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Behaviour of Strip Footing on C-Ø Soil with Three Circular Cavities

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***Abstract*— Cavity effect on behavior of surface strip footing above circular cavities was investigated using two dimensional finite element method (PLAXIS-2D). Several factors such as eccentricity of cavities, size of cavities and shape of cavities affect the bearing capacity and stability of footing. In present study the effect of three circular cavities in C–Ø soil on bearing capacity of strip footing was analyzed for various conditions. The bearing capacity ratios were determined with respect to no cavity condition. These graphs provide a data base useful for design of shallow strip footing centered with three underground circular cavities. The results can also be used to design construction of a footing on existing cavities.**

***Keywords*— Finite Element Analysis, Multiple Circular Cavities, PLAXIS-2D, Strip Footing, Underground Circular Voids**

I. INTRODUCTION

The stability of any structure depends on ultimate bearing capacity (UBC) of soil on which it resting, which plays major role in field of soil engineering. Presence of cavities affects the bearing capacity of foundation soil. There are so many natural and manmade causes to form underground cavities such as sewer lines, conduits, underground pipelines, tunnels etc. The ultimate bearing capacity of soil may change due to presence of these cavities of different shapes and size if these are located in critical region below footings.

To design a stable foundation system above a multiple cavities, it requires a method of stability analysis for foundation above cavities. The knowledge acquired can help to select suitable position of underground structure such as tunnels, aqueducts, conduits etc. to minimize its effect on stability of existing foundations. Also the knowledge will be useful for design of foundation of soil bed with existing multiple cavities.

II. LITERATURE REVIEW

From the literature, the studies on the interaction between shallow foundation and tunnel are focused on single or double cavities above single footings.

In actual field condition, there may be more than two underground cavities in the soil deposit which affects the bearing capacity of surface footings located above them.

Badie & Wang (1984) and Wang & Badie (1985) studied stability of surface footing above underground cavity in clay. They compared experimental and numerical work result.

Azam *et al.* (1991) studied the performance of strip footings on a homogeneous soil and a stratified deposit containing two soil layers both with and without a continuous void and concluded that for a two-layer soil system, top-layer thickness and strength ratio between the two layers affect footing performance.

Lee *et al.* (2015) studied effect of load inclination on the undrained bearing capacity of surface spread footing above single and two voids using finite element analysis.

Lavasan *et al.* (2016) examined the bearing capacity and failure mechanism of a shallow strip foundation constructed above twin circular voids with respect to voids diameter, embedment depth, the eccentric distance and the spacing between voids.

As was reviewed above, to date no literature on the effect of three circular cavities on bearing capacity of single footing and single circular cavity on bearing capacity of two footings exists. Therefore, this research focuses on investigating the bearing capacity of the system of footings and single and multiple circular cavities for different diameter of cavities, embedment depth, and horizontal and vertical spacing between cavities.

III. PROBLEM DEFINITION

Fig. 1 to Fig. 4 illustrates the first type of problem i.e., single footing above three circular cavities As shown in the figures a strip rigid footing of width B is placed on soil model with Young's modulus E, a uniform unit weight γ, friction angle ϕ and Poisson's ratio μ.

The performance of footing above cavities may be affected by location, shape, size and number of cavity which are expressed through dimensionless parameters i.e. size of cavity b/B, vertical distance of the top of cavity from bottom of footing Z/B, vertical distance between two cavities Z_C/B, are considered in this study. These configurations were divided in four groups, i.e., All In One Row, All In One Column, Right Angle Placement and Skew Placement as show in Fig. 1, 2, 3 and 4 respectively.

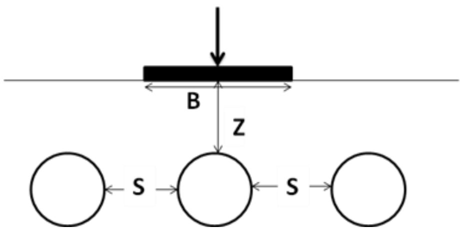

Fig. 1. All in One Row

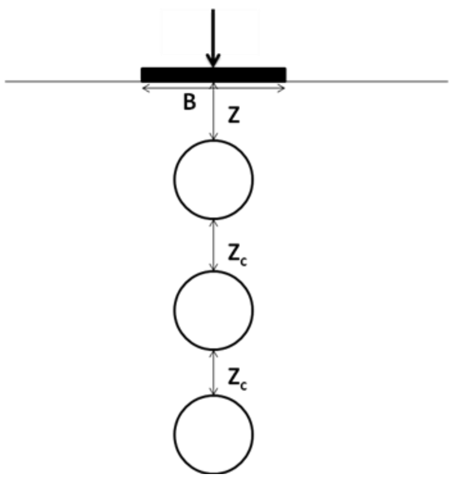

Fig. 2. All in One Column

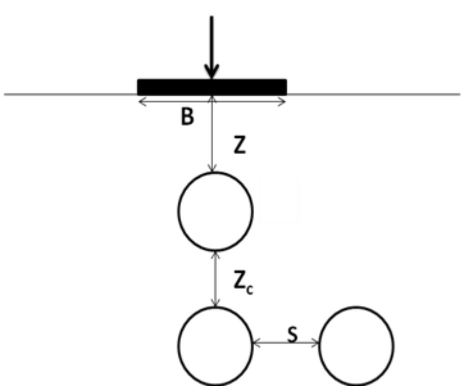

Fig. 3. Right Angle Placement

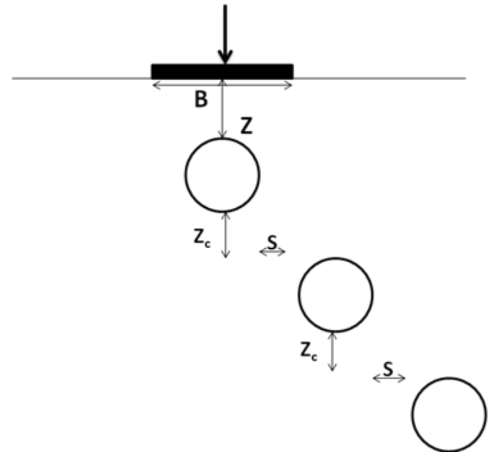

Fig. 4.Skew Placement

IV. Finite Element Analysis

A commercially available two-dimensional finite element program PLAXIS 2D was used to model the footings and cavities system. The soil was modeled with fifteen node triangular element.

The well-known Mohr-Coulomb model was considered as a first order approximation of real soil behavior. The parameters of soil used for this elasto-plastic model and the rigid concrete strip footing having width 2 m are given in Table 1.

Table 1
Soil And Footing Parameters

Properties	Soil	footing
Unsaturated Unit weight (γ)	18 kN/m^3	24 kN/m^3
Young's modulus (E)	25×10^2 kN/m^2	30×10^6 kN/m^2
Cohesion (C)	50 kN/m^2	-
Friction angle (Φ)	28°	-
Dilatancy angle (Ψ)	0°	-
Poisson's ratio (μ)	0.3	0.2
Equivalent thickness (t)	-	0.4 m
Axial stiffness (EA)	-	25×10^{6}kN/m
Flexural rigidity (EI)		32×10^4 kN-m^2/m

Fig. 5 shows a typical deformed finite element mesh and modeled boundary conditions were assumed such that the vertical boundaries are free vertically and constrained horizontally while the bottom horizontal boundary is fully fixed. The size of soil model was 20B×15B. The global coarseness of the mesh adopted was fine.

Cavity cluster is refined to remove bug errors. No specific interface elements along the soil and footing were used. Then ultimate bearing capacity (UBC) of footing was evaluated from load-settlement curve by tangent line method and results were interpreted in the term of BCR (Bearing Capacity Ratio).

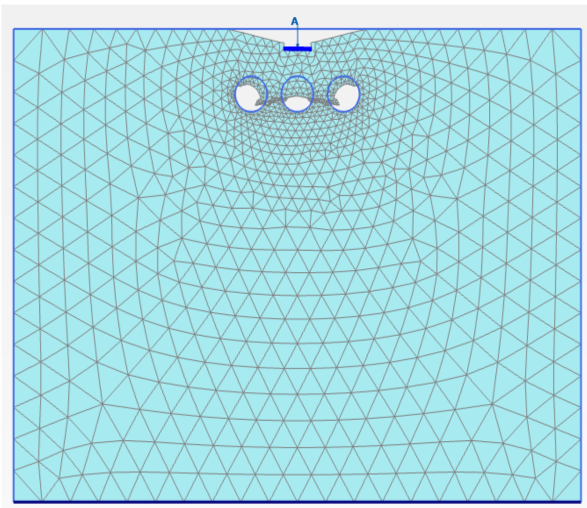

Fig. 5: Deformed Mesh

Table II summarizes all the varied parameters used in the study. The bearing capacity analysis of strip footing was carried out under the point load applied at the centre of footing.

TABLE II
CAVITY PARAMETER SINGLE FOOTING ABOVE THREE VOIDS

Single Footing				
Configuration	**X/B**	**Z/B**	**A (m^2)**	**S/B, Z_c /B**
All In One Row	0, 0.5, 1	0.5, 0.75, 1, 1.5, 2, 3	0.5	0.25
All In One Column	0, 0.5, 1	0.25	0.25, 0.5, 0.75, 1	0.25
Right Angle Placement	0, 0.5, 1	0.5	0.25, 0.5, 0.75, 1	0.5
Skew Placement	0, 0.5, 1	0.25	0.25, 0.5, 0.75, 1	0.25

V. RESULT AND DISCUSSION

The effect of cavity on the bearing capacity is evaluated by Bearing Capacity Ratio (BCR) as:

$$BCR = \frac{\text{Bearing Capacity of Soil with Cavities}}{\text{Bearing Capacity of Soils without Cavities}}$$

The magnitude of BCR can quantitatively evaluate the cavity effect on the bearing capacity of footing foundation. BCR is the reduction factor of bearing capacity for ground with no cavity.

Effect of Size and Eccentricity for Single Footing above Three Circular Cavities:

As shown in Fig.6 to Fig.9 for circular cavities In One Row, All In One Column, Right Angle Placement and Skew Placement parameters cavity depth, spacing between cavities and size has an influence on BCR.

i. *All In One Row*

As shown in Fig.6 shows the variation of BCR with respect to crest depth Z and eccentricity X. As Z and X increases the BCR increases. At Z/B reaches to the effect of cavities has no influence on bearing capacity.

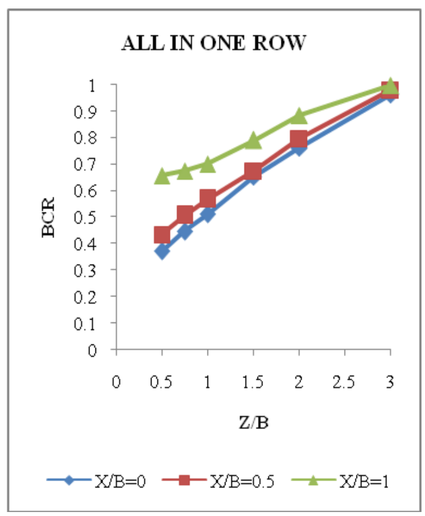

Fig.6: Variation of BCR with respect to Size and Eccentricity of Cavity for All In One Row

ii. *All In One Column*

As shown in Fig.7 shows the variation of BCR with respect to single cavity area A and eccentricity X. As area (A) increases the BCR decreases and BCR increases with increase in eccentricity(X).

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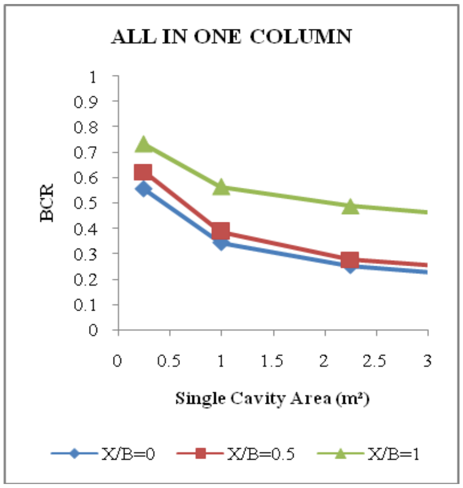

Fig.7: Variation of BCR with respect to Size of Cavity for All In One Column

iii. Right Angle Placement:

As shown in Fig.8 shows the variation of BCR with respect to single cavity area A and eccentricity X for Right Angle Placement. As area (A) increases the BCR decreases and BCR increases with increase in eccentricity(X).

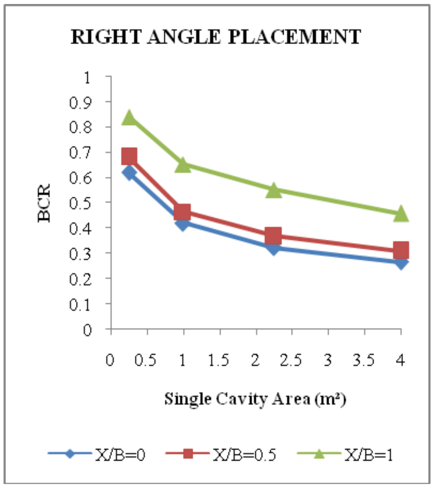

Fig.8: Variation of BCR with respect to Size of Cavity for Right Angle Placement

iv. Right Angle Placement:

As shown in Fig.9 shows the variation of BCR with respect to single cavity area A and eccentricity X for Right Angle Placement. As area (A) increases the BCR decreases and BCR increases with increase in eccentricity(X).

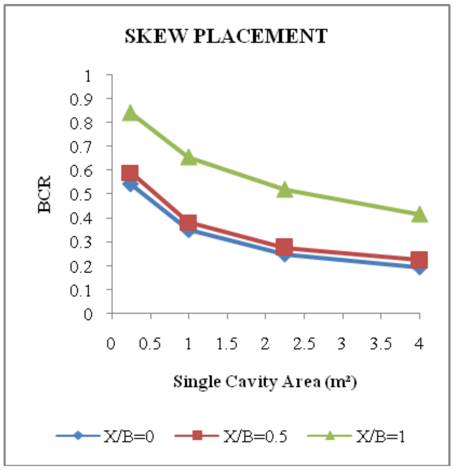

Fig.9: Variation of BCR with respect to Size of Cavity for Skew Placement

VI. CONCLUSIONS

From the above study following conclusions can be drawn,

i. Bearing Capacity Ratio (BCR) of shallow foundations in presence of underground cavities is less than in case of without cavities, depending on the geometry and configuration of cavities.
ii. Bearing Capacity Ratio (BCR) increases with increase in crest depth of cavities.
iii. Bearing Capacity Ratio (BCR) increases with increase in distance of the cavity from the center of footing.
iv. Bearing Capacity Ratio (BCR) decreases with increase in size of cavity.

Acknowledgement

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