SUSTAINABLE, COMPOSITE, AND THERMALLY EFFICIENT PRECAST CONCRETE LOAD BEARING AND ARCHITECTURAL PANELS USING CFRP GRID

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SUMMARY

This paper investigated the use of a carbon fiber reinforced polymer (CFRP) material, configured as a grid and placed in composite action with rigid foam insulation, as the main shear transfer mechanism for precast prestressed sandwich load bearing and architectural wall panels. The CFRP/rigid insulation shear transfer mechanism provides composite action between the two concrete wythes in sandwich wall panels, allowing for greater structural capacity, higher thermal efficiency, and a longer service life. The program examined various parameters believed to affect the shear transfer including the type of rigid insulation, the insulation thickness, and the spacing between the rows of CFRP grid. The program was designed to determine the characteristics of the shear transfer mechanism of the grid/insulation as affected by these parameters.

1. PRECAST CONCRETE SANDWICH PANEL SYSTEM

For the last fifty years, precast prestressed concrete sandwich wall panels have been used as building envelopes for various applications including schools, office buildings, and warehouses. Panels are constructed with two outer concrete layers separated by rigid foam insulating core, providing for better thermal efficiency. In place, sandwich wall panels can provide the dual function of transferring load and insulating the structure (PCI Committee on Precast Sandwich Wall Panels, 2011). They are designed to behave either in full composite, non-composite, or partially-composite action. At least a partial degree of composite action is typically desirable, as it allows for thinner panels, affords a weight savings, and results in an all-around more efficient structural system. Composite action between concrete wythes is achieved by connecting them through the core insulation material to transfer shear forces, which can be accomplished by using one of several techniques. Traditional shear connectors include steel trusses, bent wire connectors, or solid concrete zones cast between the concrete wythes. Although these techniques have been shown to produce the desired composite action they also create several unwanted side-effects such as thermal bridging, increased weight, and vulnerability to corrosion, to name a few. This study investigated the use of the carbon fiber reinforced polymer (CFRP) grid shown in Fig. 1 as a shear transfer mechanism. One feature that makes CFRP grid a desirable option for shear transfer in sandwich wall panels is its inherent lack of thermal conductivity. A core of rigid foam insulation crossed only by CFRP grid has been shown to provide full composite action without any thermal bridging, which cannot be accomplished with traditional steel and concrete alternatives.

Fig. 1: Schematic of Grid and Insulation
2. EXPERIMENTAL PROGRAM

The extensive experimental program completed at North Carolina State University consisted of sixty-six concrete sandwich wall panel specimens, representative of a section of a full scale wall. The specimens are referred to as “push-out” specimens due to the testing configuration described below. All panels were tested to evaluate the different parameters believed to affect the performance and strength of the CFRP grid in direct shear. The testing parameters considered in the program were the type and thickness of the rigid foam insulation, the spacing between lines of grid, the effect of the concrete-foam bond, the transverse strength of grid, the presence of gaps in the lines of grid.

3. TEST SETUP

The test setup used for all push-out specimens is shown in Fig. 2. Panels were tested in a double shear configuration to eliminate eccentric shear forces. The panel specimens were constructed with three wythes of concrete to allow for this double-shear configuration. Each specimen was supported vertically at the bottom edge of the two outer concrete wythes by 2” square steel bar stock. Load was applied by two 60-ton hydraulic jacks through two HSS steel beams to distribute the load evenly through the inner concrete wythe. As load was applied, the center wythe was forced downward with respect to the outer wythes. The applied load was measured along with relative vertical displacements between the concrete wythes at eight locations. Relative horizontal motion between the outer wythes was also measured at two locations.

4. TEST RESULTS

The load deflection relationship measured for a typical panel is shown in Fig. 3. Test results indicate that the parameters have a pronounced effect on shear flow. The use of expanded polystyrene foam (EPS) provides greater shear resistance in comparison to extruded polystyrene foam (XPS), due to its superior bond characteristics, for a given amount of CFRP grid. Results showed that an increase in the thickness of the EPS insulation reduced shear flow capacity; a result not clearly observed for XPS insulation. Increasing the grid spacing had little effect on the capacity of XPS panels; however it was increased capacities in EPS panels. Several panels were tested with no grid to isolate the effect of the concrete-foam bond on the transfer of shear forces. Two panels with no grid and EPS foam exhibited a high degree of strength as a result of the excellent EPS bond characteristics. On the other hand, XPS panels with no grid illustrated the weak bond developed between standard XPS and concrete.
5. FAILURE MODE

It was observed that all tested panels exhibited rupturing of the grid tension cords and buckling of the compression cords, as shown in Fig. 4. Several panels also showed signs of the grid pulling out from the concrete due to insufficient embedment length. The photographs in Fig. 4 were taken after testing with the insulation removed down to the depth of the grid. Post-test inspections of the panels showed that XPS insulation was easily removed from the concrete wythes and left smooth clean surfaces, while particles from the EPS insulation remained bonded to both concrete faces after they were pried apart, as shown in Fig. 5.

6. CONCLUSIONS

Panels produced with EPS foam insulation developed higher shear strengths in comparison to panels insulated with XPS foam when the same quantity of CFRP grid is used. When using EPS foam, increasing the spacing between vertical lines of grid tends to increase the shear flow strength for a row of grid and its given tributary area, likely due to the high bond strength of EPS foam. Increasing the spacing between grids for the XPS foam did not increase the shear flow strength for a given line of grid and its associated tributary area. The tests indicated that increasing the thickness of EPS insulation foam decreases the shear flow strength while changes in the thickness of XPS foam insulation (up to 4”) had minimal effect in shear transfer behavior. Results indicate that CFRP grid oriented in the transverse direction can provide considerable shear strength, perpendicular to the applied load. Results further indicate the presence of gaps along the length of the grid do not affect the shear flow strength of the grids.
7. DESIGN EXAMPLE

The following example illustrates the shear grid required to achieve composite action. The design value selected for the grid is based on tests similar to those presented above. The design value was chosen by performing a statistical analysis prescribed by the building code.

Given the typical example:
L=9 m; a=1 m; h=10 m; \(f'_c\) = 35 MPa & 2400 Kg/m\(^3\); EPS Insulation; Wind Load \(w=1.2\)kN/m\(^2\)
b=3.5 m; t=250 mm; \(t_{\text{top wythe}}=t_t=75\) mm; \(t_{\text{insulation}}=t_t=100\) mm; \(t_{\text{bottom wythe}}=t_b=75\) mm;
Moment of Inertia=\(I=4.38 \times 10^9\) mm\(^4\); First moment=\(Q=2.44 \times 10^7\) mm\(^3\)

→ Determine the shear demands (see diagram)
→ Using US Codes (ASCE 7-05 and ACI 318-08): \(V_{1u}=(1.6wbh/L)\times(L-h/2)=29.9\) kN;
   \(V_{2u}=(1.6wbh^2/(2L)) – 1.6wba=30.6\) kN; \(V_{3u}=1.6 \times wba=6.7\) kN; Max. Shear=\(V_u=30.6\) kN
→ The corresponding shear flow = \(q_u = V_uQ/I\); \(q_u = 170.5\) kN/m
→ The shear flow capacity of a single row of shear grid for a 100 mm thick EPS insulation is \(q_n = 42\) kN/m; The design capacity with a \(\phi=0.75\); \(\phi q_n = 0.75 \times 42 = 31.5\) kN/m
→ Number of rows of shear grid required is \(N = q_u/\phi q_n = 170.5/31.5 = 5.4\) rows
→ Use 6 rows of shear grid

8. ACKNOWLEDGEMENTS

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9. REFERENCES IN TEXT: