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ORIGINAL RESEARCH ARTICLE

COMPARISON OF SQUARE AND CIRCULAR ISOLATED PAD FOUNDATIONS IN COHESIONLESS SOILS

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ABSTRACT

One of the most commonly used pad foundation types is the square footing, however, there is a necessity to compare its performance and economy with the circular pad foundation which is not often considered. This study focuses on the suitability of the square versus circular isolated pad foundation types in cohesionless soils, from a geotechnical, structural, and construction cost perspective. The square and circular pad foundation types were subjected to three (3) cases, which were: when the foundation footings have equal width or diameter (Case 1), when the foundation footings have an equal axial load capacity (Case 2), and when the foundation footings are restricted to a defined net allowable bearing capacity (Case 3). The factors evaluated in each of these cases were bearing capacity, immediate settlement, structural design, and construction cost. Additionally, a model for estimating the construction cost of reinforced concrete was proposed in this study, and it was used to estimate the construction cost of the reinforced concrete isolated pad foundation types. The results of this research work show that overall, the square isolated pad foundation type will be the better selection for most design and construction considerations

1.0 Introduction

A foundation is that portion of a structure that transmits the loads from the structure to the underlying soil. One general way of classifying foundations with respect to depth is either as shallow or deep foundations. There are important differences between the two: depending on geometry, type of soil, structural functionality, and constructive systems. Cohesionless soil is often composed of granular or coarse-grained materials with visually detectable particle sizes and with little or no cohesion between particles, such as coarse sand. It is also significant that the distribution of soil pressure is a function of the type of soil, the relative rigidity of the soil and the foundation, and the depth of contact between the foundation and the soil (Luévanos-Rojas, 2016).

In this study, the shallow foundation was evaluated in the form of an isolated pad foundation which will sometimes be referred to as a footing. A flexible footing is considered to have some degree of flexibility and hence upon application of partial pressure or concentrated load the footing bends. As the footing attains the bending curvature, the soil beneath the footing base experiences a nonlinear pressure distribution. On the other hand, a rigid footing is assumed to settle as a rigid element. It is also expected that there will be a very minimal curvature along its length or width even if it experiences a concentrated loading.

In general, bearing capacity may be explained as the largest intensity of pressure that may be applied by a structure or a structural member to the soil which it supports without causing excessive settlement or failure. Several theories have been developed by various researchers such as Terzaghi (1943), Meyerhof (1951, 1963), Hansen (1970) and Vesic (1973, 1975) regarding the estimation of bearing capacity over the years. However, this paper focuses on Terzaghi's general bearing capacity due to its popularity in use, especially for less complex bearing capacity estimation cases. Furthermore, a suitable bearing soil stratum must be able to withstand all kinds of design loads from the structure without any shear failure or destructive unallowable settlements (Bowles, 1982). Settlement considerations can be immediate, consolidation, and secondary depending on the application of load, soil type, and pore pressure dissipation. Footings founded in cohesionless soils reach almost the final settlement, during the construction stage due to the high permeability of the soil. The water in the voids is expelled simultaneously with the application of load and as such the immediate and consolidation settlements in such soils are rolled into one (Murthy, 2002). In summary, the main settlement consideration in cohesionless soils is the immediate (or elastic) settlement. The settlement behaviour is different for cohesive soils, where consolidation settlement is experienced and pore pressures greater than the hydrostatic pressures are developed due to the imposed load (Obaji et al., 2020).

One pertinent aspect following the geotechnical considerations for an isolated pad foundation is the design of the footing. The design of the foundation depends on the type of soil, type of structure, and its load. The greater the net allowable bearing capacity of the soil, the larger the load it can safely withstand. In general, the footings are designed to sustain the applied loads, induced reactions, and moments to ensure that any settlement which may occur is within the acceptable limit and the net allowable bearing capacity of the soil is not exceeded. It is also important that a structurally well-designed isolated pad foundation is economical in its construction by selecting the appropriate and safest dimensions in its design. Although, relying on the dimensions alone does not justify proper construction. However, selecting the appropriate reinforcement size and number, reinforcement arrangement, tensile strength, and ultimately due monitoring and quality control during construction will help to transmit loads safely and achieve the purpose of the isolated pad foundation on the underlying soil.

This paper, therefore, presents a comparative study of the square and circular isolated pad foundations in cohesionless soils subjected to the following conditions: footings having equal width or diameter, footings having an equal axial load, and footings restricted to a defined net allowable bearing capacity. Further comparisons of the footings in terms of the settlement, structural design, and construction cost were evaluated. It is hoped that this research study will help structural and geotechnical engineers determine where the advantage of using a square or circular footing lie in cohesionless soils.

2.0 Materials and Methods

The consideration of bearing capacity for this research study was based on the Terzaghi (1943) general bearing capacity equations. The net ultimate bearing capacity (q_{nu}) specifically for the purely cohesionless soil situation is given by the following relationships in Equations (1) and (2):

$$q_{nu} = \gamma D_f(N_q - 1) + 0.4\gamma B N_\gamma \text{ (Square Pad Foundations)} \quad (1)$$
$$q_{nu} = \gamma D_f(N_q - 1) + 0.3\gamma B N_\gamma \text{ (Circular Pad Foundations)} \quad (2)$$
$$q_{na} = \frac{q_{nu}}{Factor\ of\ Safety} \quad (3)$$

where:
q_{na} = Net Allowable Bearing Capacity (N), γ = Bulk Unit Weight of the Cohesionless Soil (kg/m^3), D_f = Depth of Foundation Footing (m), B = Width or Diameter of Footing (m)
N_q and N_γ = Bearing Capacity Factors (Das, 2014; Kumbhojkar, 1993; Terzaghi, 1943)

Throughout this study, it was assumed that γ = 19 kN/m^3, D_f = 1 m, and Factor of safety (to determine net allowable bearing capacity) = 3 for both square and circular pad foundations.

Case 1 considers when the pad foundation width/diameter = 1 m. Case 2 considers when the allowable column load on the pad foundation = 200 kN. While Case 3 considers when the net allowable bearing capacity = 200 kN/m^2.

The settlement evaluated for this study was limited to immediate settlement. Calculations were based on the theory of elasticity (Davis & Poulos, 1968; Murthy, 2002). This is given in Equation (4):

$$S_e = q_n B \frac{(1-\mu^2)}{E_s} I_f \quad (4)$$

where:
q_n = net allowable foundation pressure (N/m^2) μ = Poisson's Ratio
E_s = Modulus of elasticity of soil (N/m^2) I_f = Influence Factor

The following values were also assumed; μ = 0.3, E_s =30000 kN/m^2. Values of q_n and B were obtained from the bearing capacity considerations. The average values of the influence factor used are summarized in Table 1.

Table 1. Average values of influence factor (Bowles, 1988; Murthy, 2002)

Shape	Flexible footing	Rigid footing
Circle	0.85	0.88
Square	0.95	0.82

The structural design of the footings for the cases evaluated was in accordance with BS 8110 Part 1 (1997). Necessary calculations and parameters are given in Equations (5) to (9):

$$A_s = \frac{M}{0.95 f_y Z} \quad (5)$$

$$Z = d\left(0.5 + \sqrt{\left(0.25 - \frac{k}{0.9}\right)}\right) \quad (6)$$

where:
A_s = area of tension reinforcement (m^2) M = Maximum bending moment (N.m) d = effective depth (m), f_y = characteristic strength of steel (460 N/mm^2) Z = lever arm (m).

$$K = \frac{M}{bd^2 f_{cu}} \quad (7)$$

where:

b = effective width (m), f_{cu} = characteristic strength of concrete (35 N/mm^2)

Also, the design shear stress (v) was designed using:

$$v = \frac{V_u}{b_v d} \quad (8)$$

Note: In no case should v exceed: $0.8\sqrt{f_{cu}}$ or 5 N/mm^2, whichever is the lesser, considering whatever shear reinforcement is provided. (This limit includes an allowance for y_m of 1.25).

where:

V_u = design shear force due to ultimate load (N) b_v= breadth of section (m)

$$v_{max} = \frac{N}{col_p x\, d} \quad (9)$$

where:

v_{max} = maximum design shear stress (N/m^2) N = Applied axial load (N)

col_p = column perimeter effective length touching loaded area (m).

The following values were also assumed: Thickness of foundation = 400 mm
Concrete cover = 50 mm Column dimension = 225 mm x 225 mm.

In terms of construction, the required volume of structural concrete (comprising ordinary Portland cement, fine and coarse aggregate) was estimated based on the results from the structural design. Also, the length of reinforcement (high yield tensile steel bars) required was determined using the structural details generated.

3.0 Results and Discussion

3.1 Bearing Capacity Considerations

The square and circular isolated pad foundations were restricted to having the same width, the same axial load, and the same net allowable bearing capacity. The results obtained using the Terzaghi (1943) general bearing capacity equations are shown in Table 2.

Table 2. Bearing capacity consideration results

	Width/Diameter (m)		Axial load capacity (kN)		Net allowable bearing capacity (kN/m²)	
	Square	Circular	Square	Circular	Square	Circular
Case 1	1.000	1.000	184.376	135.293	184.376	172.260
Case 2	1.037	1.192	200.000	200.000	186.147	179.237
Case 3	1.322	1.763	349.744	488.335	200.000	200.000

Considering Case 1, the results obtained showed that the square pad foundation had a higher axial load capacity of 184.376 kN when compared with the circular pad foundation having an axial load capacity of 135.293 kN. Therefore, in the equal width/diameter situation of 1 m, the circular pad foundation could only withstand 73.378% of the axial load capacity of a similar square pad foundation. The net allowable bearing capacity for the square pad foundation also showed a similar trend with a greater value of 184.376 kN/m² when compared with 172.260 kN/m² for the circular pad foundation. The results indicate that the square pad foundation will be the better option when in a constrained area, due to its greater axial load and net allowable bearing capacity under this case. The results obtained are also in line with that of Cerato & Lutenegger (2006) where the bearing capacity of the square pad foundation ranged between 1 and 1.33 times greater than the circular pad foundation for the same width/diameter.

The results in Case 2 when the square and circular pad foundations were subjected to an equal axial load of 200 kN revealed that the square pad foundation required a lesser value of 1.032 m for its width when compared to the required diameter of 1.192 m for the circular pad foundation. Also, the square pad foundation had a slightly greater net allowable capacity value of 186.147 kN/m² when contrasted with 179.237 kN/m² for the circular pad foundation. The results in Case 2 show that when a defined axial load needs to be transmitted to the cohesionless soil, the square pad foundation will be the preferable choice because it gave a greater net allowable capacity and lesser width when compared with the circular pad foundation. The results obtained correspond with the analysis done by Luévanos-Rojas (2016) where the circular pad foundation also required a larger width than the square pad foundation when subjected to similar punching shear values.

The results from Case 3 when both square and circular pad foundations were restricted to a defined net allowable bearing capacity of 200 kN/m² indicated that the circular pad foundation will be able to withstand 39.626% more axial load than that of the square pad foundation with values of 488.335 kN as to when compared with 349.744 kN for the square pad foundation. The increase in axial load capacity is a reflection of foundation width/diameter in the Terzaghi (1943) bearing capacity equations for the two pad foundation types shown in Equations (1) and (2). This leads to an expansion in the foundation diameter from 1.322 m for the width of the square pad foundation to 1.763 m for the circular pad foundation, which represents a 33.358% increase that may not be desirable in constrained areas. Nevertheless, in this case, the results show that when the net allowable bearing capacity has been defined and provided there is ample space, the circular footing can give a greater axial load capacity.

3.2 Settlement Analysis and Considerations

In this section, the authors compared the analysis of immediate settlement based on the elastic theory with the simulation results of Settle3D software (Version 4.023 by Rocscience Inc.). While the immediate settlement operates on elastic theory, the adapted software considers the soil segmented into finite layers. The soil area was modelled as a cohesionless soil with an area 10 times the size of the width or diameter of the foundation considered. The model soil depth used for computations was 20 m. The vertical stresses due to the imposed load on the soil were estimated using the multiple layer stress computation method proposed by Yue (1995) & Yue (1996), which gave similar results to the Boussinesq (1883) method. A screenshot of the Settle3D model interface is shown in Figure 1.

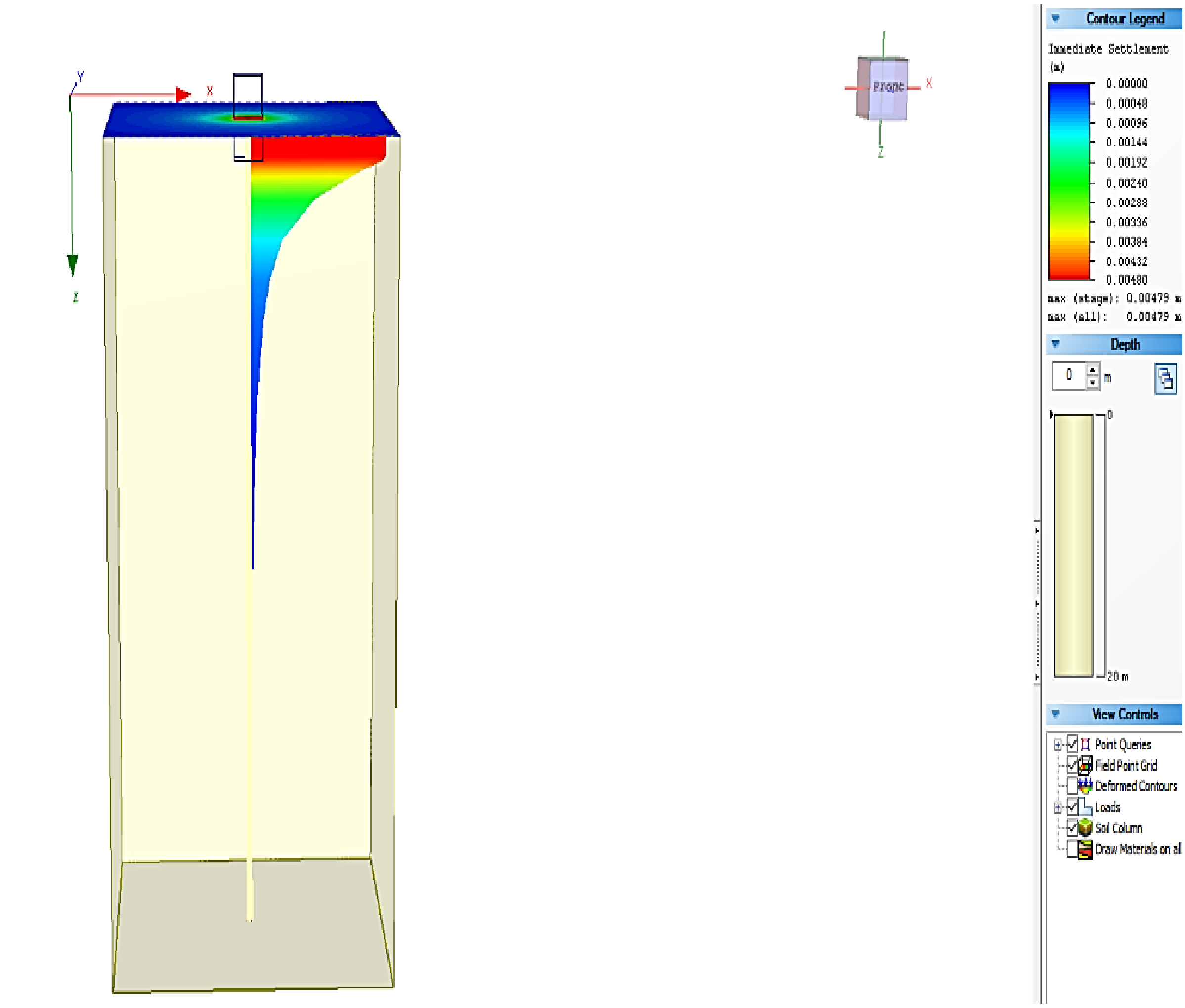

Figure 1. Settle3D software interface

From the evaluation of the immediate settlement, flexible and rigid footings were evaluated for both square and circular shapes. The three cases evaluated in this study were considered. The settlement analysis was based on the values obtained in Table 2 for each of the cases considered respectively. Table 3 shows the results based on the calculations from the theory of elasticity, while, Table 4 shows the results from the analysis using the Settle3D software.

Table 3. Immediate settlement results based on calculations from the theory of elasticity

	Flexible footing (mm)		Rigid footing (mm)	
	Square	Circular	Square	Circular
Case 1	5.3	4.4	4.6	4.6
Case 2	5.6	5.5	4.8	5.7
Case 3	7.6	9.1	6.6	9.4

Table 4. Immediate settlement results based on results using Settle3D software

	Flexible footing (mm)		Rigid footing (mm)	
	Square	Circular	Square	Circular
Case 1	7.4	6.2	4.8	4.1
Case 2	7.7	7.5	5.0	5.1
Case 3	10.2	11.8	6.8	8.3

Figures 2 – 4 show the influence of the vertical stresses on the immediate settlement in the soil below the foundation, considering the square and circular foundation types for flexible and rigid behaviour based on the analysis using Settle3D software.

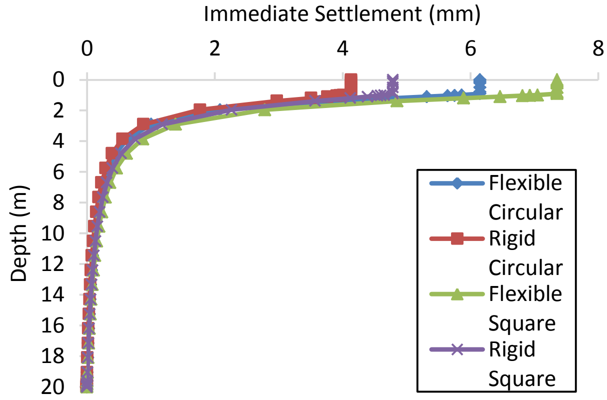

Figure 2. Variation of immediate settlement for equal width/diameter (Case 1)

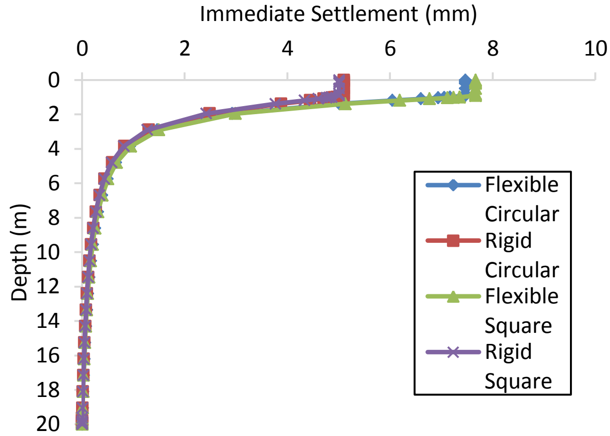

Figure 3. Variation of immediate settlement for equal axial load capacity (Case 2)

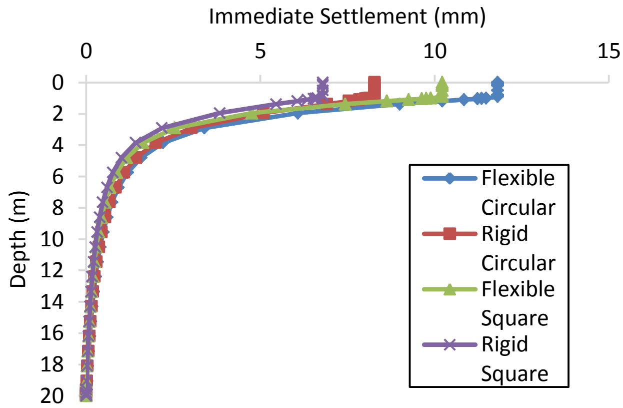

Figure 4. Variation of immediate settlement for an equal net allowable bearing capacity (Case 3)

There is a slight difference observed in the results obtained from the calculations based on the theory of elasticity and the results using the Settle3D software from Tables 3 and 4. This slight variation of results is due to the difference in the analytical approach based on the theory of elasticity and the multiple layer stress computation method considered in the Settle3D software. Also, the Settle3D software divides the soil into finite layers which may lead to a more accurate computation than using the conventional calculation of immediate settlement based on the theory of elasticity which considers the soil as a whole. Therefore, the results from Settle3D software were employed in this study.

From the results in Case 1, the square footing had a greater settlement of 7.4 mm as opposed to 6.2 mm for the circular footing when considering flexible footings. Although, for rigid behaviour, the circular footing gave a reduced settlement of 4.1 mm compared with the 4.8 mm for the square footing. Therefore, in a restricted foundation area of cohesionless soil deposit, the circular footing will provide better performance when considered as a flexible footing provided the axial load transferred to the soil can be achieved considering the net allowable bearing capacity of the soil.

The results from Case 2, when the footings are subjected to equal axial loads, the square footing had a slightly greater value of 7.7 mm when compared to 7.5 mm for the circular footing. Nevertheless, when the footings were considered as rigid, the square gave a marginally lesser value of 5.0 mm when contrasted with 5.1 mm for circular, making the circular slightly better as a flexible footing and the square as a rigid footing. Interestingly, the performance of square and circular almost gave similar results for both flexible and rigid footings regarding settlement considerations when a defined axial load is expected in cohesionless soils. Although, the square footing will require a slightly lesser construction space than the circular footing under this case.

The results from Case 3 reveal that the square footing will perform better than the circular footing when considered as either rigid or flexible due to its lesser settlement values. For the flexible footing, the square had a settlement of 10.2 mm, while the circular had a settlement of 11.8 mm. Also, as rigid footings, the square had a settlement of 6.8 mm while the circular had a settlement of 8.3 mm. Hence, with a defined net allowable bearing capacity, the square footing will give a lesser settlement when contrasted with the circular footing in cohesionless soils with an additional advantage of requiring a lesser construction area than the circular footing under this case.

The settlement results obtained in this study from analysis considerations using the theory of elasticity based on the recommendations by Davis and Poulos (1968) and Murthy (2002), as well as those obtained using the multiple layer stress computation method in the Settle3D software given by Yue (1995) and Yue (1996) are within reasonable limits and not too wide apart. The results were also similar to those obtained by Cerato and Lutenegger (2006) using model footing tests on dense winter sand.

It is worthy to note however that in practice, most foundations are flexible. Even very thick ones deflect when loaded by the superstructure loads. Bowles (1996) indicated that if the base is rigid the settlement will be uniform, but the base may tilt. Therefore, based on this assumption, it is recommended that the design of most isolated pad foundations should be considered flexible unless otherwise stated.

3.3 Structural Design

In accordance with the BS 8110 Part 1 (1997), the required reinforcement for the footings (i.e. circular and square) was evaluated for the three cases. The results presented in Table 5 were based on the structural design for each of the cases considered respectively. The summary of the results is shown in Table 5.

Table 5. Structural design consideration results

	Area of reinforcement required (mm^2)		Punching shear (N/mm^2)	
	Square	Circular	Square	Circular
Case 1	6.531	6.102	0.029	0.107
Case 2	12.823	64.523	0.04	0.089
Case 3	156.490	930.429	0.153	0.376

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From the results in Case 1, the square pad foundations required a greater area of reinforcement of 6.531 mm^2 when compared with 6.102 mm^2 for the circular footing. The results from Case 2, when the pad foundations are subjected to equal axial loads, the circular footing had a greater value of 64.523 mm^2 when compared to 12.823 mm^2 of the square footing. High yield tensile reinforcements of 12 mm diameter are usually the minimum size provided for pad foundations. Hence, for both pad foundation shapes in Case 1 and Case 2, the recommended minimum reinforcement area proposed is 377 mm^2 at 300 mm c/c. Additionally, the punching shear check is satisfied.

The results from Case 3 reveal that the square pad foundation with an area of 156.490 m^2 will be an economical choice due to the lesser reinforcement required when compared to 930.429 m^2 obtained from the circular footing. Therefore, for the square pad foundation, a recommended minimum area of 377 mm^2 is proposed using the 12 mm reinforcement at 300 mm c/c. On the other hand, for the circular pad foundation, the recommended minimum area of 1010 mm^2 using 16 mm reinforcement at 200 mm c/c is proposed. Additionally, the punching shear check is satisfied.

3.4 Construction Cost Considerations

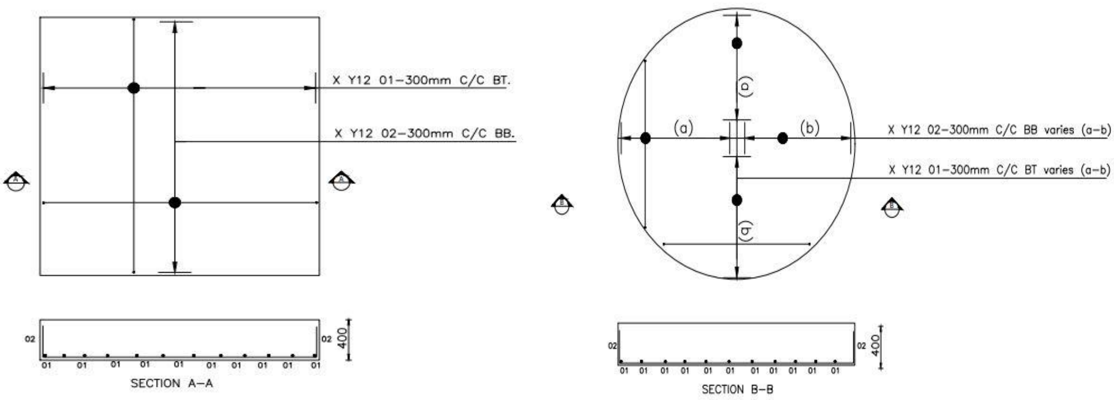
The volume of concrete to be required for Case 1 favours the use of the circular pad foundation due to its lesser area and volume especially in restricted areas in cohesionless soils thereby leading to some savings in construction cost. The volume of concrete required for the circular footing resulted in a value of 0.314 m^3 when compared with 0.400 m^3 for the square pad foundation. The consideration of Case 2 which highlights a specific axial load capacity showed that there was a marginal increase in the volume of concrete required for the circular pad foundation with a value of 0.446 m^3 when compared with that of the square pad foundation with a value of 0.430 m^3. Case 3 favours the use of the square pad foundation in areas of a defined net allowable bearing capacity with a considerable reduction in construction cost because it required a lesser volume of concrete of 0.699 m^3 when contrasted with 0.976 m^3 for the circular pad foundation.

The length of reinforcement required based on the structural design in Case 1 showed that the circular pad foundation will require a lesser length with a value of 9.880 m when compared with that of the square footing requiring a length of 12.000 m which provides an advantage for the circular footing in restricted areas. Case 2 shows a similar result with Case 1 with the circular pad foundation also requiring a lesser length of 13.590 m when contrasted to 15.370 m for the square pad foundation, thereby leading to some savings in reinforcement length with the use of the circular footing in situations of equal axial load capacity. Case 3 which highlights the situation when both pad foundation types are subjected to a defined net allowable bearing capacity also reveals that the circular pad foundation will require a lesser length of reinforcement of 33.500 m when compared with the square pad foundation requiring a length of 35.882 m, but with an increased reinforcement diameter of 16 mm as opposed to 12 mm for the square pad foundation.

Table 6 shows a summary of the construction quantities required for all the cases considered for both square and circular footings on cohesionless soils. Typical reinforcement details for the square and circular isolated pad foundations are also shown in Figure 5 (a) and (b) respectively.

Table 6. Construction quantities required for the reinforced concrete isolated pad foundations

	Volume of concrete required (m^3)		Length of reinforcement required (m)	
	Square	Circular	Square	Circular
Case 1	0.400	0.314	12.000	9.880
Case 2	0.430	0.446	15.370	13.590
Case 3	0.699	0.976	35.882	33.500



(a) (b)

Figure 5. (a) Typical reinforcement details for the square isolated pad foundation; (b) Typical reinforcement details for the circular isolated pad foundation.
(Note: X indicated on the drawing represents the number of bars and Y represents high yield steel bars).

The construction cost of reinforced concrete per m^3 was determined using a model developed in this study. The model is based on the cost of the constituent materials of concrete with the consideration of labour and additional material costs (such as the use of additives, construction equipment, cost of formwork, or excavation when necessary). The model relates the construction cost of reinforced concrete per m^3 with the characteristic strength of concrete and the cost per tonne of the various concrete materials, making the model suitable for any currency to estimate the construction cost of reinforced concrete based on the required concrete volume.

The preliminary mathematical model generated for the construction cost of reinforced concrete per m^3 for f_{cu} of 15 N/ mm² (M15) using a water-cement ratio of 0.5 without the consideration of construction profit is given as:

$$(0.3168C + 0.748S + 1.452G + 0.03R + 0.11W) \times 1.3 \times 1.2 \quad (10)$$

where: *C*, *S*, *G*, *R*, and *W* are the cost per tonne of cement, fine aggregate (sand), coarse aggregate (granite), reinforcement, and water respectively. The coefficients before each notation represent the quantity (in terms of mass) per tonne required for each of the constituent materials for M15 reinforced concrete based on the concrete mix ratio of 1:2:4 for a wet volume of 1 m^3. The constant multipliers of 1.3 and 1.2 reflect the factors for labour and additional material costs respectively.

Models based on this approach were generated for concrete grades of M5, M10, M20, and M25 in consideration of their mix ratios which are 1:5:10, 1:3:6, 1:1.5:3, and 1:1:2 respectively (The Constructor, 2021). An expression for modification factors relating to all the models was developed. This mathematical expression relates dimensionless costs and various concrete grades, using M15 reinforced concrete as the reference construction cost of reinforced concrete as shown in Figure 6.

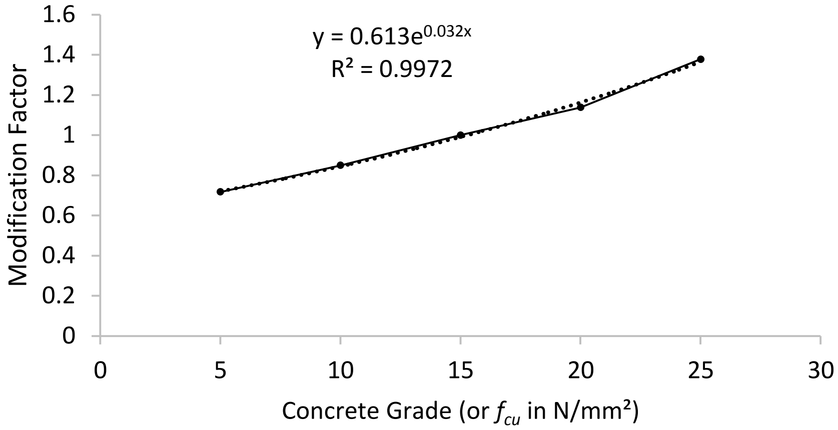


Figure 6. Modification factor for the construction cost of reinforced concrete

The modification factor indicated in Figure 6 shows an almost perfect trend with an exponential relationship and it is proposed to reasonably extrapolate the construction cost of reinforced concrete grades greater than M25. A consideration of the preliminary mathematical model generated for the construction cost of reinforced concrete per m^3 for concrete grade M15 and the modification factor was used to obtain the cost of reinforced concrete construction per m^3. Hence, the final mathematical model to estimate the construction cost of reinforced concrete (C_{rc}) of volume V_c (in m^3) with construction profit P (in %) is given as:

$$C_{rc} = (0.303C + 0.715S + 1.389G + 0.029R + 0.105W)\left(1 + \frac{P}{100}\right) V_c \, e^{0.032 f_{cu}} \qquad (11)$$

The developed model costs were validated using the construction cost of reinforced concrete in Naira (₦) as shown in Table 7 with 0% construction profit. The results were in good agreement with a maximum absolute difference of 2.4% for the concrete grades considered. The costs of the reinforced concrete constituent materials were estimated using up-to-date prices provided by Nigerian Price (2021). The model was also applied to the construction quantities of the square and circular reinforced concrete isolated pad foundations based on the volume of concrete required (V_c) as obtained in Table 6. Furthermore, the usage of the model assumes that the volume of concrete represents the volume of the reinforced concrete, considering the ease of its application for practical purposes. The results of the construction cost of reinforced concrete in this study are shown in Table 8 based on the developed mathematical model given in Equation (11), with the consideration of 0% construction profit.

Table 7. Validation of the developed model for the construction cost of reinforced concrete

Concrete grade	Construction cost per m^3 (₦)	Model cost per m^3 (₦)	Absolute difference (%)
M5	55209	55531	0.6
M10	65390	65166	0.3
M15	77027	76473	0.7
M20	87605	89742	2.4
M25	106118	105314	0.8

Table 8. Construction cost of the reinforced concrete isolated pad foundations

	Square (₦)	Circular (₦)
Case 1	58012	45540
Case 2	62363	64684
Case 3	101376	141550

The results in Table 8 indicate that the construction cost of the reinforced concrete square pad foundation was greater than that of the circular pad foundation in Case 1 only when the foundation width or diameter was defined. The construction cost of the circular pad foundation did not give economical results when compared with the square pad foundation for Case 2 where they were subjected to an equal axial load, and Case 3 when the bearing capacity was defined.

In summary, this study has focused on the comparison of the square and circular isolated pad foundations on cohesionless soils with three different cases being considered. Case 1 highlights the situation where both isolated pad foundation types were restricted to a defined width or diameter of 1m. Case 2 is based on the situation where both isolated pad foundation types were subjected to equal axial loads of 200 kN. Case 3 considers the situation where both isolated pad foundations were restricted to a defined net allowable bearing capacity of 200 kN/m^2. The summary of favourable footing selection focused on various factors considered in this study is presented in Table 9.

Table 9. Summary of favourable isolated pad foundation selection based on this study

	Case 1	Case 2	Case 3
Bearing capacity considerations	Square	Square	Circular
Settlement considerations (flexible footing)	Circular	Circular	Square
Settlement considerations (rigid footing)	Square	Square	Square
Area of reinforcement required	Circular	Square	Square
Punching shear	Square	Square	Square
Construction cost	Circular	Square	Square

4.0 Conclusion

The use of the circular pad foundation is a good choice in terms of immediate settlement considerations for a flexible footing and construction cost for Case 1. However, the circular pad foundation is not a favourable selection over the square pad foundation in terms of equal axial load capacity (Case 2). This is because the difference of the immediate settlement results for the two isolated foundation types is negligible, thereby indicating that the square pad foundation will be the overall better choice in a limited area, where foundation space is defined. Under Case 3, where both pad foundation types are restricted to a defined net allowable bearing capacity, the square pad foundation is a good choice in terms of having a reduced immediate settlement and construction cost.

Additionally, a mathematical model was proposed in this study for estimating the construction cost of reinforced concrete. The model also factors the characteristic strength of concrete and can similarly be applied to other concrete structural elements, thereby assisting project managers, quantity surveyors, contractors, builders, and engineers in making quick construction cost estimates. Overall, it can be seen that the square isolated pad foundation type is a better selection for most design and construction considerations based on this study. It is important to note, however, that the preferred isolated pad foundation to be selected for a particular construction project ultimately depends on the discretion of the consulting engineer and the construction constraints on site. Nevertheless, this research study has provided a useful guide for the selection of square or circular isolated pad foundations in cohesionless soils based on design considerations, construction limitations, and cost.

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