Experimental study on the bearing capacity of concrete blocks loaded through square and circular steel plates

Mohd Raizamzamani Md Zain¹*, Norrul Azmi Yahya¹, Lee Siong Wee¹, Oh Chai Lian¹ and Balqis Md Yunus¹

¹Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia

*Corresponding author:raizam@salam.uitm.edu.my

Abstract. The bearing capacity of concrete loaded through steel plate has been the subject of numerous studies, play as an important element that need to be considered in designing many types of concrete members such as foundation structure, the end bearing zone of prestressed post-tensioned concrete beams and even for concrete pedestal in bridges. This paper presents an experimental investigation into the bearing capacity of concrete blocks axially loaded through square and circular steel plates. The relative area of the surface of concrete block specimen to the area of the bearing plate is one of the most significant factors influencing the bearing capacity of concrete blocks. Thus, the main purpose of this study is to determine the maximum bearing capacity and observe the failure modes of concrete blocks concentrically loaded through square and circular steel plates. A total of twenty-one (21) numbers of specimens with three different types of concrete blocks were experimentally investigated. There are three (3) specimens of plain concrete blocks, nine (9) specimens of concrete blocks laterally reinforced with ties (loaded and tested under three different sizes of square steel plate) and nine (9) specimens of concrete blocks laterally reinforced with ties (loaded and tested under three different sizes of circular steel plate). The use of steel plate helps in determining the bearing capacity when concentrically loaded on top of the specimen. The results of the experimental testing herein were compared with the bearing capacity values calculated based on previous researches and international standards. Experimental results demonstrate that concrete blocks laterally reinforced with ties loaded and tested under larger relative area of the steel plate gave lower value of bearing capacity compared with other reinforced specimens. Meanwhile, the failure pattern of concrete blocks under the bearing load was found to vary with the increase in sizes of steel plates.

1. Introduction
At present, the demand of using concrete is increasing especially in construction fields due to its versatility and easy availability of its constituent materials. Nowadays, concrete is being applied for many functions and there is uncountable of innovation of concrete around the world. Concrete is a mixture of cement, sand, coarse aggregate made of crushed stone and water. With the use of reinforced concrete, cracking strength can be enhanced. As demonstrated and pointed out by previous studies ([1], [2], [3], [4] and [5]), several circumstances like vertical and radial cracks were observed on the unreinforced concrete blocks due to high compressive loading. Among the approach to obtain minimal numbers of cracking failure was by putting steel plate on the top surface of concrete block as
its application can be observed on many civil engineering works like concrete bridges, concrete footing, anchorage for pre-stress member and others. The term used for the strength of that concrete block towards the load applied on it was load bearing capacity.

The load-bearing capacity was first examined by [6] followed by [7], [8], [9] and [10]. The researchers found that there was a formation of an inverted pyramid under the loading bearing plate and expressed a formulation for concrete bearing capacity based on that observation. The different sizes and shapes of steel plates shows a different kind of crack failure for the concrete blocks. The enveloping concrete gives an effect to the higher compressive strength of concrete at bearing area as stated by [2], [11] and [12]. The reason was due to the local pressure that exerted on the concrete structural members.

Even though previous investigations 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 and cross-sectional shapes of steel plate on top of plain and reinforced concrete blocks. The understanding on the behaviour and generation mechanism of the bearing capacity of concrete blocks was still rather crude and lack of comprehensive research for the design purposes of concrete members. Therefore, in view of this and keeping in mind the usefulness of bearing capacity to the design of structural member, experimental investigations were performed to evaluate the ultimate bearing capacity of concrete blocks concentrically loaded via different cross-sectional shapes and sizes of steel plates and observe the possible failure modes of the concrete.

2. Theoretical developments

The development of mathematical formulation has been the subject of numerous numbers of researchers. Shelton (1957) developed an empirical formula to obtain the bearing strength of concrete [8]. The researcher stated that the maximum bearing strength of concrete, $f'_{cc}$, be conservatively estimated as the product of the concrete strength, $f'_c$, and a factor equal to $\sqrt[3]{(A_2/A_1)}$, where $A_2$ is denoted as gross area of the concrete foundation and $A_1$ as concrete bearing area or bearing plate area as in equation (1).

$$f'_{cc} = f'_c \left( \frac{A_2}{A_1} \right)^{\frac{1}{3}} \tag{1}$$

Then, [13] derived an expression for ratios of $A_2/A_1$ ranging from 1 to 40 as in equation (2).

$$\frac{f'_{cc}}{f'_c} = 1 + 4.15 \left( \frac{A_2}{A_1} \right) \tag{2}$$

where, $f'_{cc}$ represents the concrete bearing strength, $f'_c$ denotes as the compressive strength of concrete (MPa), $A_1$ represents the bearing plate area and $A_2$ represents the area of the concrete. Later, [14] expressed an equation by taken into account the analysis of upper bound limit based on the proposed formula by [13] as in equation (3).

$$\frac{f'_{cc}}{f'_c} = 0.8 \left[ 1 + 12.5 \left( \frac{f'_c}{f'_c} \right)^{-1} \right] \tag{3}$$

In which, $f'$ represents the concrete strength in tension. ACI-318 proposed an expression to estimate the bearing strength of concrete [15] as in equation (4).

$$f'_{cc} = 0.85 \phi_c f'_c \left( \frac{A_2}{A_1} \right) \tag{4}$$
where, $\phi_c$ represents the capacity reduction factor for concrete in bearing and $0.85 f'_{c}$ as the concrete compressive strength under sustained loads.

In addition, to estimate the bearing capacity of concrete blocks, [12] proposed an expression as in equation (5).

$$P_p = 0.8A_t\left(f'_c + 12.5f_t\left(\frac{A_c}{A_t} - 1\right)\right)$$

(5)

In which, $P_p$ represents the maximum bearing strength of concrete, $f_c$ denotes the strength of concrete in uniaxial tension and is equal to $0.33\sqrt{f'_{c}}$ (MPa), $f'_{c}$ as the compressive strength of concrete (MPa) and 0.8 as the proposed reduction factor for sustained load.

3. Methods

A series of experimental investigations have been conducted to examine the bearing capacity of plain and reinforced concrete blocks and observe its possible mode of failure. The test was carried out subjected to concentric compression load. Detailed description on the specimen preparation, experimental testing and test set-up were elaborated as on the following sub-topics.

3.1. Material properties

In order to provide optimum strength and durability, water-cement ratio of 0.46 was used. There are two types of bearing steel plates were used, square and circular cross-sectional shapes as depicted in figure 1. The square steel plate having dimensions of 50 mm x 50 mm, 100 mm x 100 mm and 150 mm x 150 mm in cross section and 10 mm thickness. Meanwhile, circular steel plates having diameters of 50 mm, 100 mm and 150 mm with the same thickness as square shape.

3.2. Specimen preparation

Reinforced concrete (concrete consist of reinforcement bar embedded in the concrete) was chosen as the concrete block specimens while plain concrete acting as a control specimen. All concrete block specimens with the characteristic strength of 30 N/mm$^2$ were cast from a concrete mix as depicted in table 1. Then, the concrete was poured into the prepared mould.

![Figure 1. Square and circular bearing steel plate.](image)

| Table 1. Proportion of concrete per m$^3$. |
|------------------------------------------|
| Water, kg/m$^3$ | Cement, kg/m$^3$ | Fine aggregate, kg/m$^3$ | Coarse aggregate, kg/m$^3$  |
|-----------------|------------------|-------------------------|-----------------------------|
| 37.3            | 80.8             | 108.8                   | 88.3                        |
|                 |                  |                         | 176.5                       |

Twenty-one (21) numbers of concrete blocks including plain concrete and reinforced concrete blocks were prepared. From a batch of concrete, six 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 examine the mechanical properties of the mix. A total of twenty-one (21) numbers of concrete block specimens were cast and tested up to failure subjected to concentric compression load after 28 days achieving its designated age. The specimens were concentrically loaded through square and circular steel plates. Detailed configurations of the concrete block specimens were shown as in table 2 and figure 2.

| Specimen designation | Block Cross section | Block height | Plate cross section (10 mm thickness) | Remarks                  |
|-----------------------|---------------------|--------------|---------------------------------------|--------------------------|
| PC-01, PC-02, PC-03   | 200 mm x 200 mm     | 200 mm       | -                                     | Plain concrete blocks    |
| PC-SQ50-01, PC-SQ50-02, PC-SQ50-03 | 200 mm | 200 mm | 50 mm x 50 mm                          |                          |
| PC-SQ100-01, PC-SQ100-02, PC-SQ100-03 | 200 mm | 200 mm | 100 mm x 100 mm                        |                          |
| PC-SQ150-01, PC-SQ150-02, PC-SQ150-03 | 200 mm | 200 mm | 150 mm x 150 mm                        |                          |
| PC-CS50-01, PC-CS50-02, PC-CS50-03 | 200 mm | 200 mm | 50 mm diameter                         | Re-inforced concrete blocks |
| PC-CS100-01, PC-CS100-02, PC-CS100-03 | 200 mm | 200 mm | 100 mm diameter                         |
| PC-CS150-01, PC-CS150-02, PC-CS150-03 | 200 mm | 200 mm | 150 mm diameter                         |

Note that:
PC-01 denotes the un-reinforced (plain) concrete block with the characteristic strength of 30 MPa of first specimen.
PC-SQ50-01 denotes the reinforced concrete block with the size of square steel plate (50 mm x 50 mm in cross-section) of first specimen.
PC-CS50-01 denotes the reinforced concrete block with the size of circular steel plate (50 mm diameter) of first specimen.

3.3. Experimental details and test set-up
The bearing surface of the machine and specimen was cleaned and any loose grit or other extraneous materials from the surfaces of the specimen that will be in contact with the platens were removed. The main purpose was to ensure smooth contact between the bearing plate and concrete surface. The excess moisture from the surface of the concrete block specimen also was cleaned before placing in testing machine.
The top platen of the testing machine bore directly on the entire area of the steel bearing plate. The piston was lowered gently to the upper surface of the concrete block specimen using a lever. The specimens were loaded continuously until failure. The test set-up for the specimens is shown in figure 3. A linear variable differential transformer (LVDT) was used to determine cross-head displacement under the applied bearing load. The maximum load and any crack occur on the concrete block specimens were recorded and observed.

4. Results and discussion
A relationship between the bearing load and displacement, results of bearing strength test and its comparison with previous literatures were discussed on the following sub-topics.

4.1. Load bearing capacity-deformation relationship
The maximum load capacity and displacement values were attained using data acquisition system, recorded by the computer. The maximum load bearing capacity and deformation relationship were plotted with regards to the experimental measurements for twenty-one (21) numbers of concrete block specimens as shown in figure 4.
With regards to the results shown in figure 4, for the unreinforced concrete blocks denoted as PC-01, PC-02 and PC-03, its average maximum value of load bearing capacity was recorded as 0.033 kN/mm² with 9.34 mm deformation. Reinforced concrete block specimens loaded through square steel plate denotes as RC-SQ50-01, RC-SQ50-02 and RC-SQ50-03 gave the average maximum value of bearing capacity as 0.116 kN/mm² with 3.42 mm deformation. In addition, for reinforced concrete block specimens denotes as RC-SQ100-01, RC-SQ100-02 and RC-SQ100-03, its average maximum value of load bearing capacity was recorded as 0.051 kN/mm² with 4.12 mm deformation. For reinforced concrete block specimens denotes as RC-SQ150-01, RC-SQ150-02 and RC-SQ150-03, 0.039 kN/mm² with 9.30 mm deformation was recorded.

Meanwhile, for reinforced concrete block specimens loaded through circular steel plate denotes as RC-CS50-01, RC-CS50-02 and RC-CS50-03, its average maximum value of load bearing capacity was recorded as 0.155 kN/mm² with 2.60 mm deformation. Reinforced concrete block specimens denotes as RC-CS100-01, RC-CS100-02 and RC-CS100-03 gave the average maximum value of bearing capacity as 0.081 kN/mm² with 4.04 mm deformation. For specimens denotes as RC-CS150-01, RC-CS150-02 and RC-CS150-03, 0.052 kN/mm² with 5.40 mm deformation was recorded. The result of each type of specimen and its comparison with previous studies were then presented in table 3 and figure 5.

| Specimen designation | Average Ultimate Load (kN) | Average Bearing Capacity (kN/mm²) | Average deformation (mm) |
|----------------------|---------------------------|---------------------------------|-------------------------|
| PC                   | 1339.95                   | 0.033                           | 9.34                    |
| RC-SQ50              | 290.42                    | 0.116                           | 3.42                    |
| RC-SQ100             | 513.83                    | 0.051                           | 4.12                    |
| RC-SQ150             | 897.82                    | 0.039                           | 9.30                    |
| RC-CS50              | 303.32                    | 0.155                           | 2.60                    |
| RC-CS100             | 636.36                    | 0.081                           | 4.04                    |
| RC-CS150             | 927.11                    | 0.052                           | 5.40                    |

![Table 3. Experimental results of bearing capacity.](image)

**Figure 5.** Comparison for concrete block specimens loaded through square and circular steel plates.

Experimental investigations indicate that concrete block specimen having smaller size of circular steel plate (50 mm in diameter) gave higher maximum value of bearing capacity compared to other concrete block specimens loaded through circular steel plate. The same behaviour can be observed for
the concrete block specimens loaded through square steel plate. Thus, in other words, as the length or diameter of the bearing plate increased, decreasing the relative area of the surface of concrete block to the area of the steel bearing plate and the ultimate bearing capacity decreases. Based on the value of specimen deformation, experimental results demonstrate that specimen loaded through smaller size of steel plate (either square or circular steel plates) gave lower values of deformations and higher values of bearing capacities.

4.2. Mode of failures
Among the type of failure modes that have been observed during the experimental testing is in the forms of localized damage, which can be detected at the outer edge of the contact area. It has revealed that these observations especially for unreinforced concrete blocks are comparable with previous studies ([3], [4], [16] and [17]) where the vertical cracks, non-explosive crack, edge crack and inverse pyramid failure have been detected at the outer edge of contact area, as shown in figure 6 until figure 12.

![Figure 6](image1)

**Figure 6.** Mode of failures for unreinforced concrete blocks subjected to concentric loading; (a) Vertical crack, (b) Non-explosive crack, (c) Inverted pyramid shape and (d) Conical shape.

![Figure 7](image2)

**Figure 7.** Mode of failures for reinforced concrete blocks concentrically loaded through 50mm x 50mm square steel plates; (a) Vertical crack, (b) Radial crack, (c) Brittle crack and (d) Splitting along the vertical planes.

![Figure 8](image3)

**Figure 8.** Mode of failures for reinforced concrete blocks concentrically loaded through 100mm x 100mm square steel plates; (a) Splitting wedge, (b) Edge crack, (c) Edge crack outside lateral bar and (d) Vertical crack.
Figure 9. Mode of failures for reinforced concrete blocks concentrically loaded through 150mm x 150mm square steel plates; (a) Vertical crack, (b) Splitting wedge, (c) Brittle crack and (d) Edge crack.

Figure 10. Mode of failures for reinforced concrete blocks concentrically loaded through 50mm diameter circular steel plates; (a) Radial crack, (b) Brittle crack and (c) Edge crack outside plate area.

Figure 11. Mode of failures for reinforced concrete blocks concentrically loaded through 100mm diameter circular steel plates; (a) Medium splitting wedge, (b) Edge crack and (c) Crack outside lateral bar.

Figure 12. Mode of failures for reinforced concrete blocks concentrically loaded through 150mm diameter circular steel plates; (a) Large splitting wedge, (b) Formation of small inverted cone under plate area.

Based on figure 6, the failure modes for plain concrete blocks obtained are vertical crack, non-explosive crack, inverted pyramid shape and conical shape. The initial failure in the form vertical crack can be observed as in figure 6(a) where the concrete starts to fail. Then, when the tensile stress at the top of specimen achieved its ultimate stresses and exceed the tensile strength of the concrete specimen, the formation of inverted pyramid and conical shape were detected. On the other hand, the type of failure modes for reinforced concrete block specimens loaded through various cross-sectional dimension of square steel plate are presented as in figure 7 up to figure 9. The formation of crack start with the similar phases such as vertical crack and then, splitting wedge failure, followed by edge crack until it brittle. These occurs because of the ultimate load of the concrete was attained and the tension of the concrete at the maximum value. But, there is no formation of inverted pyramid or in the form of conical shape for reinforced concrete blocks due to the presence of steel reinforcement bar.
Meanwhile, figure 10 until figure 12 shows the failure modes of reinforced concrete blocks loaded through different sizes of circular steel plate. All reinforced concrete block specimens indicate the behaviour of radial and edge cracks. As they were progressively loaded under concentric loading, radial crack and edge crack developed at the corners of the concrete blocks. The type of failure for reinforced concrete block specimens loaded via circular steel plate (150mm in diameter) shows the formation of small inverted cone under plate area and large splitting wedge. When the load reaches its limiting value, a small inverted cone can be observed on the block specimens. Large splitting wedge punched out from beneath the steel bearing plate as can be observed in figure 12(a).

5. Conclusions
The conclusions of the present study were drawn as follows:
1) For all reinforced concrete block specimens, the ultimate bearing capacity decreases related with decreasing value in ratio of unloaded area to loaded area.
2) Concrete block specimens loaded through smaller size of steel plate (either square or circular steel plates) gave lower values of deformations and higher values of bearing capacities.
3) Concrete blocks specimens loaded through circular steel plate gave higher values of bearing capacities compared to specimens loaded via square steel plate due to the reason that stress concentration for circular steel plate quite uniform throughout the contact surface.
4) High stress concentration at the shape edge of the square steel plate contribute to the lower values of bearing capacities for concrete block specimens loaded through square steel plate compared to specimens loaded via circular steel plates.

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References
[1] Escobar-Sandoval, D., Andren, S.W., & Gary, F.D. 2006. Concentrically loaded circular steel plates bearing on plain concrete. *Journal of Structure Engineering*, 132(11), pp. 1784-1792.
[2] Ince, R., & Arici, E. (2004). Size effect in bearing strength of concrete cubes. *Construction and Building Materials*, 18, pp. 603-609.
[3] Kameswara Rao, C.V.S., & Swamy, R.N. 1974. Bearing strength of steel fibre reinforced concrete. *Build. Sci.*, 9, pp. 263-268.
[4] Mohd Raizamzamani M.Z. & Norrul Azmi, Y. 2017. Experimental Study on Bearing Strength of Concrete Blocks under Concentric Compression Load. *Pertanika J. Sci. & Technol.* Vol. 25 (S), pp. 67 – 76.
[5] Rodolfo B., Carin L. R. & Juan T. Santos. 2014. Bearing strength of confined concrete. *ACI Structural Journal*, pp. 1317 – 1327.
[6] Baushinger, J. 1876. Tests with Blocks of Natural Stone. *Mechanisch und Technischen Laboratorium der Kgl. Technischen Hochschule*, Munich, 6, 13.
[7] Meyerhof, G.G. 1953. The bearing capacity of concrete and rock. *Magazine of Concrete Research*, pp. 107-116.
[8] Shelson, W. 1957. Bearing capacity of concrete. *Journal of the American Concrete Institute*, 54(5), pp. 405-414.
[9] Au, T., & Baird, D.L. 1960. Bearing capacity of concrete blocks. *Journal of the American Concrete Institute*. 56, pp. 869 – 880.
[10] DeWolf J.T. 1978. Axially Loaded Column Base Plates. *Journal of the Structural Division ASCE*, Vol. 104, No. ST4, pp. 781-794.

[11] Ahmed, T., Burley, E., & Rigden, S. 1998. Bearing capacity of plain and reinforced concrete loaded over a limited area. *ACI Structural Journal*, pp. 330-340.

[12] Edgard D. Escobar-Sandoval, Andrew S. Whittaker, M. ASCE, & Gary F. Dargush (2006), Concentrically Loaded Circular Steel Plates Bearing on Plain Concrete. *Journal of Structural Engineering, ASCE*, pp. 1784-1792.

[13] Hawkins, N.M. 1968. The bearing strength of concrete loaded through flexible plates. *Magazine of Concrete Research*, 20(63), pp. 95-102.

[14] Nielsen, M. 1999. Limit analysis and concrete plasticity. *CRC Press, LLC, Boca Raton, Fla.*

[15] ACI Committee, Structural Building Code, & ACI Committee 318 2005. *Building code requirements for structural concrete (ACI 318-05) and commentary (ACI 318R-05)*, 2nd Edition, Farmington Hills, MI:American Concrete Institute.

[16] Al-Sahawneh, E.I., Amjad, A.Y., Hassan, R.H., & Khair Al-Deen, B. 2013. A proposed model at failure stage to assess the bearing stress of normal weight concrete. *International Journal of Engineering Research and Application*, 3, 793-802.

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