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Structural and thermal efficiency of precast concrete sandwich panel systems

Einea, Amin, Ph.D.

The University of Nebraska - Lincoln, 1992

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STRUCTURAL AND THERMAL EFFICIENCY OF PRECAST CONCRETE SANDWICH PANEL SYSTEMS

by

Amin Einea

A DISSERTATION

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Doctor of Philosophy

Major: Interdepartmental Area of Engineering

Under the Supervision of Professors
Maher K. Tadros and David C. Salmon

Lincoln, Nebraska

August, 1992

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BY

Amin Einea

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STRUCTURAL AND THERMAL EFFICIENCY OF PRECAST CONCRETE SANDWICH PANEL SYSTEMS

Amin Einea, Ph.D.
University of Nebraska, 1992

Advisers: Maher K. Tadros and David C. Salmon

Precast concrete sandwich panels (PCSP) are structurally and thermally efficient elements used for exterior walls in multi-unit residential, commercial, and warehouse buildings throughout the world. A typical PCSP consists of two precast reinforced concrete layers (called wythes) separated by a layer of insulation and connected with connectors which penetrate the insulation layer. The connectors used in the majority of available PCSP systems consist of concrete webs or blocks, steel elements, or a combination thereof. Because of their low thermal resistance, steel and concrete connectors can cause significant reduction in the effective thermal resistance of the panel through thermal bridging. The objective of this research is to develop a connecting system capable of improving the thermal and structural performance of PCSPs.

This dissertation first presents a review of existing PCSP systems. Next, evaluation of selected fiber reinforced plastic (FRP) connectors is summarized. The structural performance of a few FRP connectors is evaluated through a series of pure-shear (push-out) tests performed on small scale specimens. The initial evaluation and the first phase of testing led to the selection of a FRP bent-bar connector. The bar is fabricated in a

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a deformed spiral shape through which a pair of prestressing strands or reinforcing bars can be threaded to provide anchorage in the concrete wythes. Phase two (pure shear tests) and phase three (flexural tests) were performed on small scale specimens to evaluate the structural performance of the bent-bar connector. In addition, the structural performance of the connector was analytically evaluated by developing finite element models for panel behavior in testing phases two and three. Experimental and analytical results from finite element and differential equation analysis are in good correlation.

This dissertation also includes a brief study of stresses and deformation due to differential volume changes. Volume changes often contribute a large portion of the stress or out-of-plane deflection of PCSPs. The finite element model, calibrated with the results of testing phase three, is used to evaluate the effectiveness of the differential equations for computing deflections due to differential volume changes. Both methods are compared with a practical design method for evaluating stresses and out-of-plane deflection due to differential volume changes.

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To my parents

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TABLE OF CONTENTS

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ABBREVIATIONS

FEM : Finite Element Modeling

FRP : Fiber Reinforced Plastic

PCSP : Precast Concrete Sandwich Panel

TERMINOLOGY

Some of the terminology used in this paper is defined below and in Chapter I.

Connectors: Various concrete, steel, or plastic elements that penetrate the insulation layer and connect the concrete wythes in PCSPs.

Fully Composite Panels: Sandwich panels whose wythes are connected in such a way that both wythes resist the applied flexural loads as if they were an integrated section.

Non-Composite Panels: Sandwich panels in which the two concrete wythes are connected with elements (connectors) that have no capacity for longitudinal shear transfer.

Open/Closed-Cell Insulation: Cellular insulation in which gas can/cannot readily pass from one cell to another. In closed-cell insulation, cells are primarily independent of one another preventing the movement of gas between the cells and thereby reducing the temperature transmission between neighboring cells.

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Partially Composite Panels: Sandwich panels in which the connectors can transfer between zero and 100% of the longitudinal shear required for fully composite panel.

R-value ($°F•ft^2•h/Btu$): is the thermal resistance, equals to the reciprocal of the thermal conductance which is defined as the number of British thermal units (Btu) which passes through a one quare foot area of material in one hour if the temperature difference between both surfaces of the material is one degree Fahrenheit.

U-value ($Btu/°F•ft^2•h$): is the reciprocal of thermal resistance (U=1/R).

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Chapter I
INTRODUCTION

Precast concrete sandwich panels (PCSP) are composed of two reinforced concrete layers (called wythes) separated by a layer of insulation. The concrete wythes are connected through the insulation layer by concrete webs, metal connectors, plastic connectors, or a combination of these elements, Figure 1.1.

PCSPs are favored as wall panels over other construction materials because of their superior thermal and structural efficiency. PCSP walls require "lower peak loads by about 13% for heating and 30% for cooling" than insulated metal or wood-framed walls having the same U-value under the same heat gradient conditions [1]. However, these values ignore the significant thermal efficiency loss due to using thermally conducting connectors such as steel and concrete connectors.

The main objective of the research project summarized in this dissertation is to devise a PCSP system to maximize its thermal efficiency while maintaining its structural efficiency. This system is designed for use in low rise commercial buildings and warehouses. It consists of PCSPs spanning 12 ft to 55 ft vertically and ranging in width from 4 ft to 12 ft, and are produced in long fixed or rolling (moving) beds.

PCSPs can be non-composite, partially composite, or fully composite panels depending on the percent of composite action they possess. A technical definition of the percent composite action in PCSPs is not well established in the literature. The general structural definition of composite action, however, can be summarized as follows. The definition of composite action differs between that defined under service loads and that

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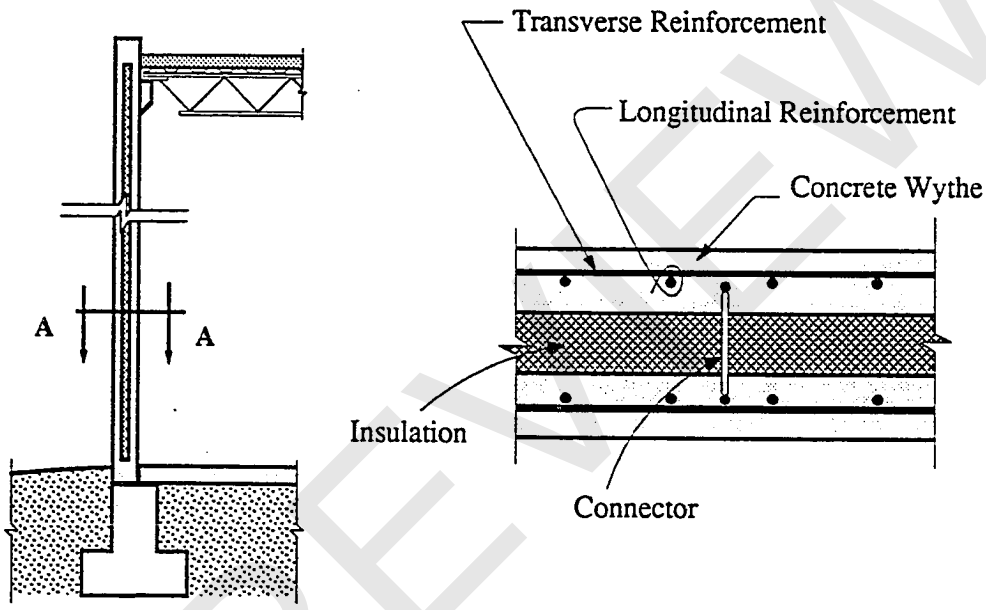

a) Vertical section

b) Section A-A

Figure 1.1. Typical load-bearing PCSP wall.

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