# Bearing Strength Behaviour of Bridge Concrete Pedestal with Confined Reinforcements

*Mohd Raizamzamani Md Zain, Norrul Azmi Yahya, Lee Siong Wee, Oh Chai Lian, Abdul Samad Abdul Rahman*
*Faculty of Civil Engineering, Universiti Teknologi Mara, 40450 Shah Alam, Selangor, Malaysia*

*Manicka Dhanasekar*
*Queensland University of Technology, Brisbane, QLD 4001, Australia*

## ABSTRACT

*This paper deals with the bearing capacity of the unreinforced and reinforced bridge concrete pedestals/concrete blocks when concentrically loaded through square steel plate under axial compressive loading. It is well known that the presence of the lateral reinforcement gave a higher value of bearing capacity of concrete block. The main purpose of this study is to determine the ultimate bearing strength and observed the failure modes of confining reinforcement on the bearing strength of concrete blocks. A total of nine numbers of specimens with three different types of concrete pedestals was experimentally investigated. There are three specimens of concrete pedestals reinforced with ties, three specimens of concrete pedestals reinforced with spirals and three plain concrete pedestal. The use of square steel plate helps in determining the bearing capacity when concentrically loaded on top of the specimen. Experimental results indicate that the reinforced concrete blocks with spirals and ties gave larger bearing capacities than unreinforced concrete blocks. While the concrete block with higher steel percentage gave a slightly higher bearing capacity. The modes of failure between reinforced and unreinforced concrete blocks were differ between each other as the inverted pyramid and a conical shape failure occurs in the plain concrete block, while reinforced concrete block mostly gave a splitting crack on the outside of the lateral reinforcements.*

**Keywords:** *Bearing strength, Square steel plates, Bridge concrete pedestals, Confining reinforcements*

---

ISSN 1823-5514, eISSN2550-164X

Received for review: 2017-09-13
Accepted for publication: 2018-04-01
Published: 2019-08-31

## Introduction

The bridge is an important part of our life which connecting two areas or providing passage over a gap or barrier such as a river or roadway or any other physical obstacle. The structure of the bridge can be divided into two main components; superstructure and substructure. Each of the bridge components has its own crucial function for the stability of the bridge system. The main superstructure components are deck slabs, beams and girders, abutments and piers. Meanwhile, bearings, expansion joints, and parapet fall under the category of substructure components. Bridge concrete pedestal is also one of the substructure components in bridges. Concrete pedestals are located under the bridge bearing at the piers crosshead or abutment-top. The main function of the concrete pedestal is to transfer loads from the bridge deck to the pier or abutment. Generally, concrete pedestal is a concrete block which similar to the shallow type of concrete footing.

The understanding of bearing capacity of concrete is essential for the design purpose of structural support members either for building or other infrastructures such as the concrete footing, anchorage for pre-stress member and even for a concrete pedestal in bridges [3]. With the provision of reinforcement, cracking strength of the bridge concrete pedestal can be improved and acts as an added mechanism to counter the tension part. This research also acts as parts of continuous study from previous researchers for a better understanding and assists civil engineers to have a deep knowledge when encountered with the complex design of structural members. The effects of several important variables such as the size of concrete blocks and steel plate, and the different type of confining reinforcements can also affect the load transfer and the failure mechanism of concrete bearing [1,7]. The problems may arise if lack of quantitative understanding on the concrete bearing capacity and its generation mechanism (or cause of a concrete failure).

As stated by a numerous number of researchers [9,11,12]), there was a case where the cracking such as vertical and radial cracking were occurring with the use of plain concrete blocks subjected to high compressive loading. In order to provide a much higher compressive load without facing the failure, the dimension of the concrete column should be enlarged. Nevertheless, the solution requires higher cost and not suitable to be used as a concrete member. Another way was by having a steel plate on the top surface of concrete block as its application can be seen on a concrete bridge pedestal and the capacity of that concrete towards the load applied on it can be called as load bearing capacity.

The load-bearing capacity was first investigated by [6] followed by some others researchers [13,16,5]. The 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. Many types of concrete blocks such as rectangular section, square section and circular section were commonly used by many researchers to study the behaviour of the load bearing strength of concrete blocks and observe its failure mechanism.

The bearing capacity of concrete somehow always related to the variety of design problems as demonstrates by two researchers [12,18]. The bearing capacity can be estimated by the assist of the steel plate positioned at the touching surface of the concrete cubes. The increasing of the bearing capacity was related to the increasing of the concrete strength, reduce the height of the concrete blocks and the total to load area ratio either for the plain or reinforced concrete blocks [1,4,14,15,17]. Rao [11] stated that the parameters like 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 on the touching surface of concrete blocks either at the center or the edge of the concrete blocks (concentrically and eccentrically loaded bearing strength) also plays an essential role in gaining the bearing strength of the concrete [1].

The strength of concrete in direct compression significantly increased if the concrete was confined laterally, a fact reflected in the ACI Building Code with its treatment of spiral versus tied columns [2], and in the method presented for the determination of allowable bearing capacity as stated by Burdette [8]. Researchers indicate that the concrete block confined with ties and spiral reinforcement provides a greater bearing strength as compared to unreinforced concrete block. In addition, the different types of confining reinforcements also show 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 for investigation on the effect of having different types of confining reinforcement such as ties and spirals.

The understanding of the behaviour of confining reinforcements and its generation mechanism on the bearing strength of concrete blocks was still rather crude and need further investigation especially 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 members, experimental investigations were carried out to determine the behaviour of confining reinforcement on the bearing strength of concrete blocks.

## Theoretical developments

Analytical consideration proposed by [4] was 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.

$$f'_{cc} = f_c'\left(\sqrt[3]{\frac{A_2}{A_1}}\right) \tag{1}$$

Later, [10] derived an expression for ratios of $A_2/A_1$ ranging from 1 to 40 as follows:

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

In which, $f'_{cc}$ represents the concrete bearing strength, $f_c'$ as the concrete compressive strength (MPa), $A_1$ as the bearing plate area and $A_2$ as the area of the lower base of the largest frustum of a pyramid. The American Concrete Institute (ACI) also proposed an expression to estimate the bearing strength of concrete as defined in [2] as follows:

$$f'_{cc} = 0.85\phi_c f'_c\left(\sqrt{\frac{A_2}{A_1}}\right) \tag{3}$$

where, $A_1$ denotes bearing plate area, $A_2$ as the area of the lower base of of the largest frustum of a pyramid, $\phi_c$ as the capacity reduction factor for concrete in bearing and $0.85f'_c$ as the concrete compressive strength under sustained loads.

After a numerous number of developments on strength of concrete bearing capacity, recent researchers realized that with the aid of confining reinforcement of the concrete, the bearing strength of the concrete will provide higher value than the plain concrete. [7] had proposed expression for the prediction of maximum bearing strength comprises of confining ties and spiral reinforcement on concrete blocks. The expression of concrete block reinforced with ties is defined as follows:

$$Pr = \left[2f'_c + 3.5\left(\left(1 - \frac{s}{L}\right)\left(\frac{2A_s f_y}{sL}\right)\right)\right]A_1 \tag{4}$$

In which, $P_r$ denotes the maximum bearing strength or equivalent to $f'_{cc}$ as in Equations (1), (2) and (3), which represents tie spacing, L as tie width, $A_s$ as area of steel reinforcing bar, $f_y$ as yield strength of steel and $A_1$ as area of the bearing plate. In addition, the proposed formula for concrete block reinforced with spirals is defined as follows:

$$Pr = \left[2f'_c + 4.5\left(\frac{2A_s f_y}{sD}\right)\right]A_1 \quad (5)$$

where, s represents the spiral pitch and D denotes as diameter of the spiral.

## Methods

### Preparation of specimen

The concrete with the characteristic strength of 30 N/mm$^2$ was poured into the molds (200×200x200mm). All specimens were cast from a concrete mix as shown in Table 1.

Table 1: Proportion of Concrete per m$^2$

| **Cement (kg)** | **Water (Kg/m$^3$)** | **Fine Aggregates(kg)** | **Coarse Aggregates(kg)** | |
|---|---|---|---|---|
| | | | 10 mm | 20 mm |
| 54.6 | 25.2 | 73.4 | 59.6 | 119.1 |

The concrete block was remoulded and placed in the curing tank after 24 hours of casting. From a batch of concrete, three numbers of concrete cubes (150 x150mm) 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 as shown in Figure 1.

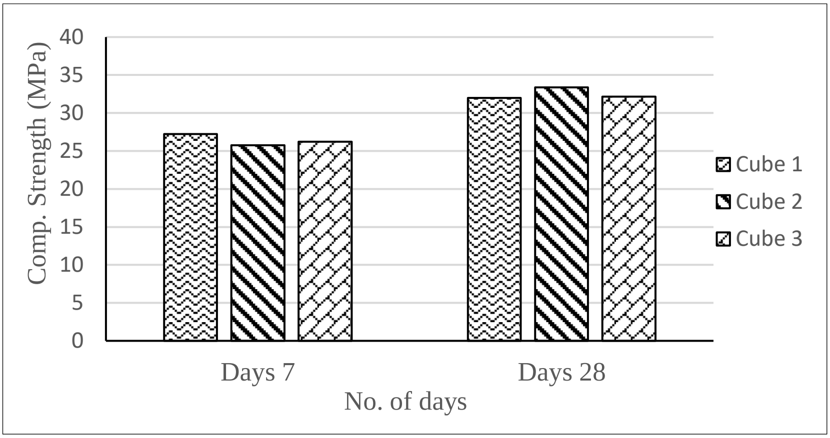



Figure 1: Mechanical properties of the concrete mix

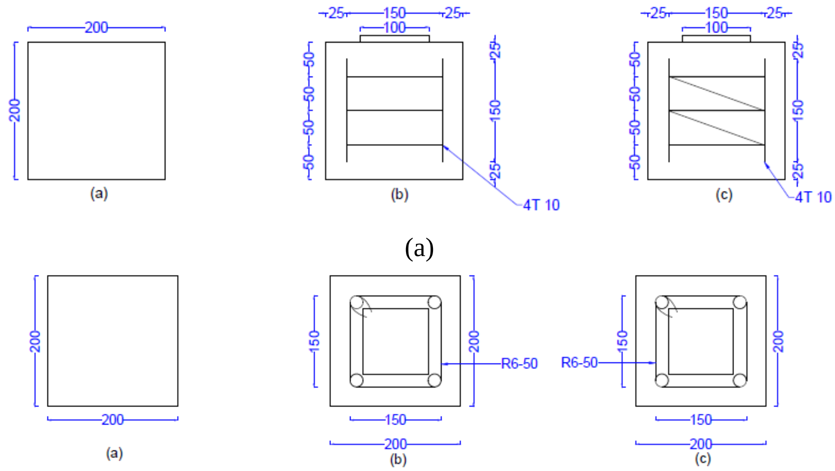
A total of nine numbers of concrete blocks was cast and tested up to failure subjected to axial compressive loading. There were three unreinforced concrete blocks, three concrete blocks laterally reinforced by ties and three concrete blocks reinforced with spirals as shown in Table 2 and Figure 2. Each of these specimens had bearing steel plate (100 x100 x100mm) concentrically placed on top of the specimens.

Table 2: Details configuration of concrete specimens

| **Specimen designation** | **Block Cross section** | **Block height** | **Plate cross section** | **Remarks** |
|---|---|---|---|---|
| PC-30-01<br>PC-30-02<br>PC-30-03 | 200mm x 200mm | 200mm | 100mm x 100mm | Concrete without reinforcement |
| RCT-30-01<br>RCT-30-02<br>RCT-30-03 | | | | Concrete laterally reinforced with ties |
| RCS-30-01<br>RCS-30-02<br>RCS-30-03 | | | | Concrete laterally reinforced with spirals |

Note that:
PC-30-01 denotes the unreinforced (plain) concrete block with the characteristic strength of 30 MPa of the first specimen.
RCT-30-01 denotes the concrete block laterally reinforced with ties with the characteristic strength of 30 MPa of the first specimen.
RCS-30-01 denotes the concrete block laterally reinforced with spirals with the characteristic strength of 30 MPa of the first specimen.

In this study, 10mm plate thickness was selected due to the reason that it is a typical range of the steel plate thickness in most experimental setup performed by previous studies, ranging from 8mm to 15mm [1,9,14].




(b)

Figure 2: Cross section concrete block (a) plain concrete block, (b) concrete block laterally reinforced with ties, (c) concrete block laterally reinforced with spirals (all dimensions in mm).

## Experimental details and test setup

All concrete block specimens have been tested up to failure subjected to axially compressive loading using a 2500 kN Universal Testing Machine (UTM). The aim of this experimental work was to determine the percentage increase in bearing strength resulting from different types of confining reinforcements. In order to ensure smooth contact between the bearing plate and the concrete surface, the bearing surface of the machine and the 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 lowered gently 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 3. The ultimate load and any crack deformities on the concrete block specimen were observed and recorded.

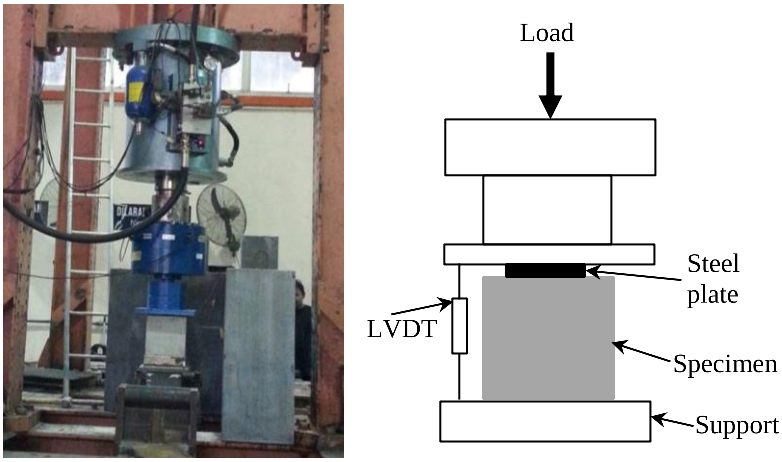



Figure 3: Experimental setup

## Result and discussions

**Load bearing capacity-deformation relationship**

The effects of lateral reinforcement either ties or spirals on the bearing capacity of concrete blocks are known to be increased when compared with the plain concrete blocks due to the strength characteristic possessed by the reinforcement when subjected to tension. Then, the study on the concrete block reinforced with ties and spirals has been performed to understand more about the area of uncertainty in prediction of strength mainly with respect to the ability of the reinforcing steel to reach yielding at ultimate loads at increasing volumetric ratio.

The load capacity and displacement values were obtained using data acquisition systems, recorded by the computer. Based on the obtained results via experimental measurements for nine (9) numbers of concrete block specimens, the maximum bearing strength and displacement relationship were plotted. The graph of bearing strength versus deformation for all specimens are shown in Figure 4.

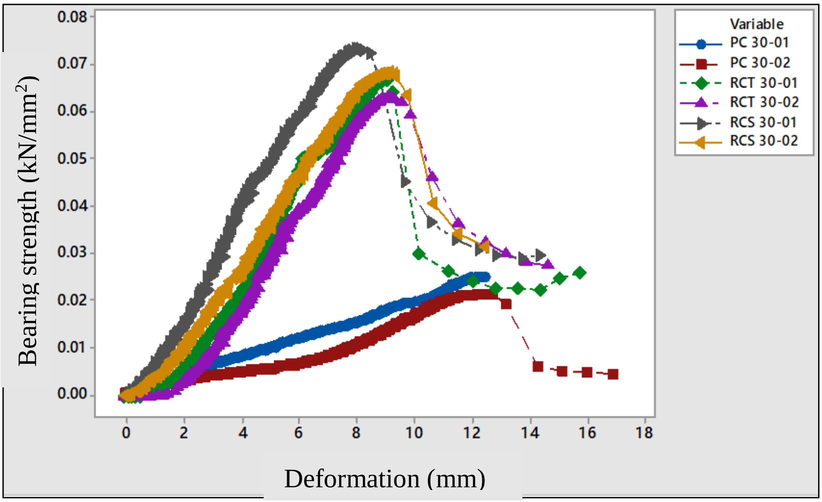



Figure 4: Graph of bearing strength versus deformation

With regards to the results depicted in Figure 3, for the plain concrete blocks labelled as PC-30-01, PC-30-02 and PC-30-03, its average ultimate value of load bearing capacity was recorded as 0.023kN/mm$^2$ with 10.75mm deformation. Meanwhile, for concrete block specimens laterally reinforced with ties denotes as RCT-30-01, RCT-30-02 and RCT-30-03, the average value of bearing strength was recorded as 0.064kN/mm$^2$ with 9.20mm deformation. In addition, for concrete block specimens laterally reinforced with spirals denotes as RCS-30-01, RCS-30-02 and RCS-30-03, the average value of bearing strength was recorded as 0.069kN/mm$^2$ with 8.71mm deformation. The result of each type of specimen and its comparison with previous studies were then presented in Table 3 and Table 4.

Table 3: Results of bearing strength test

| **Specimen designation** | **Average Ultimate Load (kN)** | **Average Bearing Strength, $f_b$ (N/mm$^2$)** | **Average deformation (mm)** |
|---|---|---|---|
| PC | 918.24 | 23 | 10.75 |
| RCT | 643.81 | 64 | 9.2 |
| RCS | 695.35 | 69 | 8.71 |

Table 4: Comparison between experimental test and previous studies

| Specimen designation | $f_b$ (Exp.) N/mm$^2$ | $f_{b(R)}$ N/mm$^2$ (Rod., 2014) | $f_{b(A)}$ N/mm$^2$ (ACI-318) | $f_b/f_{b(R)}$ | $f_b/f_{b(A)}$ |
|---|---|---|---|---|---|
| PC | 23 | 43 | 33 | 0.53 | 0.70 |
| RCT | 64 | 69 | 33 | 0.93 | 1.94 |
| RCS | 69 | 71 | 36 | 0.97 | 1.93 |

Experimental results demonstrated that the bearing strength of concrete block when confined with spirals gave a higher value as compared to concrete block confined with ties. Similarly, when compared with concrete block that had been loaded without steel plate, both confined concrete blocks (spirals and ties) gave a higher value of bearing strength with huge significant values. Test on the bearing strength of plain concrete have served to fill an essential gap in the experimental data. As can be observed on the deformation of the specimen, it indicates that the concrete block specimen laterally reinforced with spirals has the tendency to decrease the deformation of the concrete specimen.

## Confinement effects

The relationship between the ratio of unloaded (A) to loaded (A') area and the effects of confinement provided by the surrounding concrete was crucial in predicting the behaviour of concrete blocks. In this study, experimental investigation has been carried out to inspect either having the higher confinement effect will provide an increasing or decreasing value of load bearing capacity of concrete blocks loaded through steel plate. In this case, the effects of confinement were defined as the ratio of area of concrete surface divided by the loaded area of steel plates as depicted in Figure 5.

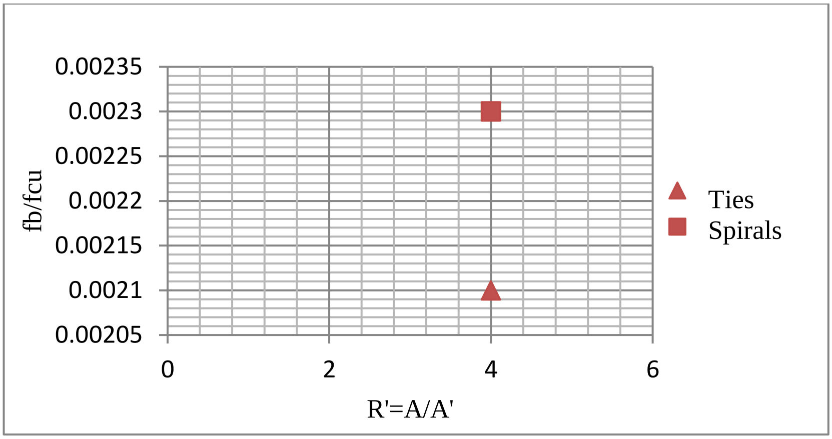



Figure 5: Relationship between confinement effect and load bearing area

The steel plate dimension of 100mm x 100mm in cross section provides a similar ratio of specimen unloaded area to loaded area as can be observed in Figure 5. As the values indicated in Figure 5 demonstrates that the bearing strength of concrete block laterally reinforced with spirals to the compressive strength of concrete was significantly larger as compared to the bearing strength of concrete blocks laterally reinforced by ties to the concrete compressive strength.

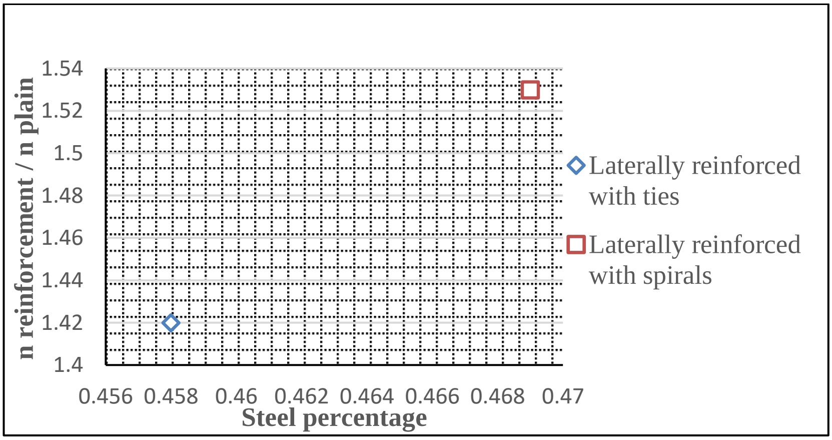



Figure 6: Relationship of steel percentage and n reinforcement/n plain for 200 x 200 x 200 mm reinforced and plain concrete blocks

The relationship of the steel percentage for the ratio of bearing strength *n reinforcement/n plain* are shown in Figure 6. In this study, *n* denotes the non-dimensional ratio of ultimate bearing strength (with reinforcement) to ultimate bearing strength (plain) and percentage of steel were calculated using volume fraction.

As depicted in Figure 6, it can clearly be observed that as the percentage of steel increase the n values also increase. Concrete blocks laterally reinforced with spirals with a steel percentage of 0.469 gave the highest ultimate bearing strength compared to the concrete block laterally reinforced with ties with the steel percentage of 0.458.

## Mode of failures

The failure of concrete blocks occurs when the forces applied on top of it exceeded the strength of concrete. The type of failure modes that have been observed during the experimental testing is in the forms of vertical crack, inverse pyramid shape, conical crack and radial crack along the height of the specimen. It has found that this observation is comparable with previous studies [3,12,14,15,17,19] where the inverse pyramid failure been observed at the outer edge of contact area, as shown in Figure 7(a). In this study of confined concrete block, the crack failure was reduced to a certain level or it would be much in various shapes of crack due to the arrangement of ties and spiral reinforcements. The behaviour of confinement (ties and spiral) on bearing strength of concrete block was increased as compared to un-reinforced concrete due to the presence of reinforcement that acts as tension resistance and significantly improve the strength of concrete when the specimen was concentrically loaded on the bearing plate of the concrete block. The modes of failure of reinforced and un-reinforced concrete block are shown in Figure 7 until Figure 9.

(a) (b) (c)

Figure 7: Type of failure when the plain concrete block was concentrically loaded without steel plate; (a) Inverted pyramid shape, (b) nonexplosive crack, (c) Conical shape failure

(a) (b) (c)

Figure 8: Modes of failure when concrete blocks laterally reinforced with ties were concentrically loaded through 10 mm thick steel plate; (a) Radial crack, (b) Edge crack outside lateral bar, (c) Edge crack.

(a) (b) (c)

Figure 9: Modes of failure when concrete blocks laterally reinforced with spirals were concentrically loaded through 10 mm thick steel plates; (a) Radial crack, (b) Edge crack, (c) Edge crack outside plate area

As depicted in Figure 7(a), when the load reaches its limiting value, an inverse pyramid shape can be observed in the specimens. A conical wedge punched out from beneath the steel bearing plate as shown in Figure 7(b) and (c). Meanwhile, concrete block specimens that were confined with ties shows the behaviour of radial crack and edge crack as shown in Figure 8. Edge cracking also can be seen outside the lateral bar of the ties reinforcement as shown in Figure 8(b). In addition, Figure 9 shows concrete block specimens laterally reinforced with spirals after failure. As they were progressively loaded under concentric loading, radial crack and edge crack developed at the corners of the concrete blocks. Similar as concrete block with ties specimen, the spirals concrete block also shown the mode of failure of edge crack outside the plate area as shown in Figure 9(c).

## Conclusions

The following conclusions were derived through this study:

1) Confined concrete blocks (spirals and ties) gave a higher value of bearing strength if compared with plain/un-reinforced concrete.

2) The specimen having lower value of bearing capacity experiencing much more deformation. Concrete block specimen laterally reinforced by ties or spirals has the tendency to decrease the deformation of the concrete specimens.
3) The non-explosive crack, inverted pyramid and the conical shape of failure can be observed in plain concrete specimens due to the reason that no reinforcing bar to hold the failure when the concrete specimen reaches its limiting value. When the maximum tensile stress at the top of the block exceeds the tensile strength of the concrete, then the failure can occur in the concrete blocks.
4) For the confined concrete blocks, the modes of failure occurred in the forms of radial crack and wedge crack at the corner of the specimen. The crack failure tends to occur at the outer side of the lateral reinforcement due to the presence of lateral reinforcement which provide strength to the concrete specimen and holds the failure in such a long time before it fails completely. Therefore, it is necessary to provide reinforcement bar within the concrete specimen to increase the bearing capacity and help in avoiding the failure.
5) The bearing strength increases linearly with increasing confining steel ratio.

## Acknowledgements

The authors gratefully acknowledge the financial supports by Ministry of Higher Education under Research Acculturation Grant Scheme (RAGS) (RAGS/1/2015/TK01/UITM/03/1) and also thankful to all staff in Concrete, Fabrication and Heavy Structures laboratories, Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam for their assistance in completing these experimental works.

## References

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

[2] 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.

[3] 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.

[4] Al-Taan, S.A. 2005. Bearing capacity of steel fibrous concrete. Civil Engineering Department, Mosul University, Mosul.

[5] Au, T., & Baird, D.L. 1960. Bearing capacity of concrete blocks. *Journal of the American Concrete Institute*. 56, 869 – 880.

[6] Baushinger, J. 1876. Tests with Blocks of Natural Stone. *Mechanisch und Technischen Laboratorium der*, Munich, 6, 13.

[7] Bonetti, R., Wollmann, C. L. R., & Santos, J. T. 2014. Bearing strength of confined concrete. *ACI Structural Journal*, *111*(6), 1317–1327.

[8] Burdette, E. G., Jones, W. D., & Fricke, K. E. 1983. Concrete bearing capacity around large inserts. *Journal of Structural Engineering*, *109*(6), 1375–1386.

[9] 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), 1784-1792.

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

[11] Kameswara Rao, C.V.S., & Swamy, R.N. 1974. Bearing strength of steel fibre reinforced concrete. *Build. Sci.*, 9, 263-268.

[12] Ince, R., & Arici, E. 2004. Size effect in bearing strength of concrete cubes. *Construction and Building Materials*, 18, 603-609.

[13] Meyerhof, G.G. 1953. The bearing capacity of concrete and rock. *Magazine of Concrete Research*, 107-116.

[14] Mohd Raizamzamani, M.Z. & Yahya, N.A. 2016. Experimental Study on Bearing Strength of Concrete Blocks under Concentric Compression Load. *3rd International Conference on Science and Social Research (CSSR 2016)*, Putrajaya, Malaysia.

[15] Nurul Adilah, M. & Mohd Raizamzamani, M.Z. 2016. Bearing Strength of Concrete Blocks Axially Loaded through Various Sizes of Steel Plates. Final Year Project, Bachelor of Engineering (Hons) Civil, Universiti Teknologi Mara, Malaysia.

[16] Shelson, W. 1957. Bearing capacity of concrete. *Journal of the American Concrete Institute*, 54(5), 405-414.

[17] Siti Nurul Ashikin, A. & Mohd Raizamzamani, M.Z. 2017. Experimental Study on the Bearing Capacity of Concrete Blocks Loaded through Square and Circular Steel Plates. Final Year Project, Bachelor of Engineering (Hons) Civil, Universiti Teknologi Mara, Malaysia.

[18] Yahya, N.A., & Dhanasekar, M. 2014. Explicit finite element modelling of bridge girder bearing pedestals. In Smith, Scott T. (Ed.). *23rd Australasian Conference on the Mechanics of Structures and Materials (ACMSM23)*, Southern Cross University, Byron Bay, Australia, 849-853.

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