THEORETICAL AND EXPERIMENTAL ANALYSIS OF FLEXURAL STRENGTH IN PLAIN CONCRETE FOOTING

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ABSTRACT
This article presents experimental results of five (5) concentrically loaded plain concrete isolated footings. It aims at comparing the flexural strength predicted by ACI code 318-14 with the experimentally determined flexural strength. The test method developed, the geometric and structural characteristics of footings are described. Research results are presented, and it is concluded that the criterion proposed by the code to predict flexural strength of simple concrete footings provides an appropriate safety level.

Key words: Spread footing, granular soil, flexural strength, plain concrete.

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1. INTRODUCTION
An isolated footing is the structural element responsible for transmitting load of a column to the foundation soil. It is usually constructed from reinforced concrete, nonetheless, authors [1], [2], [3] and [4] agree that in the case of small works and reduced loads, plain concrete footing can result in an interesting alternative if the support soil is in good condition. This may occur in the case of construction of light temporary structures or agricultural structures supported on compact granular materials in their natural state or on properly formed fillings. The ACI code 318-14 [5] contemplates use of plain concrete for foundations, defining it as that structural concrete without reinforcement or with less reinforcement than the minimum specified for reinforced concrete.
Also, in the case of isolated footings, which must be continuously supported on the ground and never supported on piles, their thickness is generally controlled by the flexural strength and not shear strength; and for this, a series of provisions in this regard is established. Considering the importance of safety in this type of foundation element, the objective is to analyze the relationship between flexural strength calculated according to [5] and the experimental flexural strength, so that, it can be established how conservative the code is.

1.1. Bending resistant moment (Mn)
ACI code 318-14 states that the nominal flexural strength \( M_n \) can be calculated using Equation 1, with \( \lambda = 1.0 \) for the case of normal weight concrete [5] and \( S_m \) is the modulus of elastic section of the uncracked members \( (I_g/y_t) \).

\[
M_n = 0.42\lambda \sqrt{f'_c} S_m \quad \text{Equation 1}
\]

Where, \( y_t \) is the distance from the centroidal axis to its extreme tension fiber \( (H/2) \) and \( L_g \) is the moment of inertia of the cross section with respect to the neutral axis \( (B H^3 / 12) \).

1.2. Bending or Flexure Moment (Mapl)
For concentrically loaded square insulated footings, the moment acting in the critical section \( (Mapl) \) was calculated with Equation 2:

\[
M_{apl} = \frac{P_{apl}(B-a)^2}{8B} \quad \text{Equation 2}
\]

Where \( P_{apl} \) is the load transmitted by the column; \( a \), the column size; and \( B \), footing size. Location of the critical section is established on the face of the column [5] and the distribution of the contact pressure is worked uniformly as indicated by [6].

2. MATERIALS AND METHODS
2.1. Experimental Test Equipment
Reaction frame is designed for tests where static loads of maximum 200 kN are applied. Size of footings will be limited by the plan dimensions of the sand box located just under the frame. The operation principle of the frame consists in use of reinforced concrete piles as an anchoring mechanism to cope with the reactive force from the hydraulic jack. The steel frame is shown in Figure 1.

![Test Frame](image)

**Figure 1** Rigid frame for experiment
2.2. Subsoil under spread footing
The soil inside the wooden box arranged under the frame consisted of a properly compacted homogeneous granular material. The material was characterized by testing unit weight, humidity, grain size and direct cutting. The compaction degree used guarantees non-occurrence of shear failure of the soil, for the pressures transited by the elements tested.

2.3. Elements tested
Five square footings of 450 mm by side and 80 mm thick were prefabricated (Figure 2). Concrete with 30 MPa compressive strength was used, designed for the test day. Load is transferred to the footing by means of a square pedestal 100 mm by side, monolithically cast with the footing. Figure 3 shows the manufacturing process.

![Figure 2. Dimensions of plain concrete footings](image)

![Figure 3. (a) Formwork Preparation, (b) Concreting of the test sample](image)

Figure 4 shows one of the elements tested and test layout. Load is applied to the footing by means of a hydraulic jack, the load magnitude is recorded on the digital panel connected to a cell with a 100 kN capacity. Location of failure plane is identified with help of video cameras arranged in front of each face of the tested element.
3. RESULTS AND DISCUSSION

3.1. Soil Characteristics under the Footings

Tests carried out on the foundation soil allowed to define the geotechnical properties summarized in Table 1.

Applying the Terzaghi method referenced in [7], a final bearing capacity of 1024.8 kN/m$^2$ could be established, much higher than the maximum pressure applied at the failure time (206.03 kN/m$^2$), according to the results of the elements tested. The foregoing guaranteed testing of elements without the foundation soil failing.

3.2. Resistant bending moment ($M_n$)

Magnitude of the expected bending moment for each footing tested is estimated according to Equation 1. Compressive strength of concrete was determined by testing five standard cylinders (150 mm in diameter and 300 mm in height). Considering that cylinders and footings were made in parallel, each footing was associated with the compressive strength of its corresponding cylinder. Results are summarized in Table 2.
3.3. Experimental bending moment (Mapl)
Considering that elements without reinforcement were tested to withstand bending, the failure was presented abruptly for the loads listed in Table 3. All footings failed by bending. Figure 5 shows the cracking pattern of the elements tested. In all cases, cracks are located very close to the column’s face. Using Equation 2, the bending moment causing failure for each footing was calculated (Table 3).

Table 3. Failure loads and experimental bending moment

<table>
<thead>
<tr>
<th>Footing Designation</th>
<th>Failure load $P_{apl}$ (kN)</th>
<th>$M_{apl}$ (kN-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F3-Z1</td>
<td>29.84</td>
<td>1.02</td>
</tr>
<tr>
<td>F3-Z2</td>
<td>41.72</td>
<td>1.42</td>
</tr>
<tr>
<td>F3-Z3</td>
<td>36.9</td>
<td>1.26</td>
</tr>
<tr>
<td>F3-Z4</td>
<td>33.76</td>
<td>1.15</td>
</tr>
<tr>
<td>F3-Z5</td>
<td>36.96</td>
<td>1.26</td>
</tr>
</tbody>
</table>

Figure 5. Schematic representation of cracking on the lower surface of elements tested.

3.4. Relationship between experimental results and code prediction
For the footings tested, Table 4 lists comparative results between bending moment causing failure (experimental) and resistant bending moment predicted by the code.
Theoretical and Experimental Analysis of Flexural Strength in Plain Concrete Footing

Table 4. Comparison between experimental and predicted results according to the code.

<table>
<thead>
<tr>
<th>Footing Designation</th>
<th>$\frac{M_{\text{apl}}}{M_n}$</th>
<th>$\frac{M_{\text{apl}}}{M_n}$ (Average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F3-Z1</td>
<td>0.92</td>
<td></td>
</tr>
<tr>
<td>F3-Z2</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td>F3-Z3</td>
<td>1.13</td>
<td></td>
</tr>
<tr>
<td>F3-Z4</td>
<td>1.03</td>
<td></td>
</tr>
<tr>
<td>F3-Z5</td>
<td>1.14</td>
<td></td>
</tr>
</tbody>
</table>

Taking into account that values as low as $0.33 \sqrt{f'_c}$ Mpa [8] and as high as $1.055 \sqrt{f'_c}$ Mpa [9] have been reported for the concrete rupture module, the ratio of determined bending moments for each footing is adjusted, to the extent that the code proposes to work with $0.42 \sqrt{f'_c}$ Mpa when it comes to simple concrete elements. The average ratio was 1.095, which indicates, according to the rating scale proposed by [10], that the code specification would be classified as appropriately secure since the ratio is in the range from 0.85 to 1.3.

Results of the bending moment found, both theoretically and experimentally, are shown in Figure 6, and, the ANOVA performed for these data groups in shown in Table 5.

![Figure 6](image)

Figure 6. Results of bending moments found theoretically and experimentally.

Table 5. ANOVA for Value of Bending Moment: Experimental and Theoretical

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>dF</th>
<th>Mean Square</th>
<th>Ratio-F</th>
<th>Value-P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between groups</td>
<td>0.02916</td>
<td>1</td>
<td>0.02916</td>
<td>2.62</td>
<td>0.1445</td>
</tr>
<tr>
<td>Intra groups</td>
<td>0.0892</td>
<td>8</td>
<td>0.01115</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (Corr.)</td>
<td>0.11836</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Since P-value is greater than 0.05, there is no statistically significant difference between the average of the values found between theoretical and experimental results, with a 95.0% confidence level. That is, the value provided by the calculation equation to find the bending moment was adequate and in accordance with the experimental values found in this work.
4. CONCLUSIONS
From the study results, the following conclusions are presented:
- Small footings tested showed a cracking pattern that ratifies what is specified by the code regarding location of the critical section for the flexural design of single concrete footings.
- Calculation of the bending or flexure moment acting in the critical section of insulated footings supported by granular material is safe under assumption of a uniform contact pressure.
- The value predicted by the code, for the bending resistant moment of simple concrete footings, was appropriate and safe.

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REFERENCES