eISSN:2600-7920
INTI JOURNAL
Vol.1, 2018 (13)

A comparison on shear performance of pad foundation using BS8110, EC2 and ACI318

Mohammad Panjehpour[1] and Victor Kumala Putra[2]

Centre for Advanced Concrete Technology (CACT), Faculty of Engineering and Quantity Surveying (FEQS), INTI International University, Nilai, Negeri Sembilan, Malaysia,

Corresponding Author: mohammad.panjehpour@newinti.edu.my

Abstract

This research aims to compare the design and analysis outcomes of British Code (BS 8110), Eurocode (EC2) and American code (ACI 318) on pad foundation by utilising Autodesk Robot 2018 and Excel spreadsheets. It sheds some lights on the differences among the three aforementioned codes regarding punching shear stress of pad foundation. The shear performance, particularly the punching shear, are scrutinised by taking the axial load and biaxial moments into account. The key variables are size of pad foundation. The research reveals that ACI-318 design provides the lowest overall shear stress followed by EC2 design and then BS8110 design. Nevertheless, EC2 design provides the lowest punching shear stress followed by BS8110 design and then ACI-318 design. The punching shear stress in critical perimeter is primarily governed by length and width of foundation followed by concrete cover and length of column. This research is confined to shear design and shear analysis of reinforced concrete pad foundation with the primary focus on punching shear stress. The research also touches upon the required shear reinforcements recommended by the three codes. The scope of this research is confined to only short columns.

Keywords

Shear stress, punching, pad foundation

Introduction

As the new design methods of building and construction develops, the building codes and standards undergoes massive changes with the primary goals of providing safe and sustainable structures. The British Standard (BS 8110), Eurocode (EN 1992) and American Concrete Institute (ACI 318) are currently utilised in many countries. The globalization in construction industry has increased the needs for better understanding of fundamental differences among design codes, and therefore building engineers require deciding which design code should be adopted for practical purposes. At the very beginning, BS 8110 was widely known as CP 110, which was published in 1972 by British Standard Institution. Eurocode 2, known as EN1992, is a part of a family of ten European codes. It was first published in 1992 as preliminary standards known as ENV by European Community. Before ACI 318 was set up, America had been using their very first code which was published in 1910 named “Standard Building Regulations for the Use of Reinforced Concrete.” ACI 318 was solely based on the behaviour of in-situ concrete (Anderson, 2014).

Structural design is a process of proposing suitable materials and adequate sizes for a structural element so that it can sustain loads safely (Bashir, 2014). The design of pad foundation is usually conducted by understanding the interaction of soil and structure based on the results of structural and geotechnical analysis (Abdrabbo et al., 2016). The structural design of a pad foundation and the failure mechanism are usually governed by the punching shear induced in the foundation. In most of the design codes, the punching shear theory for flat slab and pad foundation is not still differentiated (Hegger et al., 2009). The lack of research data in the design of foundation due to difficulties and challenges when conducting the experiment indicates the need for more research on pad foundations (Hegger et al., 2006).

Foundation is the lowest part of a structure which transfers dead load and live load from the structure to the soil and prevents a structure from overturning and sliding (Bhavikatti, 2010). Besides, it is to prevent excessive settlement from occurring due to the bearing capacity of the soil being exceeded (Arya, 2009). Foundation is classified into two types of shallow and deep. They are differentiated with the criterion of depth of 3 meters (Bhavikatti, 2010 and Som and Das, 2006). Shallow foundation comprises pad footing, spread footing, combined footing and raft foundation (Bangash, 2003) while deep foundation comprises piles, piers and caissons (Bangash, 2003).

Over the last decade, several studies have been conducted to compare the design and analysis of different design codes. According to Nwoji and Ugwu (2017), EC2 is not as economical BS8110 for design of foundation at service load, while for that of ultimate load EC2 is more economical than BS8110. Nevertheless, both BS8110 and EC2 are conservative in punching shear design requirements (Soares and Vollum, 2015). EC2 provides the most economical and rational results than the BS8110 and ACI 318 for punching shear of pad footings (Bonić and Folić, 2013). In general, EC2 and BS8110 are more economical compared to ACI 318. However, EC2 and BS8110 show very similar results for flexure design of pad footing while ACI 318 shows less economical results, and regarding shear reinforcement, BS8110 is the most conservative (Jawad 2006). Therefore, it is economically significant to conduct a parallel comparison among the three codes regarding the analysis of pad foundation to attain the most economical proposed design by scrutinizing the key parameters.

By a close examination of the three aforementioned codes, the considerable differences of proposed dimension of critical perimeter for pad foundation, particularly for shear design, is perceived. Therefore, this research aims to find out the fundamental differences among BS 8110, EN 1992 and ACI 318 for the shear design and analysis of pad foundation by using Autodesk Robot 2018 and Excel spreadsheet. The variables of this investigation are depth, width and length pad foundation as they play the key roles in design and analysis of pad foundation.

Methodology

To achieve the objectives of this study, three Excel spreadsheets for the design of pad foundations were generated based on the three different code provisions, which are BS 8110, EN 1992 and

ACI 318. The three spreadsheets were utilised to ease the calculation performance for shear design in detail based on predetermined parameters such as the dead load and imposed load. The generated spreadsheets were verified with the hand-calculation. Moreover, the outcomes of calculation using Autodesk Revit 2018 software were in agreement with both of spreadsheet and hand-calculation. The variables in each spreadsheet were changed to identify which one would primarily affect the pad foundation design in terms of economical and safety aspect. The process was iterated and eventually the charts were produced.

The spreadsheets consist of cells with input data such as the compressive strength of the concrete, the yield strength of the reinforcing bars and the size of foundation. The spreadsheets were then utilised to carry out all the necessary calculations for shear design. To facilitate the implementation of the research the size of the pad foundation was predetermined. The materials such as concrete and reinforcing bars were also predetermined based on the data collected from each code. Afterwards, the data was inserted in the spreadsheets. The dead load and imposed load were specified to calculate the total design load based on the load factors from each code. The design load was utilised to evaluate the shear resistance of the structural element. Then, the same variables were altered in each code to further understand the effects of those parameters on pad foundation design. The variable used are listed below.

Size of the foundation: 1.5 m × 1.5 m × 0.3 m
Size of the short column: 0.3 m × 0.3 m
Axial dead load: 300 kN
Axial live load: 150 kN
Moment from dead load in x-x direction: 10 kNm
Moment from live load in x-x direction: 5 kNm
Moment from dead load in y-y direction: 10 kNm
Moment from live load in x-x direction: 5 kNm
f_{cu}: 30 MPa
f_y: 460 MPa
Concrete cover: 50 mm
Size of reinforcing bars: 20 mm

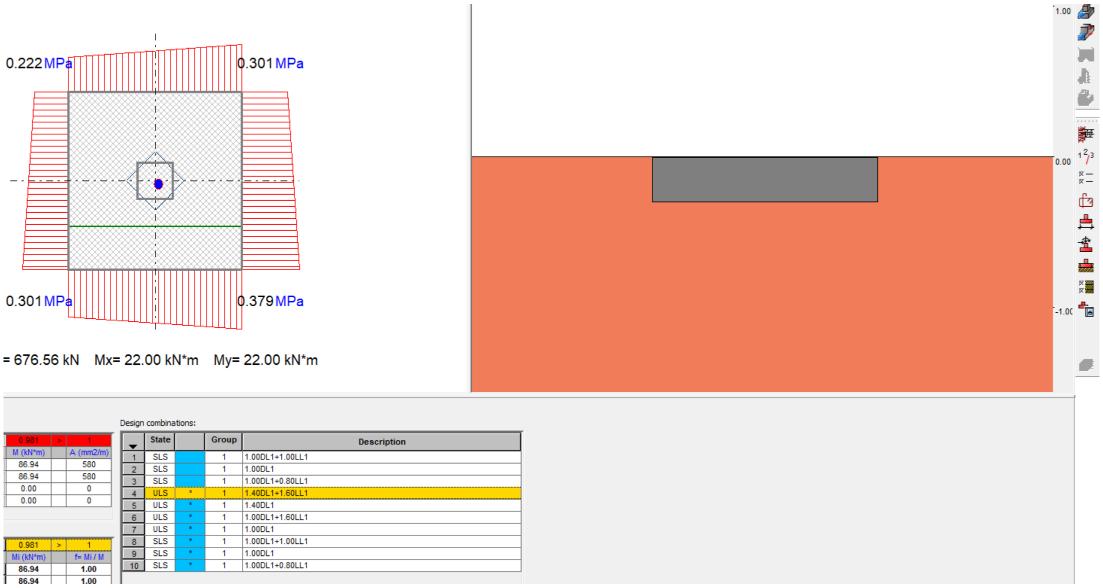
The pad foundation was checked on the pressure pattern exerted by the foundation to the ground to identify whether the foundation was in full compression or partial compression to calculate the coefficient in four corners of the pad foundation. The coefficients obtained were then used to calculate the pressure in every edge. The pressure distribution diagram was drawn based on the edge pressures. These values were used to calculate the pressure exactly at the column face for all faces based on the pressure distribution diagram.

Simulation and verification was conducted to compare the results from the spreadsheets with those of Autodesk Robot 2018. The detailed process is summarised below:

1.In the first window of Robot structural analysis, the Building Design template was chosen.
2.The design code and load combinations were changed to either BS, EC or ACI in the tools of Job Preferences.

3.The model was then created by going into the design, and providing reinforcement of RC elements module.
4.In this new window, foundation was created by choosing the tool new foundation.
5.The parameters were changed to the desired parameters.
6.The loading was added for RC elements.
7.The analysis was performed by choosing analysis tab.
8.The results of resistance bending moments in X and Y direction as well as shear stress were then investigated.

The results using spreadsheets are very similar to those of Robot structural analysis with approximately less than 1% difference. This is simply due to rounding up and rounding down of the results. Figure 1. indicates the analysis outcomes of Autodesk Robot 2018.



= 676.56 kN Mx= 22.00 kN*m My= 22.00 kN*m

0.981	>	1
M (kN*m)		A (mm2/m)
86.94		580
86.94		580
0.00		0
0.00		0

0.981	>	1
Mi (kN*m)		f= Mi / M
86.94		**1.00**
86.94		**1.00**

Design combinations:

	State		Group	Description
1	SLS		1	1.00DL1+1.00LL1
2	SLS		1	1.00DL1
3	SLS		1	1.00DL1+0.80LL1
4	ULS	*	1	1.40DL1+1.60LL1
5	ULS	*	1	1.40DL1
6	ULS	*	1	1.00DL1+1.60LL1
7	ULS	*	1	1.00DL1
8	SLS	*	1	1.00DL1+1.00LL1
9	SLS	*	1	1.00DL1
10	SLS	*	1	1.00DL1+0.80LL1

Figure 1. The pad foundation analysis outcomes using Autodesk Robot 2018

This research covers solely the design of reinforced concrete pad foundation, based on BS 8110, EN 1992 and ACI 318 under similar loading condition for dead load and imposed load by excluding other external factors such as seismic factor as specified in ACI 318, wind factor, volume change of soil and differential settlement of soil. Besides, all pad foundations designed are assumed to be built on the same soil having sufficient and similar physical, mechanical and chemical properties. The stability analysis of the foundation is not considered in this research. In addition, all tension reinforcements are assumed to be yielded. As the use of shear reinforcement in pad foundation is usually considered impractical the shear reinforcement is assumed zero.

Results and Discussion

Figure 2. illustrates the comparison among the ACI318, BS8110 and EC2 in terms of resistance moments in X and Y direction which indicate the shear performance of a pad foundation analysed using the three codes. The results are generated using both Autodesk Robot 2018 and Excel spreadsheet for the purpose of verification. Figure 3. indicates the shear stress at the distance of d (effective depth) from the face of the column. The results obtained from spreadsheet calculations are reliable and correct when compare with Autodesk Robot outcomes. Therefore, the model created using Autodesk Robot is valid.

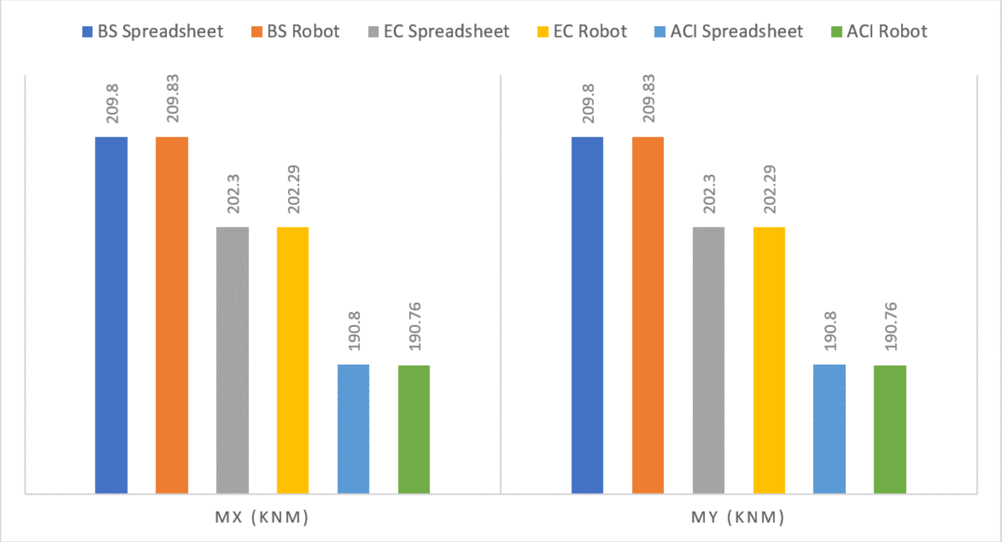


Figure 2. Comparison of the pad foundation design outcomes in terms of bending moments in X and Y direction

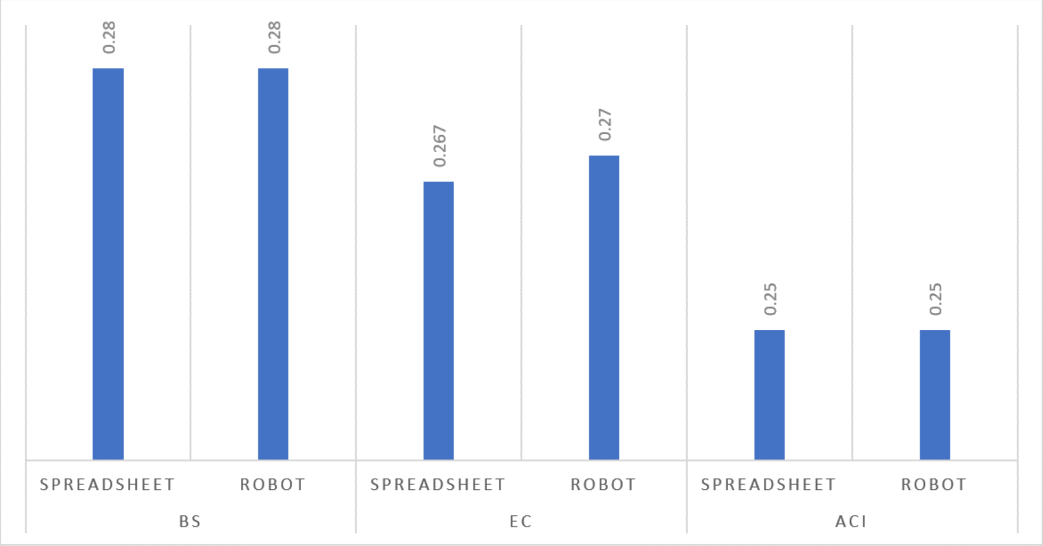


Figure 3. Comparison of the pad foundation design outcomes in terms of design shear stress at the distance of effective depth from the face of column

The shear performance of the pad foundation is evaluated by the changing the variables of foundation depth, width and length. Overall, the punching shear stress increases slightly as the foundation becomes larger. This is because larger foundation size will have a higher self-weight which leads to higher axial load and consequently higher punching force. Moreover, larger foundation imposes less pressure to the ground which will result in a lower upwards shear force and consequently lower punching shear. These finding are supported by the study conducted by Bonić and Folić (2013).

A slight increase in foundation depth significantly reduces the punching shear stress. This is because thicker foundation allows higher effective depth, increase of punching shear area and a lower punching shear stress. The punching shear stress decreases slightly as the column length increases. An increase in column length results in a larger punching area leads to a lower punching shear stress.

ACI design results the lowest shear stress in both X and Y direction followed by EC design and then BS design. The average shear stress based on EC design is approximately 5% more than ACI design whereas the shear stress based on BS design is approximately 9% more than ACI design. In other words, the difference between the shear stress based on BS design and EC design is approximately 4% with EC design having the lesser shear stress. This is also due to the differences in the ultimate limit state load combination which results in different design shear forces.

EC design has the lowest punching shear stress followed by BS design and then ACI design. This is also supported by the study conducted by Nwoji and Ugwu (2017), Nwofor et al. (2015), and Jawad (2006). It can be observed that the punching shear stress evaluated using ACI design is significantly higher. One of the reason is also due to the load factors resulting in a slightly different design axial load. Besides, it is also due to the differences in the critical perimeter specified in each code which are as follows:

- Critical perimeter for BS is 1.5d from column face in the shape of a square.
- Critical perimeter for EC is 2d from column face in the shape of a square.
- Critical perimeter for ACI is 0.5d from column face in the shape of a square.

By a close examination of design methods proposed by the aforementioned three codes, EC design has the least area of reinforcement required for bending in both X and Y directions followed by BS design and then ACI design. The average area of reinforcement required based on BS design is approximately 14% more than EC design while the area of reinforcement required based on ACI design is approximately 16% more than EC design. To put it simply, the difference between the area of reinforcement required based on BS design and ACI design is very small, approximately 2%, with BS design having the lesser area of reinforcement required. A primarily reason for this is the different load factors for dead load and live load. The ultimate limit state load combination using EC is the lowest followed by BS and ACI resulting in different design moment and therefore affecting the area of reinforcement. Furthermore, the calculations and equations for area of reinforcement based on each code are governed by few different variables based on different assumptions and derivations. These finding are in agreement with the research conducted by Hawileh et al. (2009).

Based on the minimum area of reinforcement, the comparison results showed that the minimum reinforcement as per ACI design is the highest followed by BS design and then EC design. This is because the minimum percentage of reinforcement required in ACI design is 0.18% while that of BS design and EC design which is 0.13%.

Conclusions

ACI design has the lowest overall shear stress in both direction followed by EC design and then BS design. The average overall shear stress based on EC design is approximately 5% more than ACI design while that of BS design is approximately 9% more than ACI design. In other words, the difference between the overall shear stress based on BS design and EC design is approximately 4% with EC design having the lesser shear stress. This is due to the differences in load combination under ultimate limit state which results in different design shear forces. EC design provides the lowest punching shear stress followed by BS design and then ACI design. The punching shear stress in critical perimeter is primarily governed by the length and width of foundation followed by concrete cover and length of column. ACI design has the highest minimum required reinforcement. Regarding the minimum area of reinforcement and shear performance, EC provides the most economical design followed by BS design and then ACI design. The experimental research on the shear performance of pad foundation would shed some light on the finding of current research. For further exploration, it is worth including the seismic and wind loading for the evaluation of shear performance of pad foundation. Further research on rectangular cross-section columns would widen the scope and consequently the applicability of this research finding.

Acknowledgement

The authors of this article appreciate the technical support from the Center of Advanced Concrete Technology (CACT) in INTI International University.

References

Abdrabbo, F., Mahmoud, Z. I., and Ebrahim, M. (2016). Structural design of isolated column footings. Alexandria Engineering Journal, 55, pp. 2665-5678.

American Concrete Institute. (2014). ACI318M-14: Building code requirements for structural concrete. ACI: USA.

Anderson, N. S. (2014). The Reorganized ACI 318-14 Code [PowerPoint Presentation].

Arya, C. (2009). Design of structural elements: concrete, steelwork, masonry and timber design to British Standards and Eurocodes. 3rd ed. Taylor & Francis: London.

Bangash, M. Y. H. (2003). Structural detailing in concrete: A comparative study of British, European and American codes and practices. 2nd Ed. Thomas Telford Ltd.: London.

Bashir, S. (2014). Design of short columns according to ACI 318-11 and BS 8110-97: A comparative study based on conditions in Nigeria. Near East University.

Bhavikatti, S. S. (2010). Basic civil engineering. New Age International (P) Ltd., Publishers: New Delhi.

Bonić, Z. and Folić, R. (2013). Punching of column footings – comparison of experimental and calculation results. Građevinar, Vol 65, 10, pp. 887 – 899.

British Standards Institution. (1997). BS8110-1: Structural use of concrete: Code of practice for design and construction. BSI: London.

British Standards Institution. (2004). BS EN1992-1: Design of concrete structures: General rules and rules for buildings. BSI: London.

Hawileh, R. A., Rahman, A. and Malhas, F. (2009). Comparison between ACI 318-05 and Eurocode 2 (EC2-94) in flexural concrete design. Structural Engineering and Mechanics, Vol 32, No. 6, pp. 705 – 724.

Hegger, J., Sherif, A.G. and Ricker, M. (2006). Experimental investigations on punching behaviour of reinforced concrete footings, ACI Structural Journal, Vol 103, Issue 4, pp. 604 – 613.

Hegger, J., Sherif, A.G. and Ricker, M. (2009). Punching strength of reinforced concrete footings, ACI Structural Journal, Vol 106, pp. 706 – 716.

Jawad, A. A. H., (2006). Strength Design Requirements of ACI-318M-02 Code, BS8110, and EuroCode2 for Structural Concrete: A Comparative Study. Journal of Engineering and Development, Vol. 10, No. 1.

Nwofor, T., Eme, D.B., and Sule, S. (2015). A comparative study of BS8110 and Eurocode 2 standards for design of a continuous reinforced concrete. International Journal of Civil Engineering and Technology, Vol 6, Issue 5, pp. 76 – 84.

Nwoji, C. U. and Ugwu, A. I. (2017). Comparative study of BS 8110 and Eurocode 2 in structural design and analysis. Nigerian Journal of Technology, Vol 36, No. 3, pp. 758 – 766.

Soares, L. F. S. and Vollum, R. L. (2015). Comparison of punching shear requirements in BS8110, EC2 and MC2010. Imperial College London.

Som, N. N. and Das, S. C. (2006). Theory and practice of foundation design. 3rd ed. Prentice-Hall: New Delhi.