# Letter of Equivalency

**RE:** Equivalence of Straight 45° GFRP Corner Bars to Traditional Bent Corner Reinforcement

**To Whom It May Concern,**

Rebar X Glass Fiber Reinforced Polymer (GFRP) has tensile capacity and test results that substantiate that straight GFRP bars placed at 45° can provide equal or greater directional tensile capacity than bent steel or bent GFRP bars traditionally used at 90-degree footing corners. Using ASTM-verified tensile strengths for the common #4 and #5 GFRP bar sizes, along with **conservative** ACI-aligned calculations, the analysis shows that properly detailed 45° GFRP bars can fully replace conventional bent-corner reinforcement in footings. This approach avoids bend-strength reductions in GFRP and provides a practical, field-ready, and code-compatible detail

## 1. Introduction

GFRP (Glass Fiber Reinforced Polymer) reinforcement is increasingly used in concrete applications where corrosion resistance, durability, and long service life are required. As adoption expands into residential, commercial, marine, and infrastructure applications, many builders and engineers seek guidance on field detailing practices—**especially for corner reinforcement in footings, grade beams, and Insulated Concrete Form (ICF) wall systems**.

In traditional steel construction, continuity at corners is often provided using bent or hooked corner bars. However, FRP bars behave very differently from steel: the fibers that carry tension do not tolerate bending radii well, and the bend region can experience significant strength reduction. For this reason, straight-bar anchorage and development length requirements are emphasized in ACI 440 guidance for GFRP.

This paper examines a practical, **code-aligned** alternative: *using straight GFRP bars placed at 45° to tie orthogonal main bars at concrete corners*. The purpose is to show, through clearly presented calculations and reference to industry standards, that straight 45° GFRP bars can provide equal or greater tensile capacity than conventional bent-corner reinforcement, when detailed properly.

## 2. Purpose and Scope of Analysis

This paper evaluates two field scenarios:

**Case 1 — #4 Main Bars at a Corner**
A single **#5 GFRP bar at 45°** is used as the corner tie.

**Case 2 — #5 Main Bars at a Corner**
Two **#5 GFRP bars at 45°** are used as the corner ties.

The analysis considers:

- Tensile test results (ASTM D7205)
- Ultimate tensile strength values
- Design tensile stress
- Cross-sectional areas of #4 and #5 bars
- Bar capacity resolved into principal directions at 45°
- Required development length (referenced, not calculated here)
- Cover/spacing compliance

The objective is to show that the proposed straight 45° GFRP corner reinforcement provides **equal or greater directional tensile resistance** than the fully stressed main bars they connect.
The information presented here supports design professionals by offering a clear, test-based comparison of alternative corner-reinforcement details. Final application should follow project-specific engineering requirements.

## 3. Background on Bent Bars vs. Straight Bars in GFRP Design

### 3.1 Steel (ACI 318)

In steel reinforcement, bent or hooked bars are optionally used for anchorage. ACI 318-19 accepts:

- Straight-bar development length (25.4.2)
- Hooked-bar development length (25.4.3)

Anchorage is provided if either development requirement is satisfied.

### 3.2 GFRP (ACI 440.1R and ACI CODE-440.11-22)

- Bent GFRP bars may experience some localized reduction in tensile strength at the bend due to fiber curvature and resin stresses.
- GFRP reinforcement cannot be field-bent; it is produced from cured thermoset matrices (vinyl ester or epoxy) that cannot be reshaped.
- All bent GFRP shapes must be factory-formed under controlled conditions with proper bend radii to protect fiber integrity and maintain performance.
- Because of these material characteristics, GFRP detailing relies primarily on straight-bar embedment and development length, rather than hooks or tight bends.
- ACI 440 provides specific guidance for bend radii, straight-bar development length, and the differences in tensile behavior between straight and bent regions.
- The straight 45° bar layout evaluated in this paper is an additional code-aligned option and is not intended to replace or diminish the use of bent GFRP shapes manufactured within compliant parameters.
- Due to the behavior of cured thermoset matrices, GFRP reinforcement is not bent in the field; bent shapes are produced under controlled factory conditions to preserve fiber integrity. Straight-bar development length is therefore an important part of GFRP detailing practice.

The tensile characteristics of GFRP reinforcement vary between straight and bent regions due to fiber orientation effects. ACI 440 therefore provides specific guidance for minimum bend radii and encourages consideration of straight-bar development length where practical. This analysis examines a straight-bar alternative but does not limit or discourage the use of bent GFRP shapes manufactured within code-compliant parameters.

## 4. Required Tension in Main Bars (Conservative Worst Case)

We conservatively assume each main bar can reach its full design tensile stress:

$$T_{bar,\ req} = A_{main} f_{fd} \quad \text{(MAIN BAR required tension)}$$

| | Case 1 (#4 Main Bars @ Corner) | Case 2 (#5 Main Bars @ Corner) |
|---|---|---|
| Main Bar Tension Required | .2 x 142,500 = 28,500 lb = 28.5 kips | .31 x 142,500 = 44,175 lb = 44.2 kips |

## 5. Capacity of Straight 45° GFRP Corner Bars

When a diagonal bar is placed at 45°, only a component of its axial tension acts along each principal direction:

$$T\_(each\ dir) = (A\_45\ \ x\ f\_fd)/\sqrt{2}$$

| | Case 1 (#4 Main Bars, One #5 GFRP at 45°) | Case 2 (#5 Main Bars, Two #5 GFRP Bars at 45°) |
|---|---|---|
| Axial Capacity | .31 x 142,500 = 44,175 lb = 44.2 kips | .31 x 142,500 = 44,175 lb = 44.2 kips |
| Directional Capacity | $T\_(each\ dir)$= 44.2/√2 ≈ 31.2 kips | $T\_(each\ dir)$= 88.4/√2 ≈ 62.5 kips |
| Compare to required main-bar tension | 31.2 ≥ 28.5<br>✔ One #5 at 45° is adequate for #4 main bars. | 62.5 ≥ 44.2<br>✔ Two #5 bars at 45° are adequate for #5 main bars. |

## 6. Development Length and Detailing Requirements

This paper evaluates **tensile capacity only**. Full acceptance of the detail requires:

1. Development Length (ACI CODE-440.11-22)

Each diagonal #5 bar must have sufficient straight embedment so that:

$$\boxed{l\_provided\ \ \geq l\_df}$$

Where $l\_df$ is based on:

- required bar stress
- bar diameter
- bond characteristics
- concrete compressive strength

2. Cover and Spacing (ACI 318-19)

- **3 in. cover** required in footings cast against earth.
- Minimum clear spacing: $s_{clear}$ >= max($d_b$, 1.0 in., 4/3$D_{agg}$)

## 7. Equivalence to Bent Corner Bars

Traditional steel corner reinforcement relies on bent or hooked bars meeting development length rules. GFRP materials behave differently:

- Bent GFRP bars exhibit characteristic changes in tensile behavior within the bend region, which are addressed through proper bend radii and factory-controlled forming.
- Straight embedment is the primary anchorage mechanism.
- A 45° straight-bar layout aligns with ACI's GFRP detailing philosophy.

Even when the main bars are fully stressed to their design tensile capacity, the straight 45° GFRP corner bars provide **equal or greater directional strength** — demonstrating that the detail performs under the strongest possible testing scenario assumed in design practice.

Note that while ACI does not specify orthogonal bar spacing, the "1 in. minimum clear spacing" requirement applies to **both parallel and crossing bars** in practice, even though ACI only defines it for "parallel bars.

**Conclusion**

Based on ASTM D7205 tensile testing and conservative design assumptions:

- **One #5 GFRP bar at 45°** provides more tensile capacity in each direction than a fully stressed **#4 main bar**.
- **Two #5 GFRP bars at 45°** provide more tensile capacity in each direction than a fully stressed **#5 main bar**.

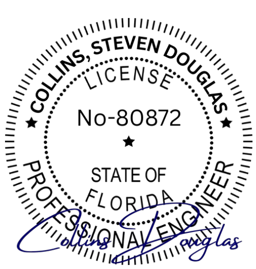
When required development length and detailing provisions are met, straight 45° GFRP corner bars serve as a **structurally valid and code-aligned alternative** to traditional bent-corner bars used in steel reinforcement practices.

This Rebar X Paper provides a transparent, calculation-based justification that supports field use of straight GFRP bar details while leaving final engineering design decisions to the project engineer of record.

Please contact me with any questions.

See stamp below

Sincerely,
Engr Collins, Steven, PE

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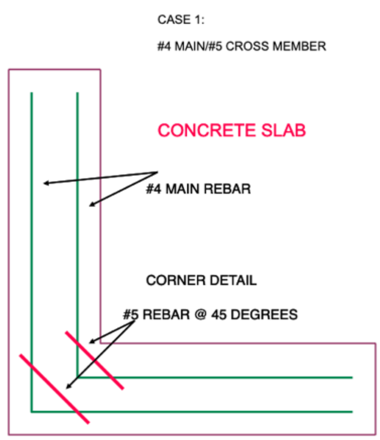
# APPENDIX

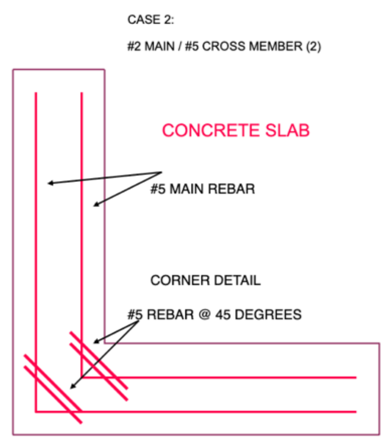
## Quick Reference Equations

| Property | Equation |
|---|---|
| Ultimate Tensile Strength | $f_{fu}$ = 142,500 psi |
| Design Tensile Strength | $f_{fd}$ = 142,500 |
| Main Bar Required Tension | $T_{bar,\ req} = Af_{fd}$ |
| Diagonal Bar Capacity | $T_{45} = A45f_{fd}$ |
| Directional Capacity | $T_{each\ dir} = T_{45}/\sqrt{2}$ |
| Straight Embed Requirement | $l\_provided \geq l\_df$ |

**Drawings**

**Case 1 (#4 Main Bars, One #5 GFRP at 45°)**
**Case 2 (#5 Main Bars, Two #5 GFRP Bars at 45°)**

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