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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 ϕ 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) diameter × height (cylinder)	Height-to-width ratio (dimensionless)
Meyerhof (1953)	Concrete and rock blocks	152.4 × 152.4 × 38.1	0.25[a]
		152.4 × 152.4 × 76.2	0.5[a]
		152.4 × 152.4 × 152.4	1
		304.8 × 304.8 × 152.4	0.5[a]
		457.2 × 457.2 × 152.4	0.5[a]
Shelson (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[a]
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[a]
		153 × 153 × 51	0.33[a]
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[a]
		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	0.9[a]
		254 dia. × 457.2	1.8
		254 dia. × 914.4	3.6
		304.8 dia. × 228.6	0.75[a]
		304.8 dia. × 304.8	1
		304.8 dia. × 457.2	1.5
		304.8 dia. × 914.4	3
		355.6 dia. × 228.6	0.64[a]
		335.6 dia. × 457.2	1.29
		355.6 dia. × 914.4	2.57
		457.2 dia. × 228.6	0.5[a]
		457.2 dia. × 301.8	0.67[a]
		457.2 dia. × 457.2	1
		457.2 dia. × 914.4	2
		609.6 dia. × 304.8	0.5 [a]
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
200mm x 200mm	50mm 100mm 200mm 400mm	16	Bearing Strength Test[a]

[a]Tested 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^o to 25^o 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	36.76
2	36.88	
3	36.79	
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**.

Figure 2. Bearing Strength Test

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 (fb/fc') 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, Ac (mm2)	Plate area, As [a] (mm)	Maximum load, Fb (kN)	Bearing capacity, fb (MPa)	Bearing capacity, fb' (MPa)	fb/fc' [b]	Ac/As	h/w
1	50	200mm × 200mm	100mm × 100mm	641.6	64.16	61.57	1.67	4	0.25
2				641.7	64.17				0.25
3				516.9	51.69				0.25
4				662.7	66.27				0.25
5	100	200mm × 200mm	100mm × 100mm	516.9	51.69	52.27	1.42	4	0.5
6				642.0	64.2				0.5
7				482.0	48.2				0.5
8				449.8	44.98				0.5
9	200	200mm × 200mm	100mm × 100mm	529.9	52.99	45.27	1.23	4	1
10				548.6	54.86				1
11				334.8	33.48				1
12				397.4	39.74				1
13	400	200mm × 200mm	100mm × 100mm	354.1	35.41	36.49	0.99	4	2
14				401.7	40.17				2
15				335.5	33.55				2
16				368.2	36.82				2

Note that: [a]plate thickness is 10 mm, [b]compressive strength of concrete, fc = 36.76MPa.

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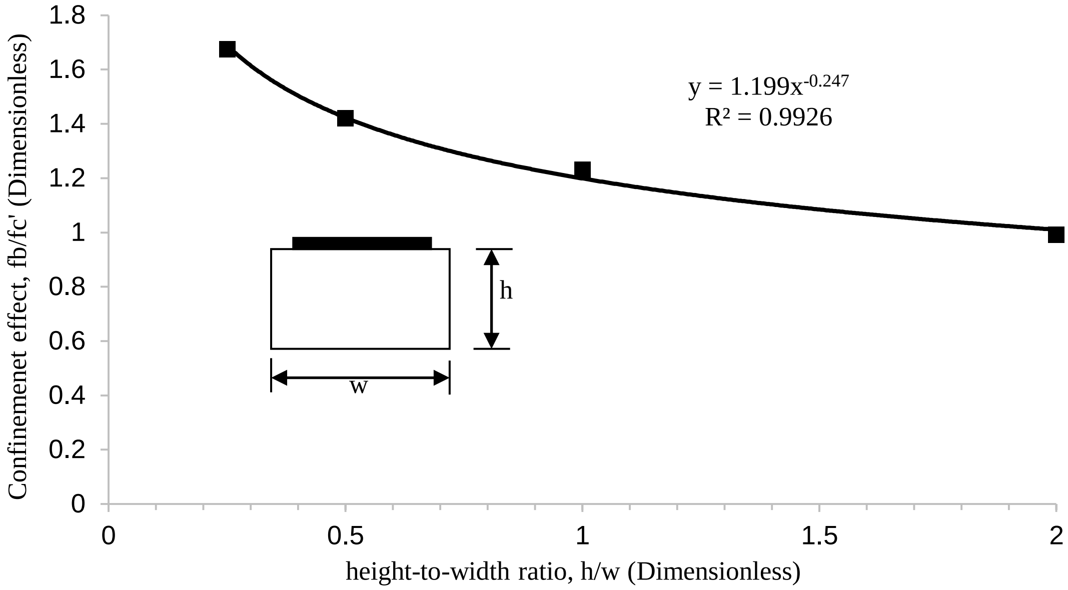

Figure 3. confinement effects of concrete block loaded through steel bearing plate

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 (fb/fc') and (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 (h/w).

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References
[1] AASHTO LRFD Bridge Design Specifications. Washington, D.C. :American Association of State Highway and Transportation Officials, 2014.
[2] ACI Committee 318, Building Code Requirements For Structural Concrete (ACI 318-99) and Commentary (318R-99), America Concrete Institute, Farmington Hills, Mich., 1999, 391 pp.
[3] *AS3600. 2009. Australia Standard for Concrete Structures; Standards Australia Limited.*
[4] Au T and Baird D L (1960). Bearing capacity of concrete blocks. *Journal of the America Concrete Institute,* **56**(3), 869-880.
[5] Adebar P & Zhou Z (1993). Bearing strength of compressive struts confined by plain concrete. *ACI Structural Journal,* **90**, 535-535.
[6] Ahmed T, Burley E and Rigden S (1998). Bearing capacity of plain and reinforced concrete loaded over a limited area. *Structural Journal,* **95**(3), 330-342.
[7] Bauschinger J (1876). Tests with blocks of natural stone. *Mech Tech Lab Kgl,* **6**, 13.
[8] Bonetti R, Roberts-Wollmann, C L, and Santos, J T (2014). Bearing Strength of Confined Concrete. *ACI Structural Journal,* **111**(6), 1317.
[9] Hamzeh O N, Tassoulas J L and Becker E B (1998). Behavior of elastomeric bridge bearings: Computational results. *Journal of Bridge Engineering,* **3**(3), 140-146.
[10] Hawkins N M (1968a). The bearing strength of concrete loaded through flexible plates. *Magazine of concrete research,* **20**(63), 95-102.
[11] Hawkins N M (1968b). The bearing strength of concrete loaded through rigid plates. *Magazine of concrete research,* **20**(62), 31-40.
[12] Hawkins N M (1970). The bearing strength of concrete for strip loadings. *Magazine of concrete research,* **22**(71), 87-98.
[13] Hyland M and Chen W F (1970). Bearing capacity of concrete blocks. *Journal of the America Concrete Institute,* **67**(3), 228-236. Komendant A E (1952). *Prestressed concrete structures* (1st ed.). New York: Mc Graw-Hill.
[14] Ince R & Arici E (2004). Size effect in bearing strength of concrete cubes. *Construction and Building Materials,* **18**(8), 603-609.
[15] Lehman D E, Roeder C W and Larsen R A (2005). Design of cotton duck bridge bearing pads. *Journal of Bridge Engineering,* **10**(5), 555-563.
[16] Meyerhof G (1953). The bearing capacity of concrete and rock*. *Magazine of concrete research,* **4**(12), 107-116.
[17] Mounir K, Montedor L C and de Hanai, J B (2006). Compression tests of cement- composite bearing pads for precast concrete connections. *Cement and Concrete Composites,* **28**(7), 621-629.
[18] Niyogi S and Das P (1978). Concrete bearing strength under combined lateral and vertical concentrated loads. *Building and Environment,* **13**(3), 185-192.
[19] Ravindrarajah R S (1999). *Bearing strength of concrete containing polystyrene aggregate*. Paper presented at the Proc. the RILEM 8th Int Conf Durability of Building Materials and Components, Vancouver, Canada.

[20] Roberts-Wolimann, C L, Banta T, Bonetti R and Charney F (2006). Bearing strength of lightweight concrete. *ACI materials journal*, **103**(6), 459.

[21] Shelson W (1957). Bearing capacity of concrete. *Journal of the America Concrete Institute,* **54**(11), 405-414.

[22] Scheffers C A, Sri Ravindrarajah R, and Reinaldy R (2011). *Bearing Strength of CFRP Confined Concrete*. Paper presented at the Advances in FRP Composites in Civil Engineering: Proceedings of the 5th International Conference on FRP Composites in Civil Engineering (CICE 2010), Sep 27–29, 2010, Beijing, China,

[23] Yahya N A and Manicka D (2014). *Explicit Finite Element Modelling Of Bridge Girder Bearing Pedestals.* Paper presented at the 23rd Australasian Conference on the Mechanics of Structures and Materials (ACMSM23), Dec 9–12, 2014, Southern Cross University, Byron Bay, Australia.

[24] Yahya N A and Manicka D. *Strategies For Mitigation Of The Failure Of Concrete Pedestals Supporting Bridge Girder Bearings.* PhD Thesis, Queensland University of Technology, 2017.

[25] Yazdani N, Eddy S, and Cai C S (2000). Effect of bearing pads on precast prestressed concrete bridges. *Journal of Bridge Engineering*, **5**(3), 224-232.

[26] Yoon D, Yoo C and Lee S (2004). On the behavior of sole plates in steel girders. *Thin-walled structures,* **42**(1), 59-77.

[27] Zhou W, Hu H and Zheng W (2013). Bearing capacity of reactive powder concrete reinforced by steel fibers. *Construction and Building Materials,* **48**, 1179-1186.