The 15th International Conference on Fibre-Reinforced Polymers for Reinforced Concrete Structures (FRPRCS-15)
& The 8th Asia-Pacific Conference on FRP in Structures (APFIS-2022)
10-14 December 2022, Shenzhen, China

CONSTRUCTABILITY OF SLABS-ON-GROUND WITH FRP MESHES AS SECONDARY REINFORCEMENT

H. Roghani[1*], F. De Caso[1], A. Nanni[1]

[1] Department of Civil and Architectural Engineering, University of Miami, Coral Gables, FL 33146, United States

* Corresponding author's email: hxr323@miami.edu

ABSTRACT

The design and construction of Slabs-on-Ground (SOG) with Glass Fiber Reinforced Polymer (GFRP) as a secondary reinforcement are not covered in the design code ACI 440.11-22. Currently, the only guidance for their design is available in the design guide ACI 440.1R-15; thus, documented field applications are essential as references for design and detailing. This study was conducted to investigate the constructability and short-term performance of SOG with GFRP meshes as a secondary reinforcement. Construction of SOG was in coastline communities with a high probability of chloride contamination, thus the conventional steel welded wire mesh (WWM) was replaced with 3 different GFRP mesh types for evaluation purposes. This study provides evidence of the use of GFRP as secondary reinforcement in non-structural applications and is a testbed for documenting constructability and serviceability features. This field implementation of nonmetallic meshes illustrates that GFRP mesh can result in a faster placement and construction time, and reduced complexity due to the light weight and layout of the material, when compared to traditional steel WWM. Some key findings and observations are reported herein, including the 'memory' feature of GFRP meshes, which return to their original position after walking or loading them once placed on the ground.

Keywords: FRP, Internal reinforcement, Secondary reinforcement, Shrinkage cracking, Slabs-on-ground.

1 INTRODUCTION

Over the last decades, a significant increase in the use of non-metallic concrete reinforcement has been observed, with Glass Fiber Reinforced Polymer (GFRP) as the most predominantly used FRP. This increase is attributed to the corrosion resistance, high stiffness-to-weight ratio, lower labor and handling costs of FRP [1, 2]; where attributes of corrosion resistance and light weight of FRP decrease the energy consumption, and greenhouse gas emissions related to installation, transportation, and maintenance of concrete structures [4]. FRP rebar has been successfully demonstrated and used in structural applications, but the use of FRP rebars and meshes as secondary reinforcement in non-structural applications is limited [2] and thus there is a knowledge gap. Moreover, due to the benefits provided by non-metallic concrete reinforcement in structural applications, coupled with supply chain issues, there has been increased interest from building contractors and other stakeholders for the use of FRP reinforcement for non-structural applications [3]. From the contractors' point of view, besides the advantageous durability performance of FRP reinforcement, the lightweight characteristic of this material makes their projects cost-effective and makes transportation, handling, and installation easier [3]. Since the design and construction of SOG with GFRP as a secondary reinforcement are not covered in ACI 440.11-22, documented field applications are essential as references for design and detailing. In this study, attempts have been made to make SOG more durable and sustainable by using GFRP meshes as the secondary reinforcement to control shrinkage cracking. These efforts provide empirical evidence to address possible constructability and serviceability issues related to the construction of SOG with GFRP meshes and the shrinkage crack control of this reinforcement.

2 BUILDING CODE COMPLIANCE

The International Building Code (IBC) [5] and the International Residential Code (IRC) [6] are the model codes that have been issued to determine the minimum requirements to prevent public safety and health hazards in the United States [7]. Since utilizing FRP as secondary reinforcement is not mentioned in IBC and IRC, an Acceptance Criteria (AC521) [8] has been issued under IBC/IRC Section 104.11. Section 104.11 allows the use of new construction material to be approved where the material is compliant with the code requirements, where the new proposed material should at least perform equivalent to the minimum applicable requirements of the IBC/IRC [3]. Thus AC521, 'Acceptance Criteria for Fiber-Reinforced Polymer (FRP) Bars and Meshes for Internal Reinforcement of Non-Structural Concrete Members' provides a framework for FRP meshes and other FRP as secondary reinforcement to comply with building code requirements.

3 GUIDELINES TO DESIGN SOG

The ACI 440.11-22 [9] has been recently published to provide the minimum requirements of materials, design and detailing of concrete reinforced with GFRP bars that are compliant with the ASTM D7957-22 [10]. The design and construction of SOG with GFRP are not covered in ACI 440.11-22. Currently, the only guidance for their design is available in the guide ACI 440.1R-15 [11]. Thus, documented field applications are essential as references for design and detailing. The newly published ACI 440.11-22 clearly states *"This code does not apply to design and construction of slabs-on-ground unless the slab transmits vertical loads from other portions of the structure to the soil"*. The ACI 440.11-22 mentions that the ACI 360R-10 [12] is a guide to designing steel-reinforced concrete and the guide provided by this document can be used with the ACI 440.1R-15 to design non-structural GFRP-reinforced SOG that does not transmit vertical loads. To this end, this study provides a case study of SOG, aimed at addressing this knowledge gap.

4 AGUILERA KEY LARGO PROJECT

The Aguilera project located in Key Largo, Florida, USA consists of a waterfront residential two-level building as seen in Figure 1. Due to its location and elevation, there is a high probability of corrosion induced by chloride contamination. Due to the high probability of corrosion, the conventional steel WWM was replaced with GFRP meshes as a secondary reinforcement to control temperature and shrinkage cracking and prevent corrosion. This residential project consisted of an approximate 4,100 ft^2 SOG with a minimum of 4 in. thickness, serving as a carport and a covered terrace.

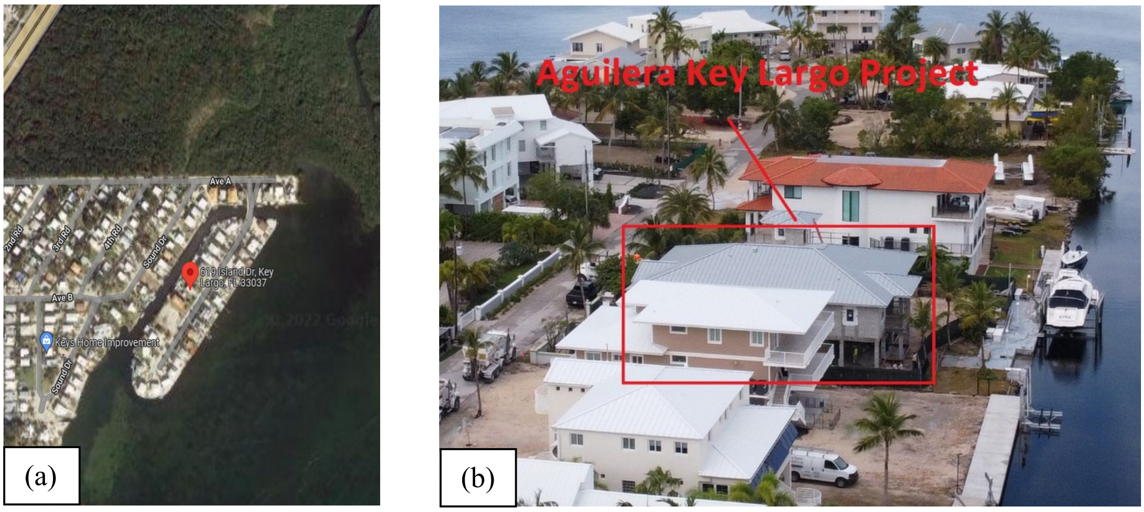

Figure 1 Aguilera project: (a) project location [13]; and (b) aerial photo

5 MATERIAL PROPERTIES

The SOG was constructed with three different GFRP meshes as secondary reinforcement. Figure 2 shows the different GFRP meshes utilized in this project, *Type 1* is a 0.134 in. nominal diameter mesh with a 4×4 in. orthogonal grid (US 1.4 in accordance with AC521); *Type 2* is a 0.134 in. nominal diameter mesh with a 6×6 in. orthogonal grid (US 1.4); both *Type 1* and *Type 2* have a helically winded string around the mesh. Lastly, *Type 3* is a sand-coated 0.226 in. nominal diameter mesh with a 6×6 in. orthogonal grid (US 4.0). The reported values of physical and mechanical properties of the meshes exceed the limits of AC521 and ASTM D7957 except for *Type 1* mesh, which did not pass the minimum requirement for guaranteed ultimate tensile force. The approximate area covered by each mesh in this project was 3,400 ft^2, 350 ft^2, and 350 ft^2 for mesh *Type 1, 2,* and *3,* respectively. The 28-day concrete compressive strength was tested in accordance with the ASTM C39 [14], "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens" and resulted in an average compressive strength of 6460 psi (44.5 MPa).

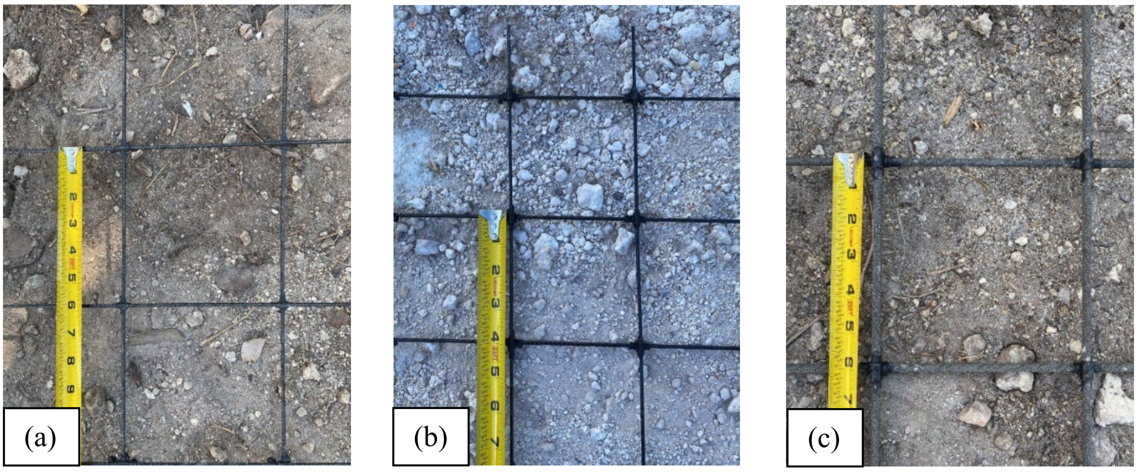

Figure 2 GFRP mesh types: (a) Type 1: 4×4 W1.4/W1.4; (b) Type 2: 6×6 W1.4/W1.4; and (c) Type 3: 6×6 W4.0/W4.0

6 CONSTRUCTION

After determining the reinforcement plan, the contractor started implementing meshes at the mid-depth of the slab supported by plastic chairs. The reinforcement limits the number of cracks and crack width, increases the load transferring ability at the joints, allowing larger joint spacing, and provides a backup strength after shrinkage cracking [3]. Non-metallic FRP reinforcements can provide these features as well as providing resistance to corrosion. Moreover, the lightweight characteristic of the FRP mesh, and the layout that was delivered in – as a roll - had a critical advantage in this as represented in Figure 4, where a construction crew member is seen lifting a roll of GFRP mesh, reducing significantly handling time. During the placement, it was observed that while walking on the installed mesh (unavoidable during construction), the GFRP mesh returned to its original position after stepping on it, reflecting a 'memory shape' characteristic that did not result in permanent deformation of the wire mesh. This further improved placement and handling of the installation of the mesh. This has also been observed in another project by Emparanza et al. [3]. Volumetric mobile mixers were used in this project to cast a total of 80 yd^3 of concrete, placed using a pump for accessing reasons. Casting started at 8:30 AM and finished by 4 PM and the SOG was cast without any construction joints (cold joints) since the entire slab was cast at the same time. The surface finishing process, as presented in Figure 3, followed standard construction practices and started with screeding using a rectangular bar to level the surface followed by the bull-floating of the surface, and surface troweling by a "walk-behind trowel" machine. The SOG was designed with 12 ft spacing saw cut contraction joints which is within the recommended range of 10 to 12.5 ft as referenced within ACI 360R-10 for both reinforced and unreinforced SOG, to limit the width of cracks. The isolation joints were implemented at the location of each column, where different types of joints limit the number of cracks and their width due to the volumetric changes [12]. The saw cuts were applied a day after casting, where the concrete SOG was left to cure under ambient conditions as represented in Figure 3. The depth of saw cuts was specified to be within 1 to 2 in., but measurements post cuts showed that some of the applied saw cuts were not within this range, resulting on average to be 0.9 in. As expected, the SOG cracked after casting due to the late saw cutting and inadequate concrete curing conditions. All the cracked sections were those reinforced with *Type 1* mesh. Nine days after the casting more cracks were observed and recorded, and the existing cracks increased in width from an average of 0.015 in. to 0.041 in. The maximum observed crack width was 0.050 in. (1.27 mm), which is more than the permissible limit of 0.028 in. (0.71 mm) as referenced within ACI 440.11-22 for structural members. While this element is not structural, the same permissible limit could be potentially specified for SOG for aesthetic reasons. A self-levelling sealant was used to seal the joints and a repair mortar was used to seal the cracks for aesthetic reasons as well as to prevent future deterioration of the concrete edges.

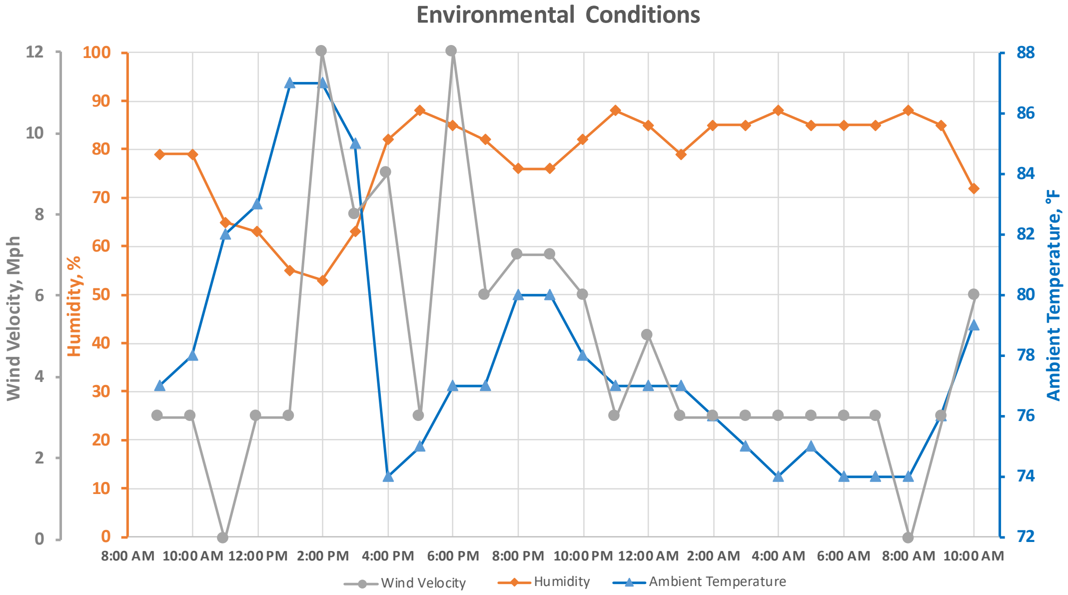

Figure 3 Environmental conditions [15]

7 SUMMARY AND DISCUSSION

To prove the efficiency of FRP as secondary reinforcement in SOG and to investigate the state of the practice in this application, a study has been conducted on a 4,100 ft^2 SOG in Key Largo. Since the construction is next to the coastline, the need for an appropriate alternative material for steel reinforcement was essential, and GFRP meshes have been utilized to solve corrosion issues:

- The conversations with the contractor and one of the workers illustrate that the GFRP mesh makes the job safer, faster, and easier. The use of this material needs a lesser number of workers, and the light weight of the mesh makes implementation easier as well as decreasing injuries to the workers.
- It was observed that walking on the meshes is unavoidable, but the GFRP meshes return to the initial height after removing the load without failure due to the elastic behavior and high tensile strength of GFRP.

This project showed that there are some steps that can be taken to increase the work quality and take more advantage of the new material:

- Working with this new technology requires more training and workshops for workers to facilitate the construction and increase the work quality.
- Applying the saw cuts in the first 1-2 hours after pouring (between initial and final sets) in addition to considering the appropriate curing method can help to avoid shrinkage cracking.

- Choose appropriate saw-cutting technologies like "walk behind" concrete saws to prevent cutting depth fluctuations and maintain proper pressure on the concrete.
- Stronger chairs uniformly distributed in shorter distances might result in better performance of FRP meshes to control shrinkage cracking, since reducing distances between supports means having more chairs to maintain the meshes at predetermined height.

Figure 4 Slab preparation and concrete casting: (a) a crew member lifting a roll of GFRP mesh; (b) mesh implementation; (c) concrete casting; (d) concrete surface screeding; (e) bull-floating of the surface; (f) concrete surface troweling

ACKNOWLEDGEMENTS

The authors would like to thank Luis & Luigi Concrete, LLC for providing the opportunity for the investigation, Galen Panamerica, LLC for supplying the GFRP meshes, and the National Science Foundation for financial support under grant No. 1916342.

REFERENCES

[1] A. Nanni, A. de Luca, H. Jawaheri Zadeh. Reinforced concrete with FRP bars: Mechanics and Design, CRC Press, 2019.

[2] M. Ekenel, H. Roghani, F. De Caso, A. Nanni, Evaluation of FRP Bars & Meshes Used as Secondary Reinforcement for Nonstructural Concrete Members for Building Code Compliance, ACI Special Publication, 356, 109-119, 2021.

[3] A. Ruiz Emparanza, B. McMahon, A. Nanni, Basalt FRP Reinforcement in Concrete Topping Slabs in a Commercial Building, Concrete International, vol. 43, no.2, 2021.

[4] M. Ibrahim, U. Ebead, M. Al-Ansari. Life Cycle Assessment for Fiber-Reinforced Polymer (FRP) Composites Used in Concrete Beams: A State-of-the-Art review. International Conference on Civil Infrastructure and Construction (CIC 2020), Doha, Qatar, 2020.

[5] "2021 International Building Code (IBC)," International Code Council, Country Club Hills, IL, 2021.

[6] "2021 International Residential Code (IRC)," International Code Council, Country Club Hills, IL, 2021.

[7] M. Ekenel, F. D. C. y Basalo, A. Nanni, Fiber-Reinforced Polymer Reinforcement for Concrete Members, Concrete International, 2021, 43(2): 18-22.

[8] "Acceptance Criteria for Fiber-Reinforced Polymer (FRP) Bars and Meshes for Internal Reinforcement of Non-Structural Concrete Members," AC521, ICC Evaluation Service, Inc., Country Club Hills, IL, Dec. 2020.

[9] ACI Committee 440, "Building Code Requirements for Structural Concrete reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars-Code and Commentary (ACI 440.11-22)" American Concrete Institute, Farmington Hills, MI, 2022.

[10] ASTM D7957/D7957M-22, "Standard Specification for Solid Round Glass Fiber Reinforced Polymer bars for Concrete Reinforcement," ASTM International, West Conshohocken, PA. (2022). DOI: 10.1520/D7957_D7957M-22.

[11] ACI Committee 440, "Guide for the Design and Construction of Structural Concrete Reinforced with Fiber-reinforced polymer (FRP) Bars (ACI 440.1R-15)" American Concrete Institute, Farmington Hills, MI, 2015.

[12] ACI Committee 360, "Guide to Design of Slabs-on-Ground (ACI 360R-10)" American Concrete Institute, Farmington Hills, MI, 2010.

[13] Google. (n.d.). [Island Drive, Key Largo, FL]. Retrieved November 6, 2022, from https://bit.ly/3NEPFXG

[14] ASTM C39/C39M-21, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens," ASTM International, West Conshohocken, PA. (2021). DOI: 10.1520/C0039_C0039M-21.

[15] Time and Date. "Past weather in Key Largo, FL for Monday, May 16, 2022." Retrieved November 6, 2022, from http://bit.ly/3FU4Ni2