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Experimental Study on Bearing Strength of Concrete Blocks under Concentric Compression Load

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ABSTRACT

The present study examines the interaction between concrete and steel plate, particularly on the load bearing capacity of concrete blocks under confinement effects. 12 concrete blocks with the dimensions of 200 mm × 200 mm in cross section and 200 mm high were tested up to failure under compression load through 10 mm thickness of steel bearing plate. A series of experimental testing were performed to determine the maximum load bearing capacity in different sizes of steel plate and to identify the possible failure modes. The experimental data obtained from the experimental investigations were compared with pre-existing experimental data obtained from literature and mathematical formulation in various international standards. Experimental results indicate that the use of larger bearing plate gave higher value of load bearing capacity compared with small bearing plate due to larger contact area, thus, resulting in better effect of confinement. It was found that the concrete blocks fail in the shape of inverse pyramid when the steel plate is placed on top of it. Besides, other failures are vertical cracks and splitting cracks which appeared at the outer edge of contact area.

Keywords: Bearing strength, concrete block, confinement effects, steel bearing plate

INTRODUCTION

Bearing capacity characteristic of concrete is a very important parameter in designing structure support for building and other infrastructure such as concrete footing, anchorage for pre-stress member and even for concrete pedestal in bridges. The size of concrete blocks and steel plate can affect the load transfer and failure mechanism of concrete bearing. However, problems may

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arise if there is lack of quantitative understanding of the concrete bearing capacity and its generation mechanism.

According to researchers (Escobar-Sandoval, Andren, & Gary, 2006; Ince & Arici, 2004; Rao & Swamy, 1974), vertical and radial cracking occurred with the use of plain concrete blocks subjected to high compressive loading. In order to provide a much higher compressive load without facing failure, the dimension of the column concrete should be extended. Nevertheless, this solution involves a high cost and not suitable. Another method was by placing steel plate on top of concrete block as can be seen on concrete bridge pedestal and the capacity of that concrete towards the load applied on it is called as load bearing capacity.

The load-bearing capacity was first studied by Bauschinger (1876), Meyerhof (1953), Shelson (1957), and Au and Baird (1960). Researchers noticed a formation of an inverted pyramid under the loading bearing plate and formulated a theory for concrete bearing capacity based on that observation.

Various types of concrete blocks such as rectangular section, square section and circular section were used by researchers to study the behaviour of load bearing strength of concrete. The understanding of bearing capacity of concrete is important for the design purpose of concrete members such foundation structures, end-bearing zone of pre-stressed post-tensioned beam, bridge bearing on concrete columns and many others (Al-Sahawneh, Amjad, Hassan, & Khair, 2013).

The bearing capacity of concrete is somehow always related to the variety of design problems as shown by Rao and Swamy (1974), and Yahya and Dhanasekar (2014). The bearing capacity can be calculated by the steel plate positioned at the touching surface of the concrete cubes. The increase in bearing capacity was related to the increase in the concrete strength, reduction in the height of the concrete blocks and the total to loaded area ratio either for the plain or unreinforced concrete cubes (Ahmed, Burley, & Rigden, 1998; Al-Taan, 2005). Ragip, Ince and Arici (2004) found that parameters such as the loaded area, loaded member cross-section, specimen size, specimen height, conditions of loading and concrete compressive strength can hugely affect the bearing resistance of the concrete blocks.

The position of steel plate at the touching surface of concrete blocks either at the centre or the edge of the concrete blocks (concentrically and eccentrically loaded bearing strength) also plays an essential role in the bearing strength of the concrete (Ahmed, Burley, & Rigden, 1998). The different position of steel plates shows a different kind of crack failures for the blocks.

Even though previous experimental studies do not specify all the pertinent aspects of the bearing problem if unreinforced concrete been chosen, there was a need to investigate the effect of having difference sizes of steel plate on the touching surface of concrete block. There is lack of knowledge on the behaviour and generation mechanism of the bearing capacity of unreinforced concrete blocks which means there is a need for further investigation especially for the design purposes of concrete members. Therefore, the aim of this study were: a) to investigate the ultimate bearing capacity of normal plain concrete blocks subjected to axial thrust; and b) observe the failure modes of the specimens.

Analytical Consideration

In order to estimate the bearing capacity of concrete, Hawkins (1968) had derived an expression for ratios of A_2/A_1 ranging from 1 to 40 as follows:

$$\frac{f'_{cc}}{f_c'} = 1 + \frac{4.15}{\sqrt{f_c'}}\left(\sqrt{\frac{A_2}{A_1}} - 1\right) \tag{1}$$

Where,

f'_{cc} represents the concrete bearing strength

A_1 represents the bearing plate area

A_2 represents the area of the lower base of the largest frustum of a pyramid

f_c' represents the concrete compressive strength (MPa)

In addition, Shelson (1957) proposed a formula in order to determine the bearing capacity of concrete as given by Equation 2.

$$f = f_c'\left(\sqrt[3]{\frac{A}{A'}}\right) \tag{2}$$

In which, f denotes the maximum concrete bearing capacity, A as the total area of the concrete, A' as the loaded area on top of the concrete and f_c' represents the compressive (cube) strength of concrete (MPa). In this study, both expressions were used as a comparison with the results on the bearing strength of concrete blocks obtained via experimental measurements.

MATERIALS AND METHOD

Preparation of Specimens

The concrete with the characteristic strength of 50 N/mm^2 was poured into the moulds with the dimension of 200 mm × 200 mm in cross section and 200 mm in height. All the specimens were cast from a concrete mix as shown in Table 1. After the concrete undergoes the hardening process, the specimen was cured in curing tank. From a batch of concrete, three 150 mm × 150 mm concrete cubes were cast as control specimens. The concrete cubes were tested up to the failure for their compressive strength after being stored in a curing tank for 7 and 28 days to inspect the mechanical properties of the mix and the result is displayed in Figure 1. A total of 12 concrete blocks have been tested up to failure subjected to concentric compressive load. There are three unreinforced concrete blocks tested without the steel plate on top of it and nine unreinforced concrete blocks tested through square steel plates with dimensions of 75 mm × 75 mm, 100 mm × 100 mm, and 150 mm × 150 mm; respectively as shown in Table 2. The 10 mm thickness of square steel plates was concentrically placed at the top surface of the concrete block specimens. In this study, 10 mm plate thickness was selected due to the reason that it is a typical range for the steel plate thickness in most experimental setup performed by previous studies ranging from 8 mm to15 mm (Ahmed, Burley, & Rigden, 1998; Escobar-Sandoval, Andren, & Gary, 2006).

Table 1
Proportion of concrete per m²

Cement (kg)	Water (kg/m³)	Fine Aggregates (kg)	Coarse Aggregates (kg)	
			10 mm	20 mm
71.78	26.4	77.55	73.43	146.85

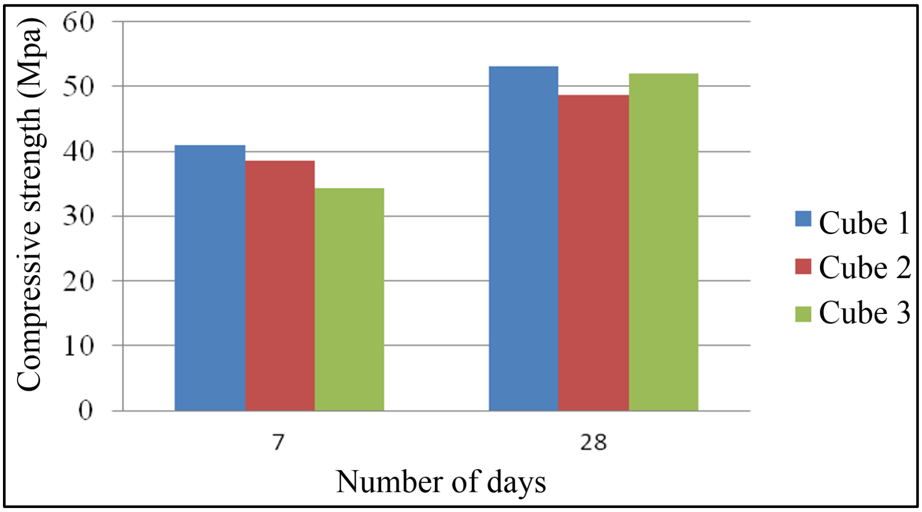


Figure 1. Mechanical properties of the concrete mix

Table 2
Details configuration of concrete specimens

Specimen designation	Length of concrete cube, L	Width of concrete cube, B	Height of concrete cube, H	Length of steel plate, l	Width of steel plate, b	Thickness of steel plate, t
*PCS**				-	-	-
C75/75	200 mm	200 mm	200 mm	75 mm	75 mm	
C100/100				100 mm	100 mm	10 mm
C150/150				150 mm	150 mm	

Note that:
PCS denotes the unreinforced (plain) concrete without the steel plate
C75/75 denotes the plain concrete with the steel plate dimension of 75 mm × 75 mm
C100/100 denotes the plain concrete with the steel plate dimension of 100 mm × 100 mm
C150/150 denotes the plain concrete with the steel plate dimension of 150 mm × 150 mm

Experimental Details and Test Setup

All concrete block specimens have been tested up to failure subjected to axially compressive loading using the Universal testing machine (UTM) with the capacity of 1000 kN to determine the increase in bearing strength resulting from different sizes of steel plates. In order to ensure smooth contact between the bearing plate and concrete surface, the bearing surface of the machine and specimen was cleaned either on the top or bottom surface. The upper platen of the testing machine bore directly on the entire area of the bearing plate.

The piston was gently lowered to the top of the concrete block specimen using a lever. The specimens were loaded continuously until failure. The experimental set-up of the concrete block specimens is shown in Figure 2. The ultimate load and any crack deformities on the concrete block specimen were observed and recorded.

Figure 2. Experimental setup

RESULTS AND DISCUSSION

Load Bearing Capacity-Deformation Relationships

Based on the results obtained through the experimental measurements for the 12 concrete block specimens, the ultimate load bearing capacity and displacement relationship are provided. The graph of load bearing capacity versus deformation for different plate sizes used is shown in Figure 3.

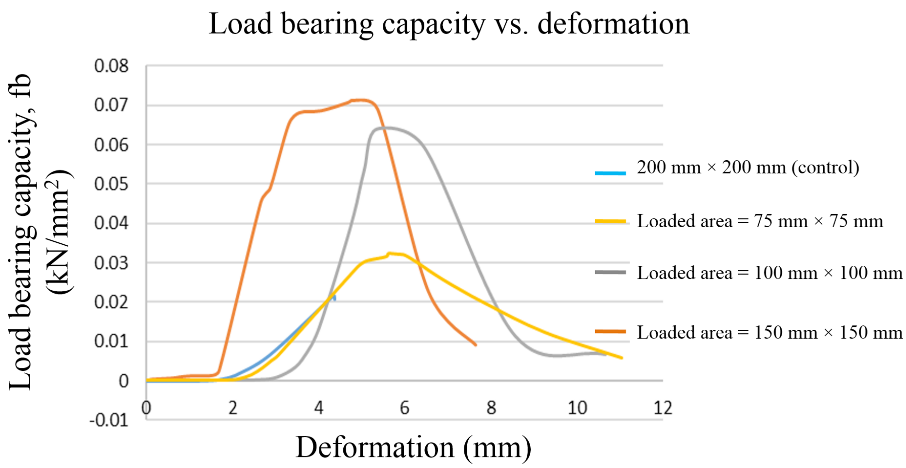


Figure 3. Graph of load bearing capacity (kN/mm²) versus deformation (mm)
Note: Unloaded area = 200 mm × 200 mm

Figure 3 shows the concrete block specimen tested without the steel plate labelled as PCS, the maximum value of bearing strength was recorded as 0.024 kN/mm² with 5.62 mm deformation. Meanwhile, for concrete specimens with the contact area of 75 mm × 75 mm and 100 mm × 100 mm denotes as C75/75 and C100/100 respectively, the average value of bearing strength recorded was 0.089 kN/mm² with 5.06 mm deformation and 0.072 kN/mm² with 5.74 mm deformation respectively. In addition, for the specimen with the size of loaded area of 150 mm × 150 mm known as C150/150, the average value of bearing strength recorded was 0.043 kN/mm² with 6.50 mm deformation. The result of each type of specimen and its comparison with previous studies are shown in Table 3 and Table 4.

Table 3
Results of bearing strength test

Specimen Designation	Ultimate Load (kN)	Bearing Strength (N/mm²)	Deformation (mm)
PCS	939.85	24	5.62
C75/75	499.10	89	5.06
C100/100	721.39	72	5.74
C150/150	971.45	43	6.50

Table 4
Comparison between experimental test and earlier studies

Specimen Designation	f_b (Exp.) (N/mm²)	$f_{b(H)}$ (Hawkins, 1968) (N/mm²)	$f_{b(S)}$ (Shelson, 1957) (N/mm²)	$f_b/ f_{b(H)}$	$f_b/ f_{b(S)}$
C75/75	89	99	96	0.90	0.93
C100/100	72	79	79	0.91	0.91
C150/150	43	60	61	0.72	0.70

Experimental results demonstrate that the concrete block specimens with the plate dimension of 150 mm × 150 mm gave lower value of bearing strength compared with the plate with the dimension of 75 mm × 75 mm and 100 mm × 100 mm. Test on the bearing capacity of plain concrete have served to fill an essential gap in the experimental data. As can be seen from the deformation of specimen, the larger cross-sectional area of the steel plate used have the tendency to increase the deformation of the concrete block specimen.

This result supports the widely held belief that the maximum bearing strength of concrete can be increased by increasing the ratio of unloaded to loaded area. The load that implies on the concrete specimen was transferred through square steel plate into the concrete block with a larger contact area. This indicates that the increase in the surrounding area corresponds with value in terms of load carrying capacity before the concrete specimen reaches its limiting value (Rao & Swamy, 1974).

Confinement Effects

The relationship between the ratio of unloaded to loaded area and the effects of confinement provided by the surrounding concrete play an important role in estimating if higher confinement effect will provide an increasing or decreasing value of load bearing capacity of concrete blocks. In this case, the effects of confinement were defined as the ratio of unloaded area of concrete block specimen divided by the loaded area of square steel plate as shown in Figure 4.

The use of different square steel plate with the dimensions of 75 mm × 75 mm, 100 mm × 100 mm, and 150 mm × 150 mm gave different value of A_2/A_1 which are 7.11, 4, and 1.78 respectively. Figure 4 shows the increasing value in load bearing capacity correlates with the increasing effects of confinement. The smaller cross-sectional area of steel plate had higher effects of confinement compared with larger cross-sectional area of steel plate.

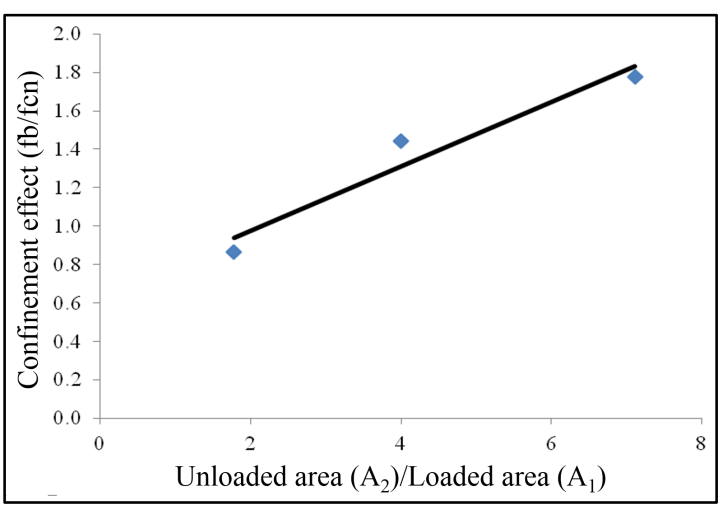


Figure 4. Relationship between confinement effect and load bearing area

Mode of Failures

The failure of concrete blocks occurs when the forces applied on top of it exceeds the strength of concrete. The type of failure modes that have been observed during the experimental testing is in the forms of localised damage, especially at the outer edge of the contact area. It has found that this observation is comparable with previous studies (Al-Sahawneh, Amjad, Hassan, & Khair, 2013; Rao & Swamy, 1974; Zhou, Hu, & Zheng, 2013) where the inverse pyramid failure has been observed at the outer edge of contact area, as shown in Figure 5. Other types of failure that have been observed during the measurements include splitting crack, brittle fracture and splitting wedge. It should be noted that there is no formation of inverted pyramid shape when the loaded area of 150 mm × 150 mm in cross section was used.

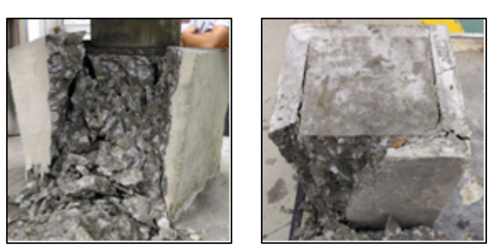
Figure 5(a) and 5(b) shows as the applied load gradually increases, the vertical crack occurs inside the concrete block specimen. Then, when the load reaches its limiting value, an inverse pyramid shape can be observed on the specimens. A conical wedge punched out from beneath the steel bearing plate is shown in Figure 5(b).

Splitting crack　　　Inverted pyramid shape

(a) Loaded area: 75 mm × 75 mm

Brittle fracture　　　Inverted pyramid shape

(b) Loaded area: 100 mm × 100 mm



Splitting edge　　　No formation of inverted pyramid

(c) Loaded area:150 mm × 150 mm

Figure 5. Modes of failure for different steel plate dimensions

CONCLUSION

The following conclusion can be drawn from his study: (1) When the specimen is loaded via a larger steel plate, an increase in deformation was observed due to the lower value of unloaded to loaded area. However, the localised damage prior to ultimate load starts to appear at the outer part of the concrete block specimens; (2) Different types of failure were observed for the different dimension of steel plate that has been used on top of concrete surface. It has been shown that when the load is being loaded through the smaller steel plate, the failure that occurs were in the formation of an inverted pyramid under the loading plate causing horizontal pressure leading to the concrete failure. When the maximum tensile stress at the top of the block exceeds the tensile strength of the concrete, then the failure can occur at the concrete blocks; and (3) The use of steel bearing plate with the dimension of 150 mm × 150 mm in cross section on the top of concrete surface results in no formation of inverted pyramid. However, edge splitting failure mode has been identified on the specimen. The occurrence of splitting was due to the existence of the edge damage at the outer edge of concrete block and it has been confirmed in the real field, especially in concrete bridge pedestal.

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