Bearing strength of concrete for difference heights of concrete blocks

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Abstract. Bearing strength of concrete is important design criteria to transmit load safely to concrete supports especially in column-foundation, corbel, bridge pedestal, support anchorage, post-tension member and other types of structure supports. Most of existing formula for concrete bearing is mainly related to its compressive strength and steel-to-concrete area ratios. Effect of different heights of concrete supports on concrete bearing is not clearly explained. Therefore, this paper is carried out to investigate the effect of concrete bearing for different heights of concrete blocks under the compression load. The confinement effects of concrete bearing on different height is also determined. Experimental results indicate that the confinement effect and bearing strength of concrete are decreased with increasing of concrete blocks heights due to slenderness effects.

1. Introduction

Bearing strength of concrete is important design criteria when designing any structure supports such as concrete footing, bridge pedestals, corbels, anchorage zone, construction fixing, bridge bearing and in post-tension members. Structural behavior of concrete bearing is strongly related the bearing capacity of concrete block loaded through a steel bearing plate. Most of existing formulas in the Australian standard, the American Concrete Institute (ACI) and the AASHTO LFRD for concrete bearing depend on concrete compressive strength and ratio of concrete-to-steel area.

Most of research works for concrete bearing usually conducted through experimental works. The early research whose responsible for investigating the bearing strength of construction materials is Bauschinger in late 1800s. The author has developed a cubic root equation for concrete bearing based on testing of rock specimens.

\[ f = f_{c} \sqrt[3]{\frac{A_1}{A_2}} \]
where $f_c$ is compressive strength of concrete, $A_1$ is unloaded area and $A_2$ is loaded area.

However, the accuracy of the prediction for concrete application is questionable. So, the Bauschinger’s formula was modified as square root form based on the Komendant (1952) and it used for the America Concrete Institute (ACI).

$$f = \phi 0.85 f_c \sqrt{\frac{A_1}{A_2}}$$

where $\phi$ is 0.7 (bearing)

Most of existing formulations for concrete bearing are not included the effect of different block heights. In concrete supports, structure support can be designed as shallow or slender footings. For example, concrete bearing pedestals in bridge is considered as a shallow footing as their height-to-width ratio lesser than 1 as highlighted by Yahya and Dhanasekar (2014, 2017). However, majority of concrete specimens in previous studies focused on height-to-width ratio greater than 1 excepts some work carried out by Meyerhof (1953), Au and Baird (1960), Hyland and Cheng (1970), Hawkins (1970) and Adebar and Zhou (1993) as tabulated in Table 1.

**Table 1.** Specimen size used in bearing strength of concrete block (from 1953 to 2014)

| Researcher (year) | Study | Specimen sizing: length × width × height (block) | Height-to-width ratio (dimensionless) |
|------------------|-------|-------------------------------------------------|-------------------------------------|
| Meyerhof (1953)  | Concrete and rock blocks | 152.4 × 152.4 × 38.1 | 0.25<sup>a</sup> |
|                  |       | 152.4 × 152.4 × 76.2 | 0.5<sup>a</sup> |
|                  |       | 152.4 × 152.4 × 152.4 | 1 |
|                  |       | 304.8 × 304.8 × 152.4 | 0.5<sup>a</sup> |
|                  |       | 457.2 × 457.2 × 152.4 | 0.5<sup>a</sup> |
| Shelton (1957)   | Concrete block | 203.2 × 203.2 × 203.2 | 1 |
| Au and Baird (1960) | Concrete block | 203.2 × 203.2 × 203.2 | 1 |
|                  |       | 203.2 × 203.2 × 101.6 | 0.5<sup>a</sup> |
| Hawkins (1968a)  | Concrete blocks loaded to rigid plates | 152.4 × 152.4 × 152.4 | 1 |
|                  |       | 228.6 × 228.6 × 228.6 | 1 |
|                  |       | 101.6 dia. × 203.2 | 2 |
|                  |       | 152.4 dia. × 304.8 | 2 |
| Hawkins (1968b)  | Concrete blocks loaded to flexible plates | 152.4 × 152.4 × 152.4 | 1 |
|                  |       | 254 × 254 × 254 | 1 |
|                  |       | 203.2 dia. × 304.8 | 2 |
| Hyland and Chen (1970) | Concrete block with hole | 153 × 153 × 153 | 1 |
|                  |       | 153 × 153 × 76.5 | 0.5<sup>a</sup> |
|                  |       | 153 × 153 × 51 | 0.33<sup>a</sup> |
| Hawkins (1970)   | Concrete for strip loadings | 152 × 381 × 712 | 1.87 |
|                  |       | 102 × 457 × 1015 | 2.22 |
|                  |       | 102 × 457 × 762 | 1.67 |
|                  |       | 102 × 457 × 635 | 1.39 |
|                  |       | 102 × 457 × 508 | 1.11 |
|                  |       | 102 × 457 × 381 | 0.83<sup>a</sup> |
|                  |       | 102 × 457 × 1015 | 2.22 |
| Niyogi and Das (1978) | Combined lateral and vertical concentrated load | 75 × 300 × 300 | 1 |
| Ince and Arici   | Size effects of | 50 × 50 × 50 | 1 |
(2004)  |  concrete cube  |  100 × 100 × 100  |  1  
|-------|----------------|------------------|  |
|       |                |  200 × 200 × 200  |  1  
Adebar and Zhou (1993) | Compressive strut confined by plain concrete | 152.4 dia. × 304.8 | 2  
|       |                | 203.2 dia. ×304.8 | 1.5  
|       |                | 254 dia. × 228.6 | 0.9a  
|       |                | 254 dia. × 457.2 | 1.8  
|       |                | 254 dia. × 914.4 | 3.6  
|       |                | 304.8 dia. × 228.6 | 0.75a  
|       |                | 304.8 dia. × 304.8 | 1  
|       |                | 304.8 dia. × 914.4 | 3  
|       |                | 355.6 dia. × 228.6 | 0.64a  
|       |                | 335.6 dia. × 457.2 | 1.29  
|       |                | 355.6 dia. × 914.4 | 2.57  
|       |                | 457.2 dia. × 228.6 | 0.5a  
|       |                | 457.2 dia. × 301.8 | 0.67a  
|       |                | 457.2 dia. × 457.2 | 1  
|       |                | 457.2 dia. × 914.4 | 2  
|       |                | 609.6 dia. × 304.8 | 0.5a  
Ahmed et al. (1998) | Reinforced concrete | 200 × 200 × 300 | 1.5  
Ravindrarajah (1999) | Concrete containing polystyrene | 200 × 200 × 200 | 1  
Roberts-Wollmann et al. (2006) | Lightweight concrete | 152 dia. × 304 | 2  
Scheffers et al. (2010) | CFRP confined concrete | 50 × 150 × 150 | 1  
Zhou et al. (2013) | Reactive powder concrete reinforced by steel fibers | 200 × 200 × 400 | 2  
Bonetti et al. (2014) | Confined concrete | 203 × 203 × 406 | 2  

*a-height-to-width ratio lesser than 1*

By referring to Table 1, majority of studies on the concrete bearing using the concrete blocks with height-to-width ratio are greater than 1. The outcome of these research findings may not represent the actual behaviour of shallow concrete footing with low height-to-width ratio. Eventually there are number of studies on bearing using low height-to-width ratios but it is mainly for rubber bearing pads used in elastomeric bearing (Hamzeh et al., 1998; Yazdani et al., 2000; Yoon et al., 2004; Lehman et al., 2005; Mounir et al., 2006). Thus, it is not applicable for concrete footing. Therefore, further study is needed to investigate the effect of this key factor on the confinement effects on concrete blocks. This paper attempts to perform this key task.

2. Methodology

2.1 Specimen preparation

A total of 20 concrete cubes has been prepared for compression and bearing strength test. Four samples of concrete cube are prepared in steel mould with dimension of 150mm × 150mm × 150mm for compression test. Another 16 concrete blocks have same concrete surface of 200mm × 200mm in four different heights of 50mm, 100mm, 200mm and 400mm. Table 2 shows the numbers of samples for material and structural testing.
Table 2. No. of specimens for testing

| Dimension (mm) | Number of samples | Type of testing          |
|----------------|-------------------|--------------------------|
| 150mm x 150mm  | 150mm             | 4                        | Compression Test         |
| 50mm           |                   |                          |                          |
| 200mm x 200mm  | 16                | Bearing Strength Testa   |
| 100mm          |                   |                          |
| 200mm          |                   |                          |
| 400mm          |                   |                          |

*aTested with steel bearing plate of 100mm × 100mm

3. Compression Test
The compression tests have been conducted based on four (4) concrete cubes with dimension of 150mm x 150mm x 150mm. The loading rate for compression test is set for 6.8 KN/s based on the pace loading rate limit in ASTM C29. The compression test machine has 3000KN capacity. The test procedure was conducted in accordance to BS8110-4:1997. Figure 1 shows the compression testing machine used for the compressive test.

Figure 1. Compressive test machine

The compression specimens are removed from the mould and stored into the curing tank for 28 days with temperature between 22° to 25° to ensure the concrete for proper curing. The concrete surface was also cleaned to achieve better results. As concrete block reaches the failure, the testing machine is stopped manually to prevent further damage to the testing machine. The compression strength is determined by divided the compression load by the concrete area. The result of compression test is tabulated as shown in Table 3.

Table 3. Result of compression test

| Sample | Compression strength, fc’ (MPa) | Average |
|--------|---------------------------------|---------|
| 1      | 36.65                           |         |
| 2      | 36.88                           |         |
| 3      | 36.79                           | 36.76   |
| 4      | 36.72                           |         |

4. Bearing Strength Test
The effect of different height on the bearing strength of concrete can be determined through bearing strength test for the concrete blocks with predefined height of 50mm, 100mm, 200mm and 400mm. The concrete block has constant concrete surface area of 200mm x 200mm. The Universal Testing Machine (UTM) with capacity of 2700 KN was used as shown in Figure 2.
For the bearing strength test, the steel bearing plate with surface dimension of 100mm x 100mm is placed at the centre of concrete blocks to simulate the concentric loading. The concrete specimens are aligned properly with the compression machine upper loaded head to achieve better results. An incremental of concentric loading was applied based on loading rate of 1.48kN/s as used by Bonetti (2014). The maximum failure load and failure modes were recorded. The result of bearing strength test is tabulated as shown in Table 4. The effect of block height on bearing strength of concrete has been evaluated through the relationship of confinement effect \( (f_b/f_c') \) and height-to-width ratio \( (h/w) \) as plotted in Figure 3.

### Table 4. Results for bearing test

| No. of sample | Height (mm) | Concrete surface area, \( A_c \) (mm\(^2\)) | Plate area, \( A_p \) (mm\(^2\)) | Maximum load, \( F_b \) (kN) | Bearing capacity, \( f_b \) (MPa) | Bearing capacity, \( f_b' \) (MPa) | \( \frac{f_b}{f_c'} \) \(^{b}\) | Ac/As | h/w |
|---------------|-------------|---------------------------------|--------------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------|------|-----|
| 1             |             | 200mm × 100mm                  | 100mm × 100mm                  | 641.6                       | 64.16                       | 61.57                       | 1.67            | 4    | 0.25|
| 2             |             |                                |                                | 641.7                       | 64.17                       |                            |                 |      |      |
| 3             | 50          | 200mm                          | 100mm                          | 516.9                       | 51.69                       |                            |                 |      |      |
| 4             |             |                                |                                | 662.7                       | 66.27                       |                            |                 |      |      |
| 5             |             | 200mm × 100mm                  |                                | 516.9                       | 51.69                       | 52.27                       | 1.42            | 4    | 0.5 |
| 6             |             |                                |                                | 642.0                       | 64.2                        |                            |                 |      |      |
| 7             | 100         | 200mm                          | 100mm                          | 482.0                       | 48.2                        |                            |                 |      |      |
| 8             |             |                                |                                | 449.8                       | 44.98                       |                            |                 |      |      |
| 9             |             | 200mm × 100mm                  |                                | 529.9                       | 52.99                       | 45.27                       | 1.23            | 4    | 1   |
| 10            |             |                                |                                | 548.6                       | 54.86                       |                            |                 |      |      |
| 11            |             | 200mm × 100mm                  |                                | 334.8                       | 33.48                       |                            |                 |      | 1   |
| 12            |             |                                |                                | 397.4                       | 39.74                       |                            |                 |      |      |
| 13            |             | 200mm × 100mm                  |                                | 354.1                       | 35.41                       | 36.49                       | 0.99            | 4    | 2   |
| 14            |             |                                |                                | 401.7                       | 40.17                       |                            |                 |      |      |
| 15            |             | 200mm × 100mm                  |                                | 335.5                       | 33.55                       |                            |                 |      |      |
| 16            |             | 200mm                          | 100mm                          | 368.2                       | 36.82                       |                            |                 |      |      |

Note that: \(^{a}\)plate thickness is 10 mm, \(^{b}\)compressive strength of concrete, \( f_c = 36.76 \text{MPa} \).
Figure 3 shows that the confinement effects of concrete blocks are significantly dropped as the ratio of height-to-width increase. This indicates that the bearing strength of concrete block will also reduce when the slender concrete blocks are used. This is important finding as existing standard on bearing strength of concrete blocks do not considered the effects of height in their prediction for bearing concrete. It can see clearly that the percentage different of confinement effect for concrete block between height-to-width ratio of 0.5 to 2 is about 67% which is more than half of confinement effect when 50mm height block were used. Based on the current relationship of \( \frac{f_b}{f_c'} \) and \( \frac{h}{w} \), a new prediction of concrete bearing can be predicted as:

\[
\frac{f_b}{f_c} = 1.2 \left( \frac{h}{w} \right)^{-0.25}
\]

where \( f_b \) is bearing of concrete, \( f_c' \) is compressive strength of concrete, \( h \) is the height of concrete block and \( w \) is the width of concrete block.

5. Conclusion
This paper has presented the beneficial effects of different heights of concrete blocks to the bearing capacities of concrete. Through the experimental results presented in this paper, it can conclude that the effect of different heights on bearing capacities of concrete block is crucial as it can change the confinement effects of concrete bearing. It also found that the percentage of confinement effect for concrete blocks for height-to-width ratio between 0.5 and 2 is dropped more than half of confinement effect when 400mm high concrete blocks were tested. Experimental data indicates that the confinement effect and bearing strength of concrete were decreased with increasing of concrete block height due to slenderness effect. However, most of the design equations in various national standards do not account for this parameter. This present research strongly recommends that standard committee members to examine this parameter in their design expression.

Based on these findings, it is suggested that current bearing failure model for bearing strength of concrete blocks can be improved if the current prediction formulation can include the effect of concrete blocks slenderness ratio \( \frac{h}{w} \).
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