UNIVERSITI PUTRA MALAYSIA

STRUCTURAL BEHAVIOUR OF PRE-CAST CONCRETE SANDWICH PANEL UNDER AXIAL AND LATERAL LOADING

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By

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Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science in the Faculty of Engineering Universiti Putra Malaysia.

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Dedicated to my beloved
Father, Mother,
Brothers and Sisters

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LIST OF ABBREVIATIONS

A	Element cross-sectional area
b	Breadth of the section
d	Effective depth
E_c	Modulus of elasticity of concrete
f_{cu}	Characteristic strength of concrete
f_y	Characteristic strength of reinforcement
FX	X-axis membrane force
FY	Y-axis membrane force
FXY	Membrane shear force
G_k	The characteristic dead load
h	Overall depth of the section
I	Second moment of area
L	Span between end restraints
MX	Bending moment about X-axis
MY	Bending moment about Y-axis
MXY	Torsion moment
M_{ab}	Bending moment at support A
M_{ba}	Bending moment at support B
FEM	Fixed end moment
R_a	Reaction at support A
R_b	Reaction at support B

SMAX	Maximum principal stress
SMIN	Minimum principal stress
TMAX	Maximum shear stress
QX	X-axis shear force
QY	Y-axis shear force
Q_k	The characteristic imposed load
θ_a	Angle of rotation at support A
θ_b	Angle of rotation at support B
γ	Concrete unit weight
ρ	Percentage of reinforcement
σ_t	Flexural stress at top of the wall
σ_b	Flexural stress at bottom of the wall

Abstract of thesis submitted to the Senate of Universiti Putra Malaysia in partial fulfillment of the requirements for the degree of Master of Science.

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April 1999

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The sandwich panel is a layered structural system composed of a low density core material bonded to and acting integrally with, a relatively thin high strength facing materials held together by shear connectors which gives different degree of composite action. In a load bearing wall the two facings act as slender columns continuously supported by shear connectors. Core material usually act as insulation material to reduce the temperature inside the building. The bending action due to eccentric load or lateral load is resisted by the tensile and compressive forces developed in outer layers while shear forces are resisted by the shear connectors. Sandwich panels are used as exterior walls in multi-unit, residential, commercial and ware house building, providing structurally and thermal efficient building element.

In this study, the structural behaviour of reinforced concrete sandwich wall panels has been investigated experimentally in pre and post-cracking phase. Each panel consists of two outer reinforced concrete layers, interconnected together by different layout reinforced concrete ribs, which act as shear connectors. Three layouts of shear

connectors have been selected for the study; these are continuous vertical concrete ribs and truss type layout ribs inclined at 45^0 and 67.5^0 with the vertical.

Finite element method has been used in analysis for comparison with the experimental test results in the pre-cracking phase and to determine the stress distribution developed in the different components of the sandwich panel under different loading conditions. Six specimens of reinforced concrete sandwich panels (two identical specimens for each shear connector layout) each of size 1200 x 2400 mm (width x height) have been cast in the laboratory and tested in vertical position under incremental vertical axial, lateral, and combined axial and lateral loading. The effect of different shear connector layout on the overall structural behaviour of the panel is highlighted. Moreover the composite behaviuor of the sandwich panels, the percentage of load transferred to the ribs and the crack pattern have been investigated and discussed. The structural response of the sandwich panel in term of deflections have been found equal to 35 mm, 27 mm and 22 mm for panels type A, B and C respectively. The lateral collapse load of the tested panels, have been found equal to 97 KN, 40 KN and 45 KN for panels type A, B and C respectively.

From the results obtained in this study, it has been found that the sandwich panel with vertical shear connector has a better overall structural response as reflected in the integrity of the sandwich wall panel systems under the action of combined axial and lateral loads, in comparison to sandwich panels with inclined layout shear connectors.

Abstrak tesis yang dikemukakan Kepada Senat Universiti Puutra Malaysia sebagai memenuhi Keperluan untuk ijazah Master Sains.

TINDAKLAK PANEL APIT KONKRIT PASANG SIAP DI BAWAH BEBANAN PAKSI DAN SISI

Oleh

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Panel apit adalah satu sistem struktur berlapis yang mengandungi bahan teras berketumpatan rendah. Bahan teras ini akan bersepadu dan bertindak serasi dengan bahan permukaan luar yang nipis tetapi berdaya tahan yang tinggi, dan kedua-duanya akan disatukan oleh penyambung ricih yang akan memberi pelbagai tindakan rencam. Ia juga akan memberi kekuatan dan kekukuhan yang unggul bagi suatu kuantiti bahan yang digunakan. Dalam dinding galas beban ini, dua permukaan luar dalam sistem tersebut akan bertindak sebagai tiang langsing yang disokong berterusan oleh bahan teras untuk merintangi daya mampatan dan lengkokan. Untuk lenturan yang disebabkan oleh beban hidup atau beban angin, bahan permukaan luar akan menanggung kebanyakan daripada daya tegangan dan mampatan, manakala bahan teras akan merintangi daya ricihan. Panel apit biasanya digunakan sebagai dinding luaran dalam bangunan berbilang unit, rumah kediaman, bangunan komersial dan gudang, yang mana dapat memberikan effisiensi yang tinggi terhadap struktur dan penghabaan dalam elemen bangunan. Dalam kajian ini, tindaklaku struktur panel apit berkonkrit tetulang telah diselidik pada keadaan pra dan pascaretakan. Setiap panel terdiri daripada dua

lapisaan konkrit tetulang luaran, disambung bersama oleh konkrit rusuk yang bertindak sebagai penyambung ricih. Tiga jenis penyambung ricih telah dipilih dalam kajian ini; ia terdiri daripada rusuk konkrit tegak berterusan dan rusuk jenis kekuda dengan kecondongan 45^0 dan 67.5^0 dari garis tegak.

Disamping itu, kaedah unsur terhingga telah digunakan untuk menentukan ketepatan bagi keputusan eksperimen pada fasa pascaretakan bagi struktur panel apit berkonkrit tetulang. Pada masa yang sama, kaedah unsur terhingga juga dipakai untuk mencari agihan tegasan yang terhasil daipada komponen komponen berlainan dan penyambung ricih. Enam contoh panel apit berkonkrit tetulang (dua contoh yang sama bagi setiap bentangan penyambung ricih) dengan setiap satu bersaiz 1200 x 2400 mm (lebar x tinggi) telah siap dituang di dalam makmal dan diuji dalam keadaan tegak di bawah tokokan beban paksi, sisi dan gabungan kedua-dua beban paksi dan sisi. Kesan penggunaan bentangan penyambung ricih yang berlainan terhadap tindaklaku struktur panel apit secara keseluruhannya telah dititikberatkan. Nilai-nilai tindakbalas struktur panel apit dari segi pesongan, telah ditentukan iaitu 35 mm untuk panel jenis A, 27 mm untuk panel jenis B dan 22 mm untuk panel jenis C. Nilai-nilai kapasiti muktamad juga telah ditentukan untuk ketiga-tiga jenis panel iaitu 97 kN, 40 kN dan 45 kN untuk panel A, B dan C mengikut turutan. Selain itu, sifat panel apit, pratusan rusuk pembawa kapasiti dan corak corak retakan telah diselidiki dan dibincangkan.

Hasil daripada kajian ini, mendapati struktur panel apit berkonkrit tetulang dengan penyambung ricih tegak memberi prestasi kestrukturan yang lebih baik, sepertimana yang ditunjukkan oleh sistem panel apit di bawah tindakan kedua-dua bebanan paksi dan sisi, dibandingkan dengan penyambung ricih condong.

CHAPTER I

INTRODUCTION

General

The conventional construction method of multi-storeyed building is to use framing system consisting of columns to support beams which hold up the roof, floors, internal partitions and external cladding. The main structural elements are the beams and the columns. The walls are normally considered as non-load-bearing walls. The strength of these walls can be exploited because of their high compressive strength. The use of a pre-cast concrete sandwich panel load-bearing wall can provide an alternative economical construction method, by eliminating the need for a beam-column frame for multi-storeyed buildings.

Sandwich panels are composed of two facing shell element boned together through shear connectors, separated by a layer of insulation. The insulated shell reduces heating and cooling cost for structure. Pre-cast concrete sandwich panel system can be constructed to achieve up to100percent composite action, depending on the ability of embedded connectors to transfer the shear generated by longitudinal flexures.

In general, panels are neither fully composite nor non-composite, but lie some where in between. When used as a wall, roof or floor element in housing, the sandwich panel provides exceptional strength, for the amount of the material used. In load bearing wall the facing shells act as slender columns continuously supported by the shear connectors, to resist compression and buckling. In bending due to eccentric load or lateral load, the facing elements resist most of the tensile and compressive forces and the shear connectors provide resistance to shear forces. The shear connectors and facing elements act integrally to provide exceptional stiffness to the member.

Industrialised Building Systems

Industrialised building system is a common practice now in construction industry and it is possible to obtain factory produced structural elements such as pre-cast frame, roof and wall. These industries are well developed, and some have facilities, which are capable of producing almost any precast structural element desired. There are many commercial types of load bearing pre-cast sandwich panel available in the market. Few firms have pre-designed elements, catalogued for consumer selection. With a known building size and loading, the elements for a complete structure are quickly fabricated from detailed standards and shipped to the site. Other firms fabricate the elements direct from consumer-supplied designs and details. A recent development of the concrete products industry has been the specialisation in the production of pre-cast concrete wall panels. Because manufacturers are looking for new viable product lines, architects and engineers are pleased with the energy performance and general aesthetics of the panels. In addition contractors have found that the use of sandwich panels allows their project site to be quickly dried in allowing other trades to work in clean comfortable environment.

Scope and Objective of the Study

The complexity of the interaction between the various components of the pre-cast concrete sandwich panel systems has led researchers to rely on experimental observations supplemented with simplified analytical studies. Most experimental work on the load resistance of the panel has included shear and /or flexural tests. The shear test performed by applying shearing forces, in the mid-thickness planes of the concrete wythes to find shear capacity of the connectors and the contribution of the insulation to shear interaction between the concrete wythes. The interface shear is important in determining the degree of composite action. In a flexural test, a panel is subjected to out-of plane transverse loads to determine the over all flexural capacity of the panel.

The main scope of this research is to investigate the effect of different types of shear connectors on the structural behaviour of pre-cast concrete sandwich wall panels, subjected to vertical axial load, lateral load in pre-cracking phase and combined vertical axial and lateral loading in post cracking phase. Three layouts of shear connectors have been selected; these are continuos vertical ribs and truss type layout ribs inclined at 45^0 and 67.5^0 with vertical. The study aims to identify the most efficient type of the shear connectors, in transferring the load between the outer shells and to study the effect of different shear connector layouts on the overall structural performance of the sandwich wall panels. In addition, the effect of different layouts shear connector on the crack patterns, stability, failure mode and ultimate load capacity of the panels are investigated.

Layout of the Thesis

This thesis is divided into 5 chapters, a brief description of the content of these chapters is presented below:

The first Chapter contains the introduction and the scope of the study. Chapter II is devoted to the literature review, which includes topics, related to the structural behaviour of pre-cast concrete sandwich panel. The methodology used in present study is covered in Chapter III that includes the procedure implemented to conduct the experimental and theoretical investigation. In Chapter IV, results from both theoretical and experimental results were presented and discussed in details. Chapter V contains the conclusion and recommendations for future work.

CHAPTER II

LITERATURE REVIEW

Introduction

Pre-cast concrete sandwich panels are a layered structural system composed of a low-density core material bonded to, and acting integrally with, relatively thin, high strength facing materials. The insulated shell reduces heating and cooling cost. In a load-bearing wall, the two facings act as slender columns continuously supported by the shear connectors to resist compression and buckling. In bending due to eccentric load and/or lateral load, the two layers resist most of the tensile and compressive forces, while the shear connectors provide resistance to shear forces. The sandwich panel offers high flexural-to-stiffness and high strength-to-weight ratios, compared to other standard forms of structural sections. The use of sandwich panels offers attractive solutions to many terrestrial, offshore, and space engineering applications when combined with lightweight materials such as aluminium. Therefore the sandwich panels used as cladding for containers and exterior walls in multi-unit residential, commercial and warehouse buildings throughout the world.

Review of Literature

Palms et al. (1978) engineers in Forest Service U.S. Department of Agriculture designed experimental unit, to evaluate the long-term performance of different types of sandwich panels used for house construction. The sandwich panels used consist of two facing boards separated by paper honeycomb core, different material were used for the boards; plywood, aluminium and hardboard. Over the 31 years, panels have been periodically removed, from the house unit and tested for bending strength, and stiffness of the panels was calculated. From the test results, it has been found that the deflection of the panels did not exceed the original design limit except the aluminium faced panels, in which the deflection exceeded the original design limit. However, the stiffness of the panels is unchanged over the exposure period. Moreover, the panels faced with aluminium and hard board show a decrease in strength with time.

Nanni et al. (1986) carried out tests on ferrocement sandwich panels subjected to bending and edge-wise compression load. Eight panels subdivided into two groups were cast. A typical panel cross-section consisted of two ferrocement facings; 10 mm thick reinforced with one layer of welded wire mesh is shown in Figure 1. The core of the sandwich was made of a polystyrene sheet, laterally confined by mortar ribs. Bending tests were carried out using a universal testing machine, with load and deflection readings taken at pre-set load increments before cracking occurred, and pre-set deflection increments thereafter. Deflections were measured by using pairs of dial gauges, at centreline and support locations.

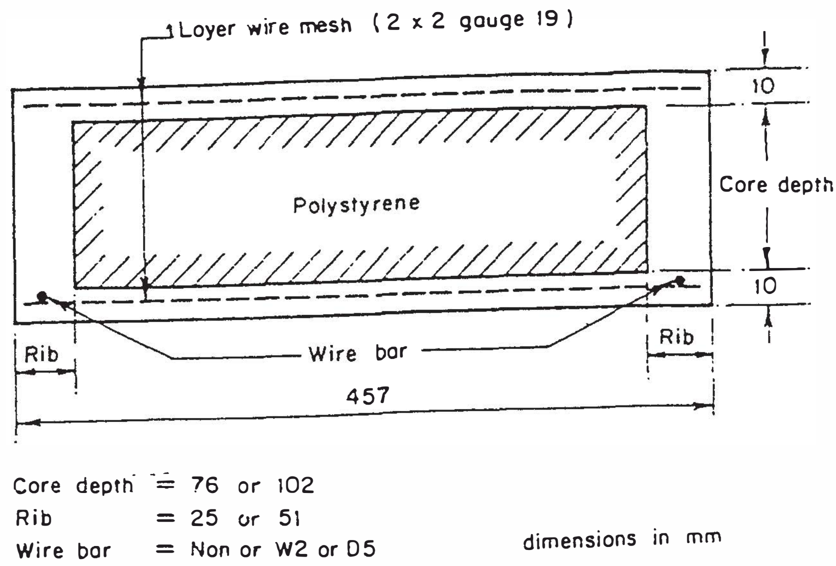

Figure 1: Typical Bending Specimen Cross-section

Four group of panel were cast. Each group differed from the others in total length has been tested under compression load, using universal testing machine. Specimen has been capped by using a steel channel, the full contact between the two surfaces was provided with thin layer of plaster of Paris. To ensure the vertical alignment and fixed end conditions for the facings, the bottom edge of the specimen was fully supported by the testing machine frame base. The load was applied through a spreader beam in-order to distribute the resulting stress uniformly over the entire specimen cross-section. Once properly positioned, the specimens were loaded to failure. The performance of the test apparatus, was checked by controlling, the strain distribution on both facing of panel. A total of six strain gauges were attached at midlength of the specimen. The result indicates that for specimens of identical cross-section the load bearing capacity decreases when the length of the specimen increases. Moreover, instability of the facings governs the ultimate capacity of sandwich panels subjected to uniform in-plane compressive load.

Davies (1987) analysed sandwich panels, consisting of metal faces and a rigid foam core, subjected to combine axial compressive load and bending moment using finite element method. In addition to the theoretical analysis, two profiles were tested, denoted as profiles A and B. Panel A was tested in both bending and axial compression whereas panel B was tested in axial compression only. From bending tests on panel A, the load deflection has been obtained then the value of the apparent flexural rigidity EI was determined. The corresponding theoretical curves were obtained for various values of the core shear modulus. The comparison between the experimental and theoretical value of EI is given in Figure 2, from which it can be deduced that the average value of G in the tested panels was 2 N/mm^2.

Three tests on panel B were carried out with nominal eccentricities of 0 mm, 57 mm and 114 mm, respectively. It has been observed that the eccentric loading has a profound influence on the results. The failure load reduces dramatically with increasing eccentricity.