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Durability and long term behavior of FRP/foam shear transfer mechanism for concrete sandwich panels

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HIGHLIGHTS

- Precast concrete sandwich panels can provide the shear transfer mechanism.
- Quality of fabrication can affect the shear strength of the panels.
- Design strength should be 30% of the sustained loads ultimate shear capacity.
- The EPS panels are more susceptible to aging effect compared to the XPS panels.

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ABSTRACT

This paper presents an experimental program to evaluate the effect of sustained loading and outdoor exposure on the shear strength of precast concrete sandwich panels connected with FRP grid/rigid foam insulation as shear transfer mechanism. CFRP and GFRP grids were considered in this study along with EPS and XPS foam. The experimental program is comprised of three different studies with a total of 26 test panels using different combinations of FRP grid and foam insulation.

1. Introduction

Precast concrete sandwich panels have been widely used for building envelopes of wide range of structures. Precast concrete sandwich panels have been produced in North America for more than 50 years [1]. The panels generally consist of two discrete concrete wythes separated by a rigid foam layer. Load-bearing concrete sandwich panels are typically subjected also to sustained gravity roof loads in addition to lateral wind pressure loads. The precast concrete panels can be designed to resist the applied loads as full-composite, partial-composite, or non-composite action. The degree of composite action depends on the ability of the FRP grid to transfer the shear forces between the two concrete wythes.

Early panels were designed as non-composite, where the inner thick wythe was designed to carry the load and the outer wythe was non-structural to protect the insulation layer between the concrete wythes [1]. Use of non-composite panels showed good thermal efficiency, while sacrificing the structural performance. Later, solid concrete zones, metal trusses and steel ties were used to achieve the composite action between the two concrete wythes. However, both types of shear connectors introduce thermal bridge and result in reduction of the *R*-values. Recently the use of Fiber-Reinforced Polymer (FRP) grid has been introduced as a shear connector due to their structural appealing benefits in addition to their superior thermal performance [2]. This approach was adopted in response to the growing demand for energy-efficient buildings and recognition of Leadership in Energy and Environmental Design (LEED) certification. Several studies have been reported on the behavior of short-term strength of precast concrete sandwich panels utilizing FRP grid/rigid foam as a shear transfer mechanism.

Frankl et al. [3] investigated the flexural behavior of six full-scale insulated precast/prestressed concrete sandwich wall panels. The panels were subjected to monotonic axial load and reverse-cycle

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lateral load, simulating gravity and wind pressure loads, respectively. The study concluded that a high degree of composite action can be achieved by using Carbon FRP (CFRP) grid as shear connectors. Further, the lateral stiffness of the test panels were greatly affected by the type and configuration of the shear connectors used as well as the type of foam.

Kim et al. [4] used CFRP grid as a shear transfer mechanism to evaluate effect of different parameters on shear flow capacity of concrete sandwich panels. The parameters included grid embedment length, insulation type and thickness, shear grid density (spacing), and the effect of repeated loading. Results indicated that the shear grid density, insulation type, and thickness have major effects on the shear strength of the system.

Bunn [5] tested 66 three-wythe precast concrete panels with CFRP grid/rigid foam insulation as shear connectors. The study investigated different parameters including, type and thickness of foam insulation, spacing between CFRP gridlines, and discontinuity of the CFRP grid. Test results showed that panels utilizing Expanded PolyStyrene (EPS) foam have higher shear strength compared to those using Extruded PolyStyrene (XPS) foam using the same CFRP grids. Bond between the rigid foam and the concrete was confirmed and evaluated by testing panel specimens with plastic sheets between the foam and the concrete to break the bond. Furthermore, the performance of CFRP grid only was investigated by removing the foam insulation. Test panels without FRP grid confirmed that the bond between foam insulation and concrete increased the shear strength of the panels. The research indicated also that increasing the thickness of EPS insulation foam decreased the shear strength of the panels.

Sopal [6] and Hodicky et al. [7] conducted a comprehensive research program to study CFRP grid/rigid foam insulation as a shear transfer mechanism for precast concrete sandwich wall panels. Research findings concluded that increasing the spacing between the CFRP grids resulted in increase of the overall shear strength due to the increase of the concrete/foam interface area. However, increasing the thickness of the insulating foam resulted in decreasing of the shear strength of the panels. Based on the research findings, an equation was proposed to estimate the shear strength of precast concrete sandwich wall panels utilizing CFRP grid and rigid foam insulation as shear transfer mechanism. Sopal [6] also performed tests on panel specimens subjected to a freeze–thaw aging regimen. Test results indicated that the freeze–thaw cycle tests, specified by the Acceptance Criteria of International Code Council Evaluation Service (ICC-ES AC422) [8] had no noticeable effect on the shear strength of the test panels.

Soriano [9] tested three-wythe precast concrete panels with GFRP grid/rigid foam. Test results showed that EPS foam provided higher shear strength in comparison to XPS foam without surface treatment. However, it was found that sandblasting of the XPS increased the shear strength of the panels due to enhancement of the bond between the foam and the concrete.

Naito et al. [10] examined the shear-deformation relationship of 14 different types of shear connectors, including CFRP and GFRP grid. Test results indicated that the shear performance of ties varied considerably and the use of EPS foam increased the shear strength in comparison to XPS foam.

Insel [11] tested sandwich wall panels utilizing CFRP grid subjected to monotonic and cyclic loadings to investigate fatigue performance. Monotonic load and various levels of cyclic load were applied to small- and medium-scale wall panels. Results indicated that for cyclic loads below the 30% of the ultimate monotonic loads, number of cycles to failure increases considerably. Furthermore, results showed a reasonable agreement between analytical model and experimental results.

Despite the extensive work performed to evaluate the behavior and strength of precast concrete sandwich panels with FRP grid as shear connectors, very limited research has been reported related to the durability and long-term behavior of these types of panels. This paper presents an experimental program undertaken to evaluate the durability of precast concrete sandwich panels connected by FRP grid/foam insulation as a shear transfer mechanism. The study investigated the effect of sustained load and outdoor exposure conditions on the shear strength of the panels.

2. Experimental program

The experimental program reported in this paper comprises three studies. The objective of the first study was to determine the short-term ultimate shear strength of the panels. The second study investigated the effect of sustained loads on the behavior of FRP gird/rigid foam as a shear transfer mechanism. The third study evaluated the effect of outdoor exposure conditions on the ultimate strength of the panels.

The three studies included a total of 26 precast concrete sandwich panel segments (referred to as panels hereafter) constructed using different FRP grid and different rigid foam types. CFRP and GFRP grids were used along with the two commercially-available foam types, EPS and XPS. EPS and XPS foams are polystyrene (transparent thermoplastic) insulations, which include polyurethane, polyisocyanurate, and phenolic [8]. Two different densities of the EPS foam were used, namely Normal Density (ND) and High Density (HD). Some panels were constructed with Sand-Blasted (SB) XPS foam, while other panels had XPS foam without surface treatment.

All test panels consisted of three-wythe concrete panels separated by two layers of rigid foam insulation and bridged by FRP grid. The panels were 44 in. (1118 mm) tall and 20 in. (508 mm) wide as shown in Fig. 1. The FRP grids were cut at a 45-degree angle of an orthogonal grid and were placed in truss orientation. Segments of three-wythe panels were used instead of two-wythe panels to allow testing the FRP grid/rigid foam mechanism in direct shear and to minimize the bending effects.

The panels reinforced with CFRP grid had a total thickness of 12 in. (305 mm), two outer concrete wythes of 2 in. (51 mm) each, inner concrete wythe of 4 in. (102 mm), and two foam layers of 2 in. (51 mm) each as shown in Fig. 2. The panels with GFRP grid had a total thickness of 16 in. (406 mm), two outer concrete wythes of 3 in. (76 mm) each, inner concrete wythe of 6 in. (152 mm), and two foam layers of 2 in. (51 mm) each as shown in Fig. 2. The width of the CFRP and GFRP grids used in this study were 3.5 in. (89 mm) and 4.0 in. (102 mm), respectively as shown in Fig. 3. The selected widths are used to simulate the typical dimensions used for the sandwich panels connected by CFRP and GFRP constructed in USA and South Korea, respectively. The selected widths also provided an embedment length into each concrete wythe of ¾ in. (19 mm) and 1.0 in. (25 mm), for the CFRP and GFRP grids respectively, indicating superior bond characteristics of CFRP grids. In addition, Fig. 3 shows the spacing between the strands of each grid.

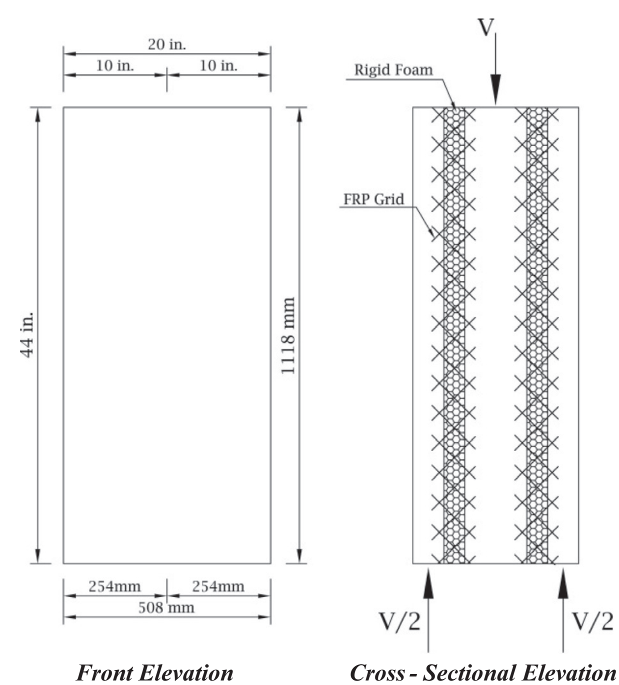

Fig. 1. Typical sectional-elevation of test panels.