Bearing Strength of Circular Concrete Blocks Varies in Heights Subjected to Concentrically Circular Loaded Bearing Plate

N A Yahya¹, N Md Nor², R Md Zain¹, C L Oh¹ and S W Lee³

¹ Fakulti Kejuruteraan Awam, Universiti Teknologi MARA, 45400 Shah Alam, Selangor, Malaysia
² Fakulti Kejuruteraan Awam, Universiti Teknologi MARA, 13500 Permatang Pauh, Pulau Pinang, Malaysia
³ Fakulti Kejuruteraan Awam, Universiti Teknologi MARA, 81750 Masai, Johor, Malaysia

*Corresponding author: azmi_216@yahoo.com

Abstract. Bearing strength is vital when transferring the heavy loaded over limited area of concrete surface. This paper examines the bearing strength of circular concrete blocks with different heights loaded under circular bearing plate. Bearing strength of concrete are strongly related to the compressive strength of concrete and the ratio of total area of concrete surface to loaded steel bearing area. This study focuses on the confinement effects of concrete for different heights of concrete blocks. Most existing design codes propose specific criteria to prevent bearing failure but not included size effect such as height of concrete block. Height of concrete block is one of important criteria in designing concrete bearing especially for shallow or slender structural supports. For the present study, there are total of 18 concrete blocks has been tested under compression and bearing test, i.e. 9 blocks for compression test (150 mm³) and 9 blocks for bearing test in three different heights, i.e. 50 mm, 100 mm and 200 mm with constant concrete diameter of 100 mm. The confinement effect of concrete is analysed based on two dimensionless units, i.e. (fb/fc) and (h/d) ratios. The failure modes for different height of concrete blocks observed. The effect of different heights on concrete bearing also explained.

1. Introduction

Structural performance for bearing strength is one of important design criteria for all concrete support types such as bridge plinth, concrete bridge pedestal, column footing foundation, anchorage for post-tension member and concrete transfer load corbel. The fundamental knowledge of bearing strength was developed based on confinement effect when load transmit to concrete surface through contact interaction of steel bearing plate. The structural performance of concrete bearings examines in many factors for the unreinforced and reinforced concrete bearing blocks. Earlier research is focused on the confinement effect of concrete bearing [1-5].

Many theories of structural performance for concrete bearing were developed that based on cone or wedge failure at the contact area of concrete bearing. The main failure mode is due to penetration of steel plate on concrete block through formation of cone failure that influence the splitting crack of the concrete blocks [6-9]. The bearing design equation for concrete incorporates with the factor of safety to account the allowable bearing stress. The allowable bearing strength of unconfined concrete [10] is taken as;
For allowable bearing stress for unconfined concrete [11] is taken as;
\[
\left( \frac{f_b}{f'_c} \right) = 0.85 \phi \left( \frac{A_2}{A_1} \right)^{0.5} \leq 2.0 \phi
\]

whereas \(f_b\) is the bearing strength of concrete, \(f'_c\) is the compressive strength of concrete, \(\phi\) is 0.6 for the safety factor, \(A_1\) is the area of bearing plate and \(A_2\) is the total surface of the concrete.

Previous researchers [4-5] derived empirical relationships between bearing strength and compressive strength for structural concrete. However, they found that design codes for allowable bearing strength characteristic is too conservative because the design limit [10-11] for bearing strength is limited to 1.19 to 1.20 of compressive strength respectively. It was also noted that the effect of concrete block height is excluded in the concrete bearing strength prediction. For the present study, the research focuses on the bearing strength of circular concrete block subjected to concentrated vertical load. This research also examines bearing strength for different block heights of circular concrete block.

2. Methodology
For the present study, the confinement effect of concrete bearing is determined based on the compression test and the concrete bearing test. For the compression test, total of nine (9) concrete cubes (150mm\(^3\)) tested for concrete mix design grade 25 MPa. For the bearing test, total of nine (9) circular concrete blocks in three different heights were examined, i.e. 50 mm, 100 mm and 200 mm.

3. Compression and concrete bearing test procedure
For the compression test, the concrete cubes were tested to determine the compressive strength using the concrete compression test machine with 3000 kN capacity for 7 days, 14 days and 28 days after completed the curing process in the curing tank (see Figure 1). The maximum compression load of concrete were recorded up to concrete failure. The target compressive strength is about 25 MPa. The constant rate of 6.8 kN/s was applied for all specimens.

Figure 1. Compression test.
The bearing strength were performed at the concrete age for 28 days. Total of nine (9) concrete blocks were tested in three different heights, i.e. 50 mm, 100 mm and 200 mm. The loading rate [9] was used for the bearing test is 6.8 kN/s. The constant circular loading plate with 100 mm diameter and 10 mm thickness was used as the loaded bearing plate and were applied at the centre of concrete surface in the bearing test.

![Concrete bearing test](image)

**Figure 2.** Concrete bearing test: steel to concrete contact-interaction.

### 4. Compression test and concrete bearing test results

Total of nine (9) of 150 mm³ concrete cubes were tested for 7, 14 and 28 days that based on loading rate for compression test is 6.8 kN/s. Figure 3 shows the consistent compression test results in the range of 25 MPa to 27 MPa. The compressive strength of concrete for 28 days are 25.34 MPa, 26.51 MPa and 27.17 MPa. The average compressive strength for 28 days is 26.34 MPa.

![Compressive strength at 28 days](image)

**Figure 3.** The compressive strength at 28 days.

In the bearing strength test, the effect of bearing strength on different height concrete is based on three designated block heights for shallow concrete bearing were considered, i.e. 50 mm, 100mm and 150 mm. For each height, minimum of three specimens were tested in order to determine the average of bearing strength of concrete blocks. Table 1 shows three different (h/d) ratios of 0.33 to 1.33. Table 1 shows all concrete specimens having the constant contact area of 7855 mm² that based on constant steel
bearing plate diameter of 100 mm. The experimental results of concrete bearing is based on confinement effect \((\text{fb}/\text{fc})\) as tabulated in Table 2.

### Table 1. Circular blocks with three different \((\text{h}/\text{d})\) ratios.

| Sample | Bearing Plate Size dia. \((\text{mm}^2)\) | Contact Area, \(A_s \text{ (mm}^2\) | height, \(h \text{ (mm)}\) | diameter, \(d \text{ (mm)}\) | \(\text{h}/\text{d} \text{ ratio (dimensionless)}\) |
|--------|---------------------------------|----------------|----------------|----------------|------------------|
| 1      | 100                             | 7855           | 200            | 150            | 1.33             |
| 2      | 100                             | 7855           | 100            | 150            | 0.67             |
| 3      | 100                             | 7855           | 50             | 150            | 0.33             |

### Table 2. Confinement effect \((\text{fb}/\text{fc})\).

| Sample | Concrete surface, \(A_c \text{ (mm}^2\) \(^a\) | \(A_c/A_s \text{ \(^b\)}\) | Maximum Load, \(P_u \text{ (kN)}\) | Average \(\text{fb}^b \text{ (N/mm}^2\) | \(\text{fb}/\text{fc}\) |
|--------|---------------------------------|----------------|----------------|----------------|----------------|
| 1      | 17673.75                        | 2.25           | 125.70         | 125.70         | 16.00          | 0.61           |
| 2      | 17673.75                        | 2.25           | 120.50         | 125.70         | 16.00          | 0.61           |
| 3      | 17673.75                        | 2.25           | 130.90         | 125.70         | 16.00          | 0.85           |
| 4      | 17673.75                        | 2.25           | 148.90         | 125.70         | 16.00          | 0.85           |
| 5      | 17673.75                        | 2.25           | 180.30         | 175.07         | 22.29          | 0.85           |
| 6      | 17673.75                        | 2.25           | 196.00         | 175.07         | 22.29          | 0.85           |
| 7      | 17673.75                        | 2.25           | 256.40         | 240.93         | 30.67          | 1.16           |
| 8      | 17673.75                        | 2.25           | 233.80         | 240.93         | 30.67          | 1.16           |
| 9      | 17673.75                        | 2.25           | 232.60         | 240.93         | 30.67          | 1.16           |

\(^a\)Bearing strength, \(\text{fb} \text{ (N/mm}^2\) = ultimate load \((\text{N})/ contact area \text{ (mm}^2\))

\(^b\)Loaded plate \(A_s\) is 100 mm diameter circular plate

For the bearing test, 200 mm-height circular concrete block has lowest bearing stress 16.00 N/mm\(^2\) as compared to 100 mm and 50 mm-height blocks (22.29 and 30.67 N/mm\(^2\)). The experimental results indicate that the concrete bearing loss its capacity as its increase the block height. The significant relationship can be developed based on the concrete confinement effects \((\text{fb}/\text{fc})\) and \((\text{h}/\text{d})\) ratios as shown in Figure 4.

Figure 4 shows that the confinement effect of concrete was gradually decreasing as increase the height of concrete blocks. It was found that the confinement effect also was reduced up almost 50% from 1.16 to 0.61 with the increasing \((\text{h}/\text{d})\) ratio from 0.33 to 1.33. These results were confirming that the heights of concrete bearing block has significant effect on confinement effect in concrete bearing. This factor is considered critical in designing concrete bearing especially dealing with slender concrete bearing where \((\text{h}/\text{d})\) ratio is greater that shallow concrete bearing. The relationship of confinement effect \((\text{fb}/\text{fc})\) and \((\text{h}/\text{d})\) ratio of concrete bearing for this research can be expressed as:

\[
(f_b/f_c) = -0.5285(h/d) + 1.2828
\]
Figure 4. Bearing test results based on (fb/fc) ratio to (h/d) ratio relationships.

5. Failure modes
The failure mode of concrete bearing mainly caused by penetration of the steel bearing plate on the concrete contact surface that cause crack extending to the outer edge of contact area which appear as the edge cracking. The critical edge crack also exhibited at the outer edge of the contact area. The line edge cracks were initiated from contact area and it was extended to the concrete edge as shown in Figure 5.

Figure 5. Crack pattern and intensity for 50 mm, 100 mm and 200 mm block heights.

From visual observation, it was noted that the edge-cracking pattern and crack intensity are less for the 200 mm height-concrete blocks as compared to the 50 mm-height concrete blocks. The small radial cracks also appeared around the circular contact area. The vertical cracking initiated at the bearing contact plates and across the top of concrete surface and spread in downward direction until its failure. This similar finding [9] was confirming the concrete cone or wedge splitting and shear failure formation in the concrete bearing.

6. Conclusions
This research aim to examine concrete bearing performance based on effect of different heights of circular loaded bearing plate, the few conclusions can be made through these findings:
The circular concrete block for low block height (50 mm) has higher load capacity as compared to 150 mm or 200 mm concrete block heights. It was found that the confinement effect also was reduced up almost 50% from 1.16 to 0.61 with the increasing (h/d) ratio from 0.33 to 1.33.

It was also found that the (h/d) ratio has high significant effect on confinement effect of concrete. The experimental results show that increase of the (h/d) ratio can decrease the confinement effect of concrete.

The formation of edge-cracking pattern and crack intensity are greater for the 50 mm-height concrete block as compared to 200 mm-height concrete block. This indicates that the level of damage is higher for the shallow concrete bearing because it able to carry greater bearing capacity as compare to shallow bearing concrete.

Prior to global failure of concrete bearing, the results indicate that radial cracking initiate from the edge of contact area. These crack lines also spreading across the top surface and propagated downward of the concrete block which confirming the failure mechanism of concrete bearing due to concrete spalling and shear failure of concrete.

7. References

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