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Development of a prototype fiber Reinforced Polymer – Concrete Filled wall panel

John Andrew Wattick [a], An Chen [b,*]

[a] Building Division, Mosites Construction Company, Pittsburgh, PA, United States
[b] Department of Civil, Construction and Environmental Engineering, Iowa State University, 426 Town Engineering, Ames, IA 50011, United States

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ABSTRACT

This paper reports the development of an innovative, prototype Fiber-Reinforced Polymer-Concrete Filled (FRP-CF) sandwich panel with significantly higher strength in both in- and out-of-plane directions, intended to be used for wall construction. The FRP-CF wall panels consist of two components; pre-manufactured FRP sandwich shell with two facesheets separated by a core, and concrete inside spaces between the core and facesheets. The FRP shell is designed to be erected on site with minimum construction time and concrete placed once erected and braced. Two types of tests were conducted: axial compression test to study the wall under gravity load and out-of-plane bending test to study the wall under lateral wind load or soil pressure. All wall panels were tested until failure to study the strength and failure mode. The results are compared to a reference reinforced concrete wall to illustrate the advantages of the FRP-CF wall, which showed considerable strength and stiffness increases.

1. Introduction

1.1. Background

Fiber-reinforced polymer or FRP composites consist of high-strength fibers (glass, carbon or aramid) saturated in a polymer resin (polyester or vinyl ester). Within the past 20 years, FRP composites have gained acceptance and are growing in popularity in civil infrastructure applications due to their favorable characteristics. FRP composites have lightweight, non-corrosive, non-magnetic, and non-conductive properties, a high fatigue life and are extremely durable. They exhibit excellent thermal insulation and energy absorption characteristics in addition to their high strength.

This paper reports the development of a Fiber-Reinforced Polymer – Concrete Filled (FRP-CF) Wall Panel, as shown in Fig. 1. In particular, this paper focuses on an evaluation of the technical feasibility of FRP-CF walls, based on: (1) concept development; (2) design of test specimens, (3) fabrication of stay-in-place FRP formwork and concrete placement; and (4) a stiffness and strength evaluation using bending and compression tests to evaluate the FRP-CF walls' mechanical properties and failure mode.

The organization of the paper is as follows. Section 2 presents a comprehensive literature review of components and considerations into the development of the FRP-CF Wall. Aspects of concrete formwork, existing polymer systems and their components are investigated to support the concept development, testing procedures and a baseline for the specimen cross-section design. Section 3 is focused on concept development of the FRP-CF wall panel. Experimental work and results are presented in Section 4 through Section 6. Discussions and concluding remarks are provided in Sections 7 and 8, respectively.

2. Literature review

Concrete is the most widely used construction material in the world, over 5 billion tons produced annually. It offers the designer versatility for structural and architectural considerations. Formwork is a temporary structure that has to support and confine fresh concrete until it has cured long enough to support itself. In addition to ensuring safe service, concrete formwork can account for 40–60% of the overall cost of a concrete structure. This is especially true for formworks that are fabricated on site. If proper attention is given to formwork design and construction, significant reduction in cost and accidents will result.

2.1. Stay-in-place formwork

Due to increasingly tighter construction schedules, formwork stripping is required to keep a project on schedule. This often leads to stripping of formwork before sufficient strength gain has been

* Corresponding author.
E-mail address: achen@iastate.edu (A. Chen).

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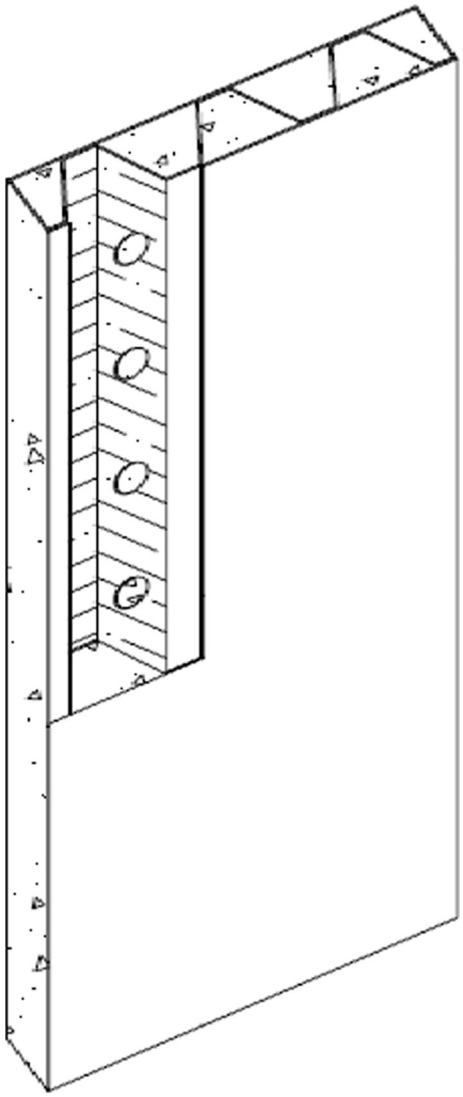

Fig. 1. FRP-CF Wall Panel.

reached. An increasingly common solution for both increasing productivity and ensuring proper concrete strength gain are stay-in-place formworks. Stay-in-place (SIP) formwork is a concrete confining structure that is designed to withstand the lateral forces of fresh concrete and remain in place after concrete has cured. Various types of SIP forms have been developed.

2.1.1. Insulating stay-in-place systems

Insulated concrete forms (ICFs) are modular blocks that require internal reinforcement. They are commonly composed of expanded polystyrene foam or recycled wood/cement mixtures. The blocks lock together by a tongue and groove joints along the edges of the block. ICFs come in various shapes and sizes depending on the manufacturer. There are two main variables with ICFs: form size and cavity shape. Exterior form size can be panel, plank or block. Internal shape of concrete is determined by the interior cavity of the form. Common cavities are flat, grid and post and beam.

2.1.2. Polymer stay-in-place systems

ICFs offer excellent insulating properties and serve as efficient method of confining fresh concrete until it cures. Due to the composition of ICFs, increase in mechanical performance of the wall cannot be achieved. Recent advancements in material development have allowed for the introduction of various polymers to civil applications. FRP, rigid polyvinyl chloride (PVC) and various metals have served as adequate concrete forms.

Research has proven that encapsulating concrete increases the mechanical performance. As concrete is loaded, micro cracks begin to form and as a result, concrete expands laterally. In unconfined concrete, spalling occurs as the tensile stresses become too great. In confined concrete, as concrete expands laterally, the confining material resists the lateral pressure exerted by the concrete. The increase in performance due to the confining effect is dependent on the cross-sectional geometry, deformation compatibility between the materials and the properties of the confining material [15].

Nanni and Bradford [18] performed compressive tests on concrete cylinders (150 mm × 300 mm) wrapped with various FRP materials. It was found that the FRP wraps increased the ultimate strength and pseudo-ductility of the concrete. It should be noted that the confined material was ineffective until the applied load was greater than the compressive strength of the confined material.

Nanni and Norris [17] studied the behavior of FRP confined concrete columns under flexure and combined flexure-compression. They concluded that unconfined specimens failed by propagation of diagonal-shear cracks where jacketed specimens failed in flexural tension and compression failure. The confined specimens experienced an increase in strength and ductility and the circular cross section saw a larger increase in performance over the rectangular ones.

Royal Building Systems™ (RBS) is a patented stay-in-place formwork extruded from a rigid poly-vinyl chloride (PVC) polymer for low to mid-rise concrete. This system provides significant enhancements in structural strength, durability, impact resistance, ultraviolet radiation and pest infestation resistance, design flexibility and ease of construction. Chahrour et al. [8,9] completed an experimental program on the RBS wall to determine its flexural and inter-element shear capacities, then developed an analytical model to predict the respective strength. As part of their study, Chahrour et al. [8,9] also developed a theoretical model based on limit state analysis. The resulting moment capacities from the theoretical model closely matched the experimental results therefore concluding that limit state analysis can be used to calculate the moment capacity of the panel.

Recently, another extruded polyvinyl chloride (PVC) panels have been developed by Octaform Systems, Inc. The PVC panels encase the concrete core to be used as a load bearing structure. Connectors join panels together to form a continuously straight or curved formwork. Reinforcing bars and concrete can be placed after the forms are erected on site. Finally, they are easy to clean, bacteria, insect and rodent resistant [12]. The PVC panel increased the compressive capacity by an average of 25.5% with an ultimate failure due to debonding of the connectors from the specimen [12]. The PVC SIPs also have shown the increase of flexural capacity and toughness.

2.1.3. SIP-Concrete interface

If stay-in-place formwork is to be used as external reinforcement for concrete, the bond between the form and the cured concrete is of significant importance in achieving composite action. Structures can be effectively designed utilizing FRP as formwork and external reinforcement in corrosive environments.

The bond between fresh concrete and a prefabricated form is known as a wet bond, and the bond of concrete to an already cured FRP laminate is called a dry bond. In a dry bond, the concrete surface is abraded and a sheet of fiber is wetted out on the concrete with an epoxy and left to cure. This method of rehabilitation has