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Performance of Strip Footing above Multiple Square Voids in C-Ø Soil

Dr. Sunil S. Pusadkar[1]
Head, Department of Civil
Govt. College of Engineering,
Jalgaon, India

Sarita S. Harne[2] Prof. S. W. Thakare[3]
[2]P.G. Student, [3]Associate Professor
Department of Civil Engineering
Govt. College of Engineering, Amravati, India

***Abstract*— Underground multiple cavities/voids can be created by different reasons such as tunneling, mining, water and gas networks and old conduits. These voids can cause serious engineering problem leading to instability of the foundation, incurring severe damage to the superstructure. With population growth there is need to study this geotechnical engineering problem regarding the foundation stability in these areas. In this paper, numerical investigation of such phenomenon is presented using PLAXIS, 2D software. This paper investigates the bearing capacity of surface strip footings on C-Ø soil with multiple square voids. The bearing capacity of strip footing influenced by placement of three voids and found that voids in single row influences more than other positions. The bearing capacity of strip footing with multiple voids is greatly influenced by position of first void.**

Keywords*— *Multiple Square Voids, Underground Square Cavity, Strip Footing, Finite Element Analysis Introduction

I. INTRODUCTION

The stability of any structure depends on bearing capacity of foundation soil, which plays major role in geotechnical engineering. The bearing capacity will change with presence of minerals in soil, with level of water table and with presence of cavities or voids in soil. The existence of underground void affects stability of rigid surface structures such as foundations, rigid pavements over tunnels and underground pipe lines and also the integral stability of structure. The void may exists exactly below the foundation or at any location within the critical region means the region of pressure bulb, it affects stability of footing.

Due to the population growth and in response to existing needs, the demand of tunnels for urban transportation has rapidly increased. These tunnels usually excavated close to the soil surface and their effects will develop to the ground level and can significantly affect the performance of shallow foundations located above these voids. Results of prior researches in this field indicated that the interaction between shallow foundation and underground voids has significant effects on the performance of shallow foundations.

The severity of damage due to presence of underground voids depends on the degree of vertical as well as lateral proximity of the voids to footing. The alternatives available to a geotechnical engineer are (i) to use piles or caissons to bridge the void and to bear on soil or rock below the void; (ii) to fill the void with acceptable materials; (iii) to relocate the foundation away from the void; and (iv) to excavate and found the foundation below the bottom of the void. From these alternatives relocation is practicable only if sufficient space is available. Other alternatives are very expensive and also are infeasible. To design a stable foundation system above a cavity, it requires a method of stability analysis for foundation above multiple cavities. Such a method is also essential for the economic design of foundations above other types of void/cavity.

The studies on the interaction between shallow foundation and tunnel focused on single or double voids which are illustrated below.

Baus and Wang (1983) studied an effect of shape and location on the bearing capacity of footing located above single void experimentally and analytically and concluded that there exists a critical depth below which the presence of a void has a negligible influence on the bearing capacity.

Peng *et al.* (2006) studied single square cavity effect on bearing capacity of foundation with respect to void depth and void eccentricity i.e., location using two dimensional elasto-plastic FEM.

Kiysumi *et al.* (2007) studied yielding pressure of spread footing above single and double voids and concluded that there is a strong tendency for a failure zone to develop near the nearest void.

Hussein (2013) carried a finite element analysis for stability of strip footing on sand bed of different relative densities with circular void and concluded that effect of voids on the BCR of sand bed is proportional inversely with relative density of sand.

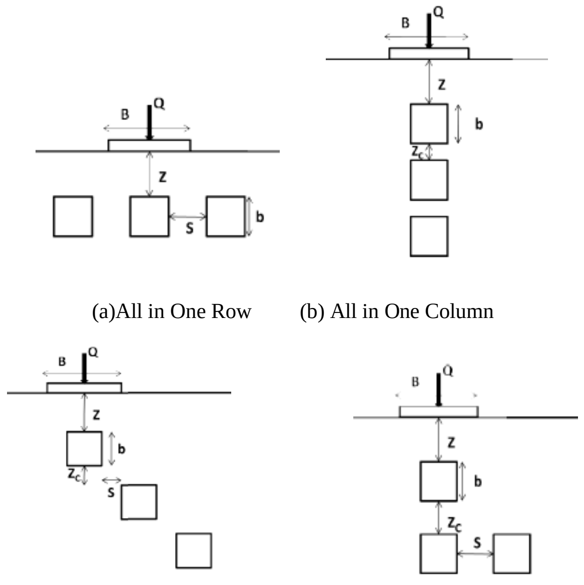
Lee *et al.* (2014) studied undrained stability of surface strip footings on clay over centered and eccentric single and double voids continuous void using finite element analysis.

In practice, there may more than two voids in the soil deposit which affects the bearing capacity of shallow foundations located above them. The study on the effect of three square voids on the bearing capacity of shallow footing doesn't exist with more than two voids. Therefore, this work focus on investigating the bearing capacity of the system of footing and three square voids for different widths of voids, embedment depth, and horizontal and vertical spacing between voids.

II. PROBLEM DEFINITION

The bearing capacity of strip footing on c-ϕ soil with three square voids in different configuration was consider for different widths of voids, embedment depth, and horizontal and vertical spacing between voids. As shown in the figures a strip rigid footing 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 voids is affected by location, shape, size and number of void which are expressed through dimensionless parameters i.e. size of void b/B, vertical distance of the top of cavity from bottom of footing Z/B, vertical distance between two cavities Z_C/B and horizontal distance between two cavities S/B are considered in this study. These configurations are divided in four groups, i.e., all in one row, all in one column, skew placement and right angle placement as shown in Fig. 1.



(a)All in One Row (b) All in One Column

(c) Skew Placement (d) Right Angle Placement

Fig. 1. Configurations of Voids

III. FINITE ELEMENT ANALYSIS

A commercially available two-dimensional finite element program PLAXIS 2D version 2012 was used to model the footing and three voids 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 are given in Table I.

TABLE I. SOIL PARAMETERS

Properties	Value
Unsaturated Unit weight	18 kN/m³
Young's modulus (E)	25000 kN/m²
Cohesion	50 kN/m²
Friction angle	28°
Dilatancy angle	0°
Poisson's ratio	0.3

The rigid concrete strip footing having 2 m width was modeled with parameters as given in Table II.

TABLE II. FOOTING PARAMETERS

Properties	Value
Unit weight	24 kN/m³
Axial stiffness (EA)	25000000 kN/m
Flexural rigidity (EI)	320000 kN-m²/m
Equivalent thickness	0.4 m
Poisson's ratio	0.2

Fig. 2 shows a typical 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 external boundaries were positions 9.5B laterally from edge of footing and 15B below ground surface. The global coarseness of the mesh adopted was fine. Cavity cluster was refined to remove discontinuity of elements. 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 Bearing Capacity Ratio (BCR).

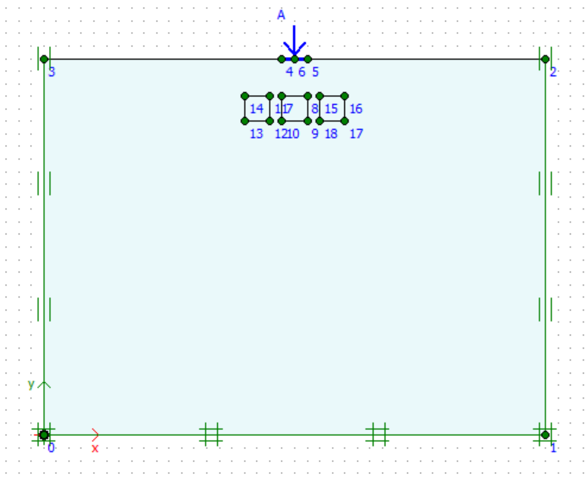


Fig. 2. Finite Element Mesh

Table III summarizes all the varied parameters used. The bearing capacity analysis of strip footing was carried out for the centric point load. As the b is 0.5m, 1m, 1.5m and 2m the area of single square cavity is 0.25m², 1m², 2.25m² and 4m² respectively.

TABLE III. DETAILS OF PARAMETERS

Configuration	No of Voids	b/B	Z/B	Z_c/B	S/B
All in One Row	3	0.5, 1, 1.5, 2	0.5, 0.75, 1, 1.5, 2, 3	-	0,0.25 ,0.5,1
All in One Column	3	0.5, 1, 1.5, 2	0.25, 0 .5	0, 0.25	-
Skew Placement	3	0.5, 1, 1.5, 2	0.25, 0.5, 0.75	0, 0.25	0, 0.25, 0.5, 1
Right Angle Placement	3	0.5, 1, 1.5, 2	0.5, 1	0, 0.25, 0.5, 1	0, 0.25, 0.5, 1, 2

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IV. RESULT AND DISCUSSION

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

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

The magnitude of BCR can quantitatively evaluate the cavity effect on the bearing capacity of footing foundation without voids subjected to same loading condition.

A. All in One Row

Fig.3 to Fig. 8 shows variation of BCR for square cavities in one row for different void depth, spacing between voids and size. The bearing capacity found to be reduces in all cases with no void condition. As the void spacing increases, the bearing capacity increases. As size of void increases, the bearing capacity reduces in all case.

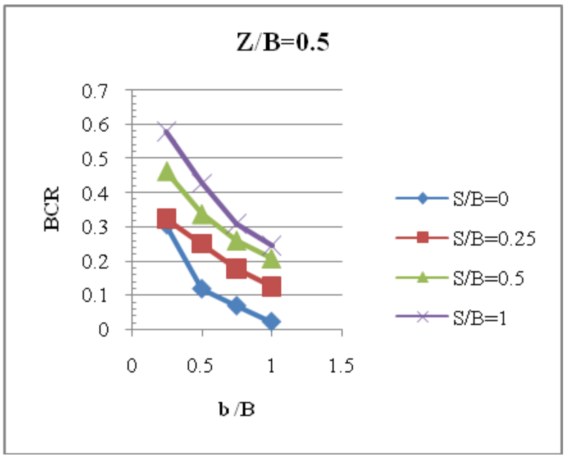

Fig. 3. Variation of BCR with respect to Size of Cavity for Z/B=0.5

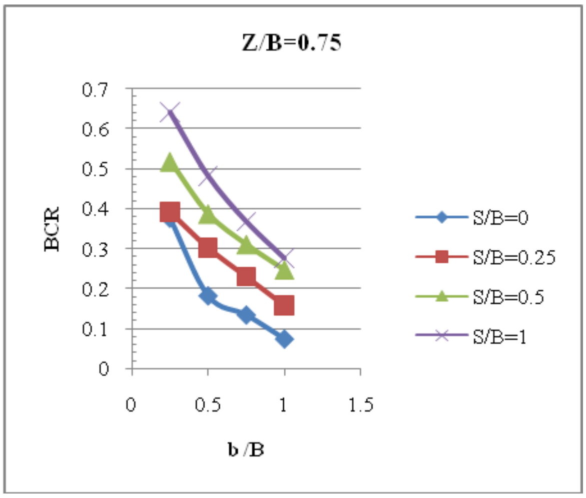

Fig. 4. Variation of BCR with respect to size of Cavity for Z/B=0.75

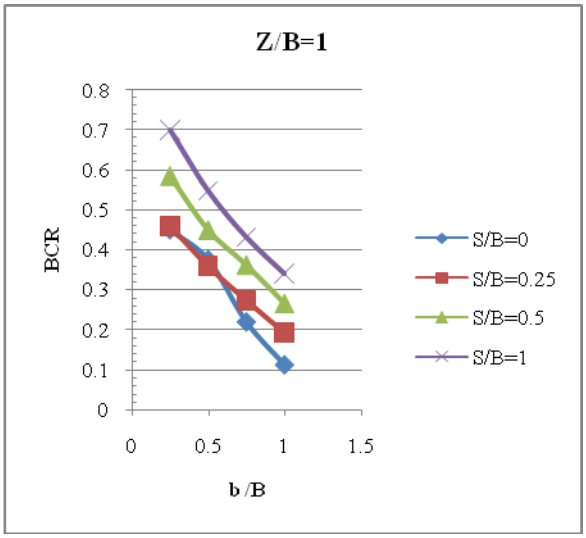

Fig. 5. Variation of BCR with respect to Size of Cavity for Z/B=1

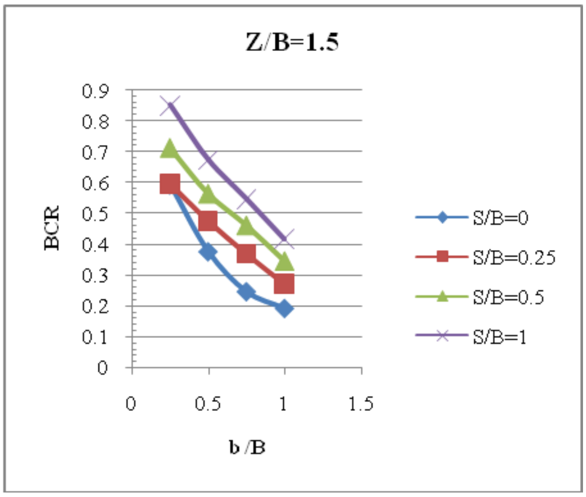

Fig. 6. Variation of BCR with respect to Size of Cavity for Z/B=1.5

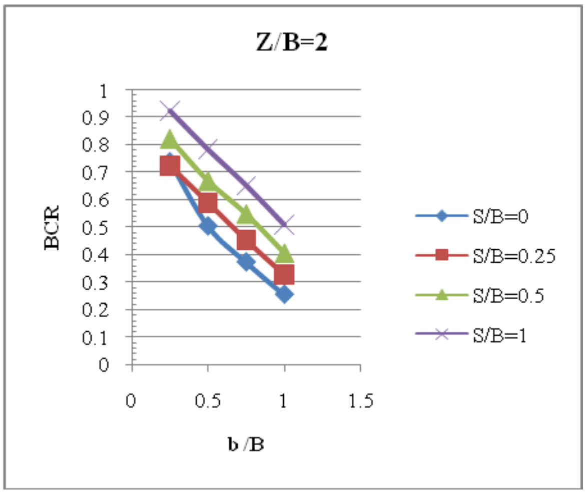

Fig. 7. Variation of BCR with respect to Size of Cavity for Z/B=0.5

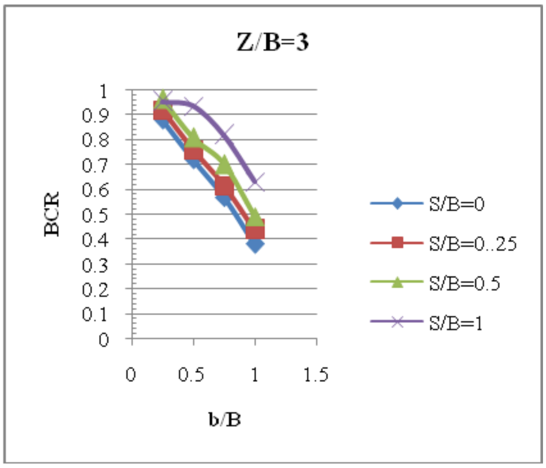

Fig. 8. Variation of BCR with respect to Size of Cavity for Z/B=3

B. *All in One Column*

As shown in Fig. 9 and Fig. 10, BCR reduces with respect to size of void and vertical distance of void. However, the distance between cavities has less influence on BCR.

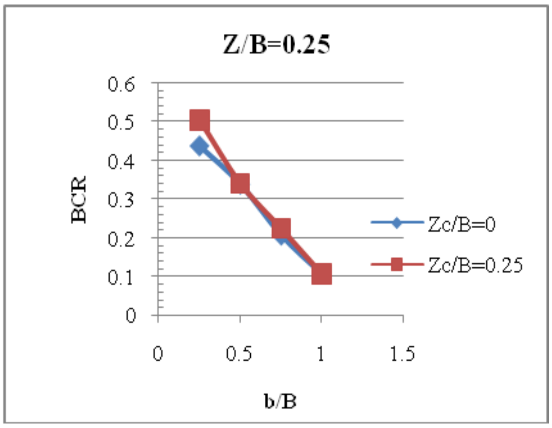

Fig. 9. Variation of BCR with respect to Size of Cavity for Z/B=0.25

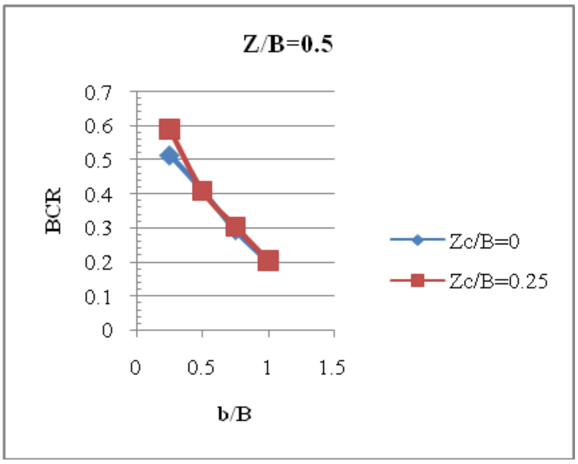

Fig. 10. Variation of BCR with respect to Size of Cavity for Z/B=0.5

C. *Skew Placement*

Fig.11 to Fig. 22 shows the variation of BCR with respect to size of cavity for various depth of voids (Z/B), spacing of voids (S/B). In skew placement of voids, the BCR is influenced by vertical spacing of first void and meagerly affected by distance between voids.

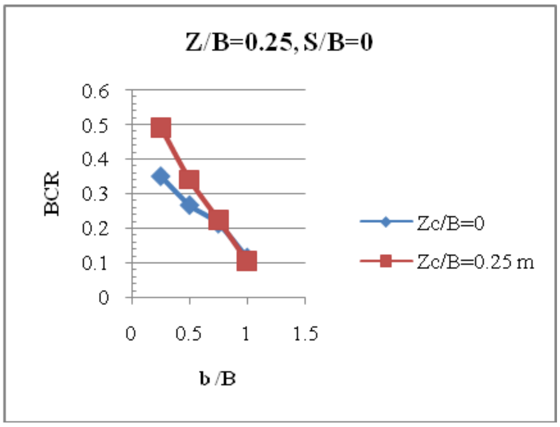

Fig. 11. Variation of BCR with respect to Size of Cavity for Z/B=0.25, S/B=0

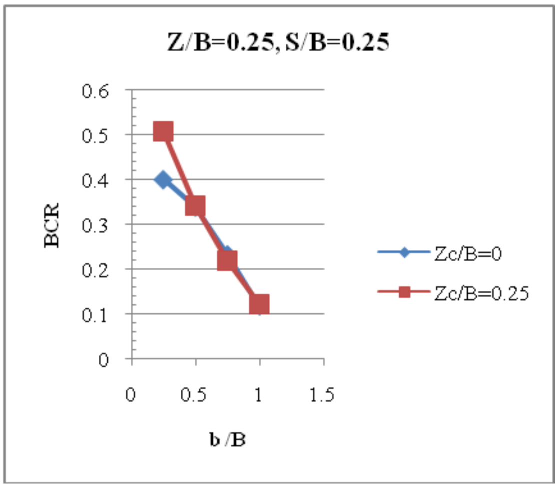

Fig. 12. Variation of BCR with respect to Size of Cavity Z/B=0.25, S/B=0.25

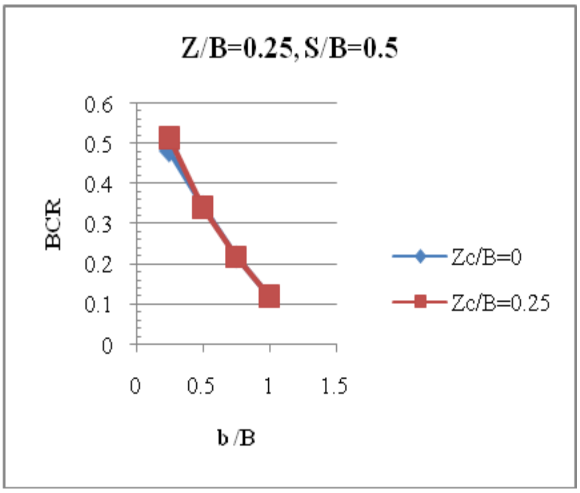

Fig. 13. Variation of BCR with respect to Size of Cavity Z/B=0.25, S/B=0.5

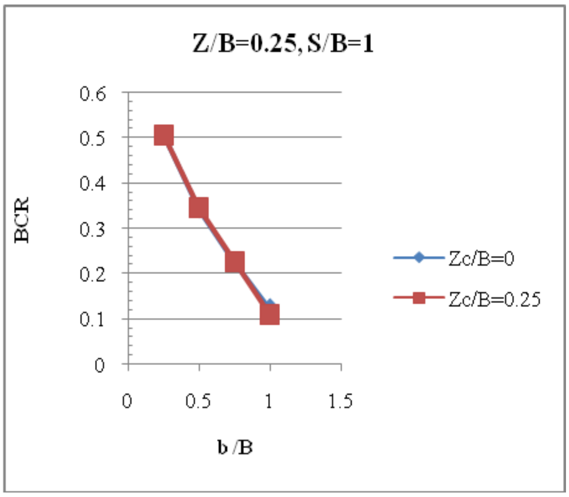

Fig. 14. Variation of BCR with respect to Size of Cavity Z/B=0.25, S/B=1

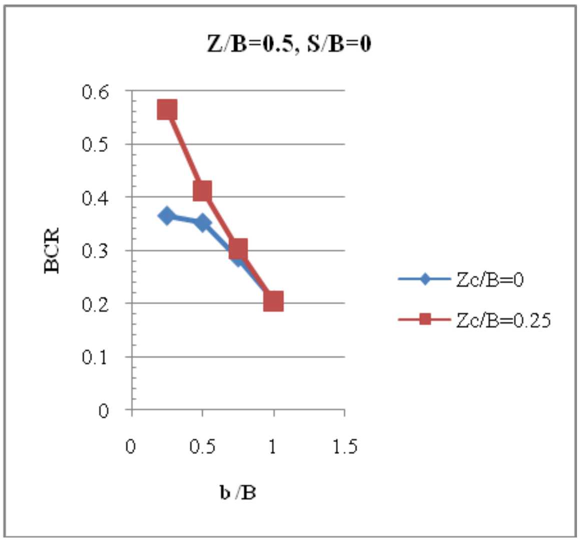

Fig. 15. Variation of BCR with respect to Size of Cavity Z/B=0.5, S/B=0

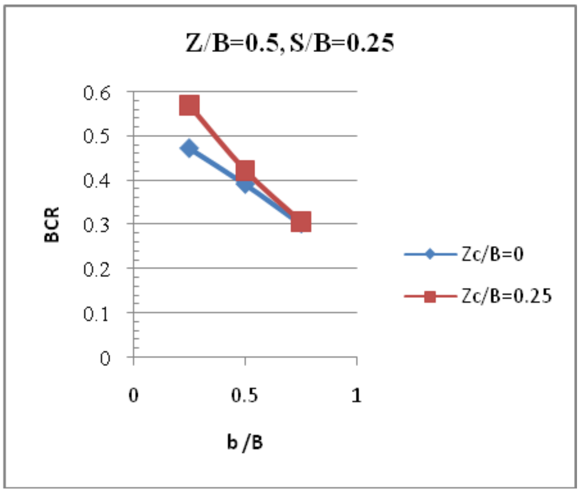

Fig. 16. Variation of BCR with respect to Size of Cavity Z/B=0.5, S/B=0.25

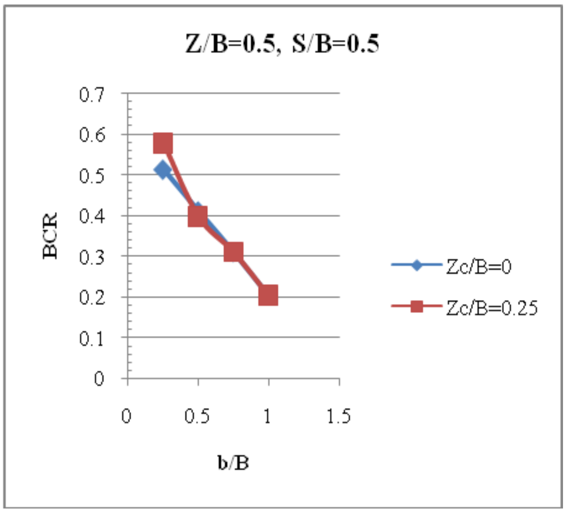

Fig. 17. Variation of BCR with respect to Size of Cavity Z/B=0.5, S/B=0.5

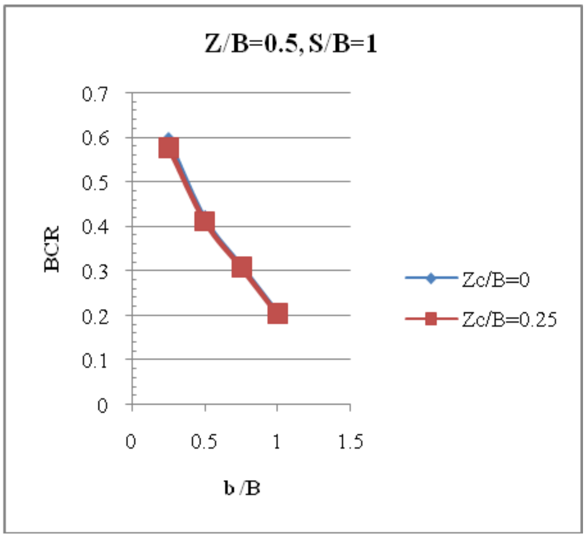

Fig. 18. Variation of BCR with respect to Size of Cavity Z/B=0.5, S/B=1

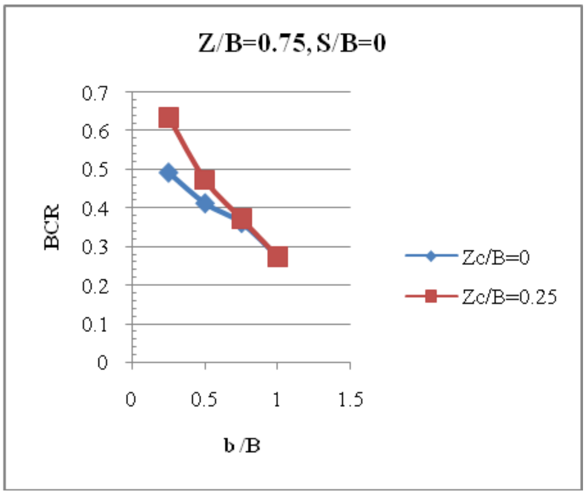

Fig. 19. Variation of BCR with respect to Size of Cavity Z/B=0.75, S/B=0

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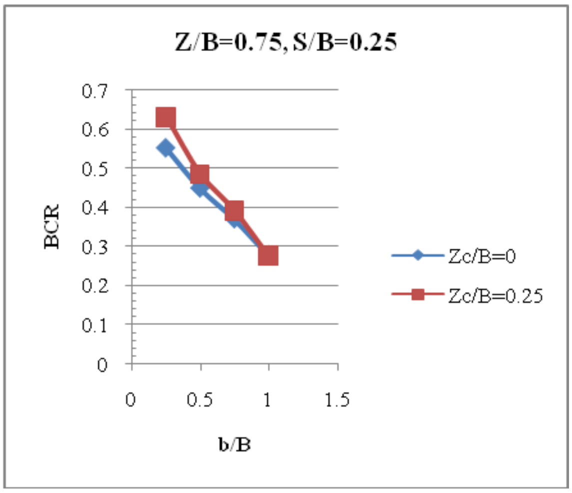

Fig. 20. Variation of BCR with respect to Size of Cavity Z/B=0.75, S/B=0.75

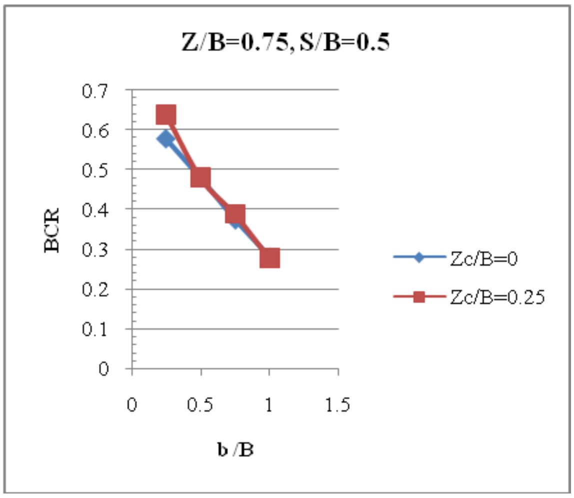

Fig. 21. Variation of BCR with respect to Size of Cavity Z/B=0.75, S/B=0.5

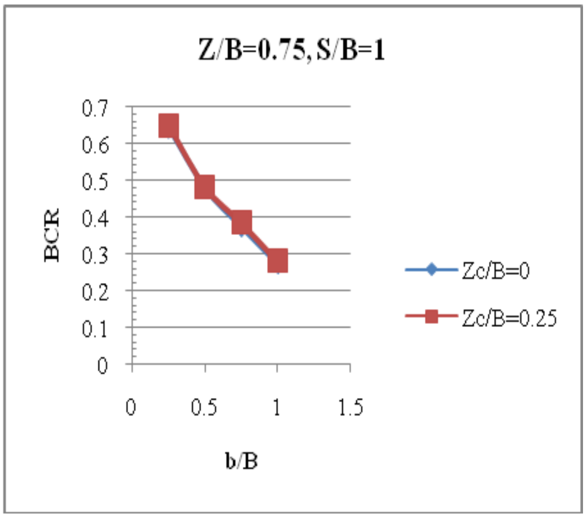

Fig. 22. Variation of BCR with respect to Size of Cavity Z/B=0.75, S/B=1

D. Right Angle Placement

Fig. 23 to Fig. 32 shows the variation of BCR with respect to size for different Z/B, S/B and Zc/B ratios for right angle placement of voids. BCR decreases with increase in size of cavity and increases with increase in void depth for constant size and spacing. As the size increases vertical spacing has no influence on BCR.

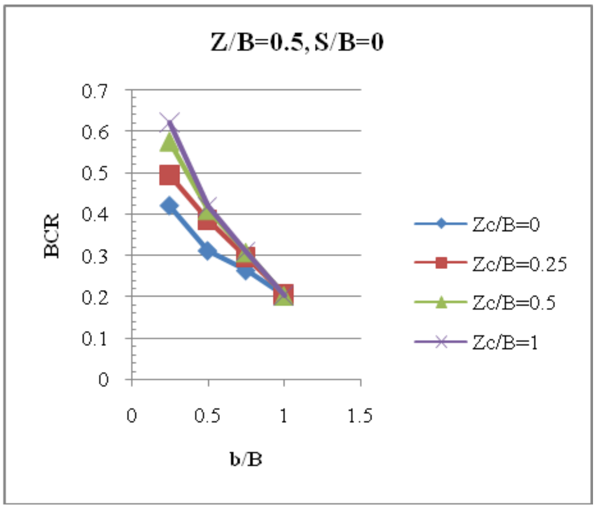

Fig. 23. Variation of BCR with respect to Size of Cavity Z/B=0.5, S/B=0

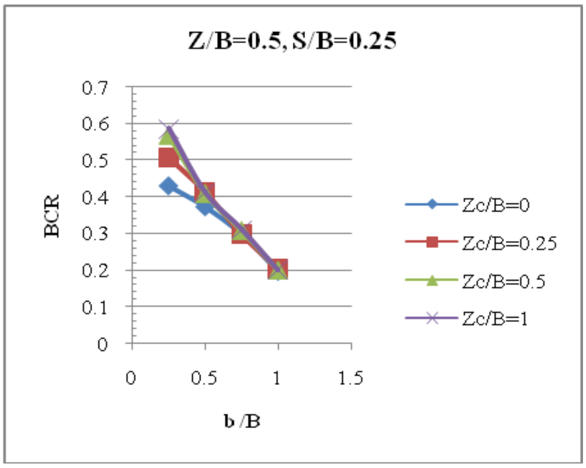

Fig. 24. Variation of BCR with respect to Size of Cavity Z/B=0.5, S/B=0.25

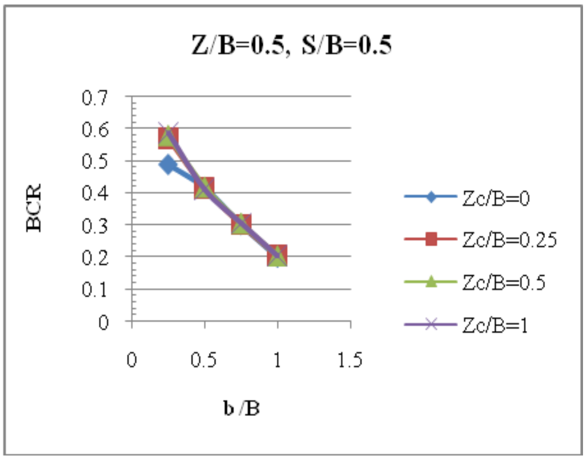

Fig. 25. Variation of BCR with respect to Size of Cavity Z/B=0.5, S/B=0.5

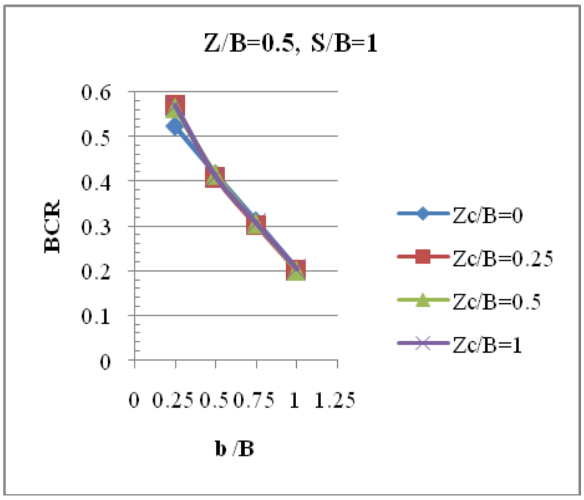

Fig. 26. Variation of BCR with respect to Size of Cavity Z/B=0.5, S/B=1

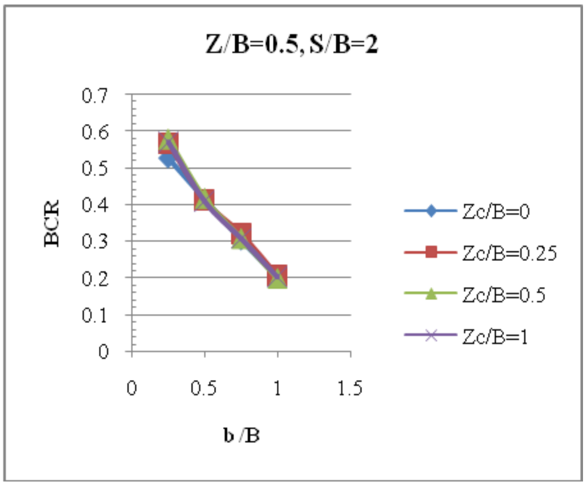

Fig. 27. Variation of BCR with respect to Size of Cavity Z/B=0.5, S/B=2

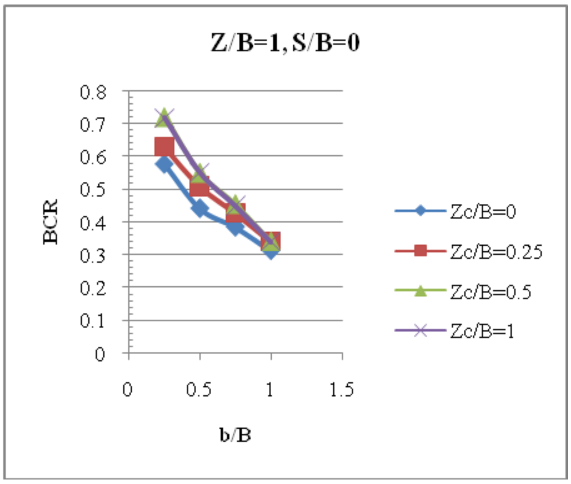

Fig. 28. Variation of BCR with respect to Size of Cavity Z/B=1, S/B=0

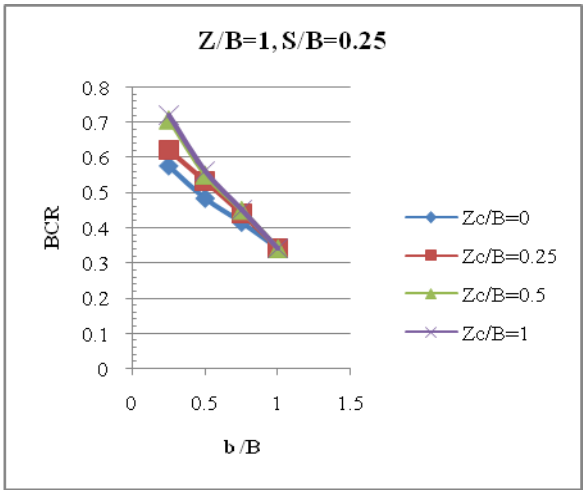

Fig. 29. Variation of BCR with respect to Size of Cavity Z/B=1, S/B=0.25

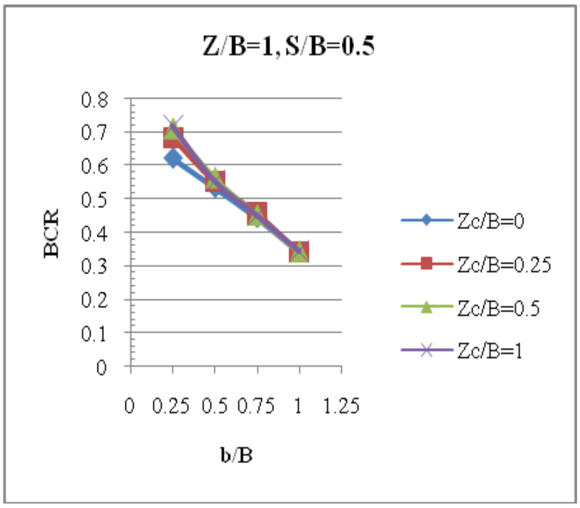

Fig. 30. Variation of BCR with respect to Size of Cavity Z/B=1, S/B=0.5

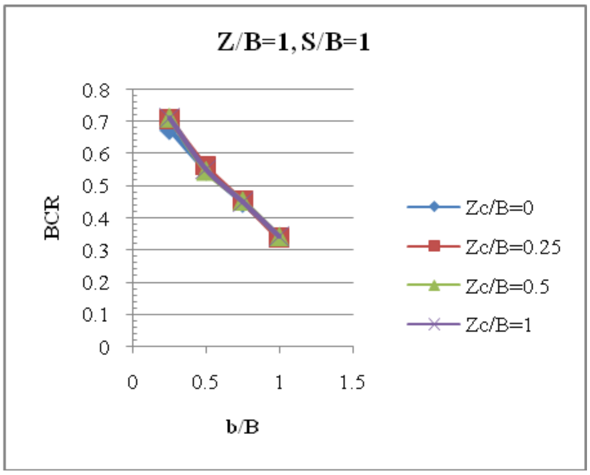

Fig. 31. Variation of BCR with respect to Size of Cavity Z/B=1, S/B=1

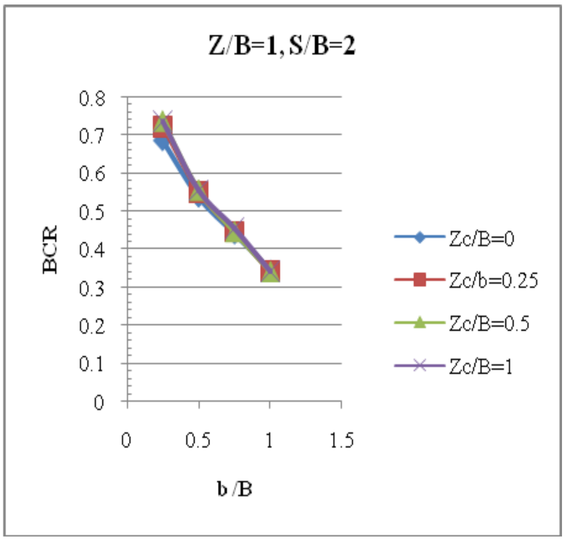

Fig. 32. Variation of BCR with respect to Size of Cavity Z/B=1, S/B=2

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V. CONCLUSION

i. Three voids beneath a surface footing leads to decrease the bearing capacity of footing depending on the geometry of system i.e., stability and bearing capacity of the footing significantly affected by the presence of the void.

ii. In all types of configuration, increasing the void size causes decrease in the bearing capacity of the footing located above them while the relative vertical and horizontal distance between voids and footing is kept constant.

iii. As the void depth increases the BCR increases.

iv. The bearing capacity of the footing situated above three square cavities is influenced by the pattern of placement of void.

v. Voids in a single row influences bearing capacity of footing than any other placement of voids.

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