Investigation on GFRP Bar Performance in High Strength Concrete Footing

Mohammad Pirgholi Kivi
Department of Engineering, Shahid Rajaee University, Tehran, Iran

Hassan Araghi
Department of Engineering, Azad University of South Tehran, Tehran, Iran

Asghar Vatani Oskouei
Department of Engineering, Shahid Rajaee University, Tehran, Iran

ABSTRACT

Usage of GFRP (Glass Fiber Reinforced Polymer) bars in construction is developing nowadays because of its unique properties among corrosion resistance, high tensile strength and ease of application and handling. Beside of its advantages however have some deferent structural behavior in compare to normal steel reinforcement in concrete members that necessary to light up accurately by appropriate test methods. One of these points is bond behavior of GFRP bars in Concrete. In this paper, structural behavior of concrete footing reinforced with GFRP bars laid on real condition, sand filled box, is studied by full scale test. Besides, bond behavior of this system focused by ACI recommended pullout test method and other properties of bars used in specimens also are tested. Upshots of study illuminate that high strength concrete allows GFRP bar to reach maximum bond strength along failure of bar surface. This bond behavior leads to appropriate behavior of footing and bars involvement in tension.

KEYWORD
GFRP bar, strain, bond strength, load-deflection, high strength concrete
1. INTRODUCTION

First time in 1948 full scale test about concrete footing was done by Richart in real condition of a spring support [1]. Latest studies have done by Hegger et al (2006, 2007 and 2009) about punching behavior of concrete footing [2, 3, 4]. Their method was based on loading concentrically through a concrete column on footing which lied on sand bed. They conclude that the consistency of the sand (loose or dense) has no further influence on the soil pressure distribution underneath the footing [2]. Also usage of FRP reinforcement in concrete structures becomes a common solution for construction especially in aggressive environment. Concrete footing for both steel and concrete frame structures often is embedded in soil for freezing problem. This underground environment is potential for corrosion creating in normal steel rebars in buried concrete structures. The aim of the investigation was to study the structural behavior.

2. EXPERIMENTAL WORKS

2.1 Material Properties

(a) Concrete
High strength concrete with cement content of 550 kg/cm³ is used for footing specimens. Average compressive strength of 59.3 MPa is achieved for concrete cylinder specimens at age of 28 days (See Table 1, 2).

Table 1 Proportions of ingredients used for concrete mix

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Quantity (kg / m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement (Type II)</td>
<td>500</td>
</tr>
<tr>
<td>Silica Fume</td>
<td>50</td>
</tr>
<tr>
<td>Water</td>
<td>210</td>
</tr>
<tr>
<td>Gravel</td>
<td>900</td>
</tr>
<tr>
<td>Normal sand</td>
<td>700</td>
</tr>
<tr>
<td>Super plasticizer</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Table 2 Mechanical properties of concrete

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Density (kg / m³)</td>
<td>2450</td>
</tr>
<tr>
<td>28 Days Compressive Strength (MPa)</td>
<td>59.3</td>
</tr>
<tr>
<td>Compressive Modules of Elasticity (GPa)</td>
<td>29.1</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>0.21</td>
</tr>
</tbody>
</table>

(b) GFRP bar
GFRP bars in size of #5 (15.88 mm in diameter) with maximum tensile strength of 710.0 MPa, longitudinal elastic modules of 43.1 GPa, and ultimate strain at failure of 0.017 are used to reinforce footing specimen.

2.2 Footing Specimen
GFRP reinforced concrete footing was tested on sand bed condition to simulate real condition of soil reaction.

Square footings with steel base plate are prepared for study. According to Figure 1 effective depth of 176 mm in calculated for footing and flexural reinforcement with proportion of 0.65 percent is used in each direction. Based on these parameters punching shear strength of 780 kN is calculated according to ACI 318-08 [5]. Steel base plate with dimension of 250×250×20 mm is anchored in concrete footing by four anchor bolts in size of 18 mm in diameter.

Fig.1 Dimensions of specimens
2.3 Test Setup & Data Acquisition

Rigid frame as shown in Figure 2 is used for loading the specimen on a soil filled bed.

![Figure 2: Rigid frame for experiment](image)

Loading is applied through a steel cube with loading area of 100 mm in 100 mm on the base plate.

Four LVDTs (linear variable differential transducers) were attached on each corner of footing to record settlement of footing under loading; moreover, one LVDT was measured total displacement of specimen’s center (See Figure 3).

![Figure 3: Test set up of loading](image)

Bar strains at five critical predicted points were got by strain gauge sensors. First strain gauge is attached on middle of bar, and other one attached on bar in distance of between base plate and column edge, and last one locate at distance of $d/2$ from base plate edge, each one in two perpendicular direction on bars (See Figure 4).

![Figure 4: Location of strain gauge sensors](image)

3. TEST & DISCUSSION

3.1 Testing and Maximum Load Bearing

Static load is applied incrementally to service load, $P_{\text{service}}$, expressed as $P_{\text{code}}/2.1$ in much literature. $P_{\text{code}}$ is calculated as 780 kN based on punching shear strength of footing according to ACI 318-08:

$$P_{\text{code}} = V_c \times b_0 \times d = 2.55 \times 1736 \times 176 = 779160 \text{ N}$$  \(1\)

where,

- $b_0$ : perimeter of critical section
- $V_c$ : nominal shear resistance
- $d$ : effective depth.

Subsequently loading is released to half of service load and these cycles are continued three times. Finally loading is raised to failure point when endurance becomes stable in curve.

Outcomes of tests indicate that specimen endured 715 kN of loading that is about 92 percent of predicted load of ACI for punching. While, in other researches it is common that code predicted load is lower than test results.

3.2 Load-deflection Behavior of Footing

Structural deflection of footing at center is calculated by subtract average of corners settlements from overall center displacement. The applied load versus the deflection at the center of the slab for test specimen is shown in Figure 5.

![Figure 5: Load-deflection curve of specimen](image)
3.3 Strain of GFRP Bar
By arrange of recorded strain at specific loading levels we can reach to an idea of strain contribution in middle bars as shown in Figure 6. Strain of bars decrease to almost zero at distance of \( d/2 \) from base plate edge probably because of improper anchorage of bar tails. Strain of central bar reaches near to 55 percent of final strain of bar at failure.

Figure 6 show one of the failed specimens and number of cracks, after testing.

Figure 7 show one of the failed specimens and number of cracks, after testing.

4. CONCLUSIONS

Based on the results of the experimental investigation on footing supported on sand, as well as on footing loaded uniformly, the following conclusions can be drawn:

1) The present experimental investigation and a test data bank comprising punching tests on footings from literature indicate that the punching load predicted by ACI 318 is more than result of experiment.

2) Experimental results indicated good bond behavior of subjected GFRP bars in high strength concrete with normal aggregate.

3) For receive to ultimate strain of bar due good bond, should restrain bar tails truly.

4) Maximum strain obtains in center of GFRP bar.

REFERENCES

[5] ACI Committee 318: Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary, American Concrete Institute, Farmington Hills, 465, 2008