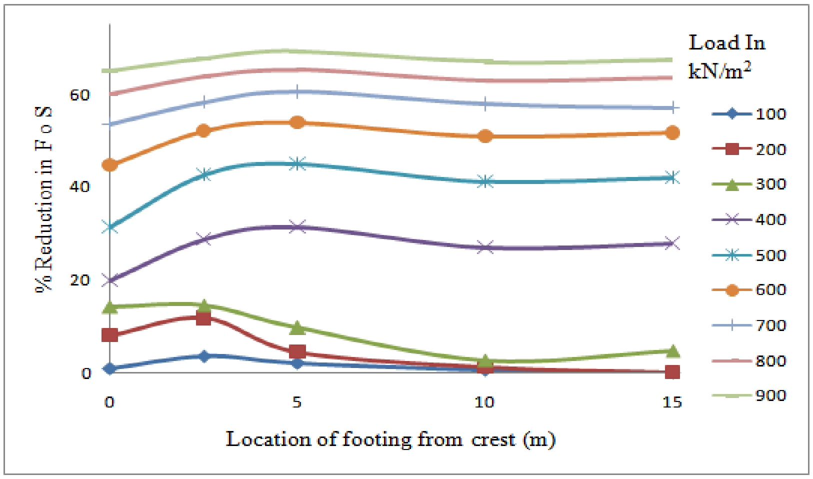


Fig 5.3: Percentage Reduction in Factors of Safety with Location of Footings for (1:2) Slope

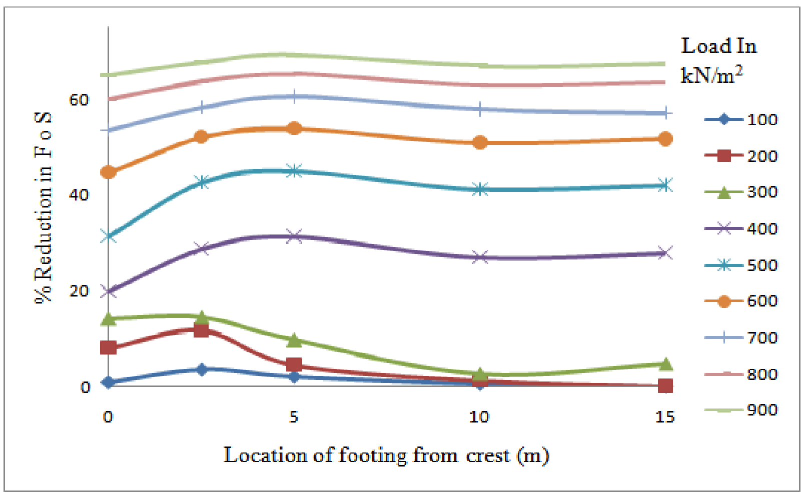


Fig 5.4: Percentage Reduction in Factors of Safety with Location of Footings for (1:2.5) Slope

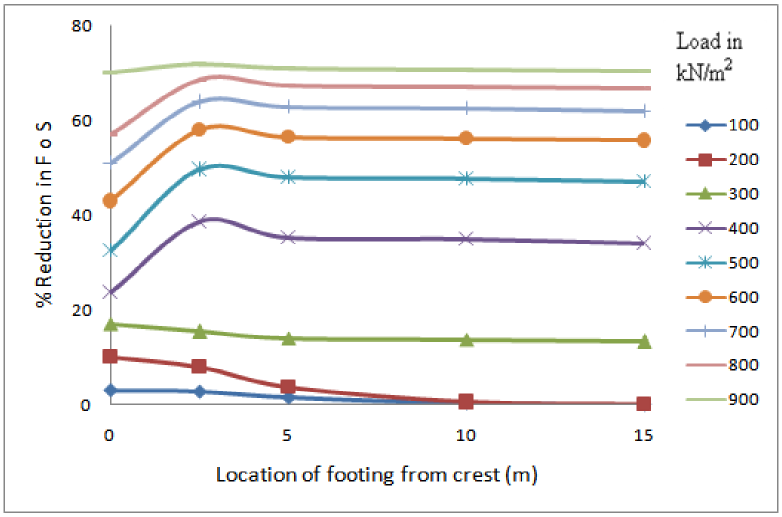


Fig 5.5: Percentage Reduction in Factors of Safety with Location of Footings for (1:3) Slope

VI. CONCLUSIONS

The stability analysis of slopes were carried out on different slopes and loads with various footing location using FEM software PLAXIS 2D. The result shows that for a slope, load and location of load, influences the factor of safety of the slopes. The factor of safety reduces when load increases on footing. The footing load i.e. in turn allowable load, control the stability of the structure. A threshold value of load of 300kN/m^2 was observed to produce minimum reduction in factor of safety. It was also observed that the factor of safety affected when the footing was placed from crest to different location on slope. The reduction in factor of safety remains constant when footing is placed beyond H/4 distance from crest. When footing is placed at crest the reduction in factor of safety is minimum.

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