



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكرو فيلم

بسم الله الرحمن الرحيم



HANAA ALY



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكروفيلم



شبكة المعلومات الجامعية التوثيق الإلكتروني والميكروفيلم



HANAA ALY



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكروفيلم

جامعة عين شمس

التوثيق الإلكتروني والميكروفيلم

قسم

نقسم بالله العظيم أن المادة التي تم توثيقها وتسجيلها
علي هذه الأقراص المدمجة قد أعدت دون أية تغيرات



يجب أن

تحفظ هذه الأقراص المدمجة بعيدا عن الغبار



HANAA ALY



Cairo University

INVESTIGATION OF OUT-OF-PLANE BENDING BEHAVIOR OF PRECAST CONCRETE SANDWICH PANELS

By

Mohamed Fawzy Abdel Aziz Gomaa

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
in
Structural Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2021

**INVESTIGATION OF OUT-OF-PLANE BENDING
BEHAVIOR OF PRECAST CONCRETE SANDWICH
PANELS**

By
Mohamed Fawzy Abdel Aziz Gomaa

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
in
Structural Engineering

Under the Supervision of

Prof. Dr. Walid Abdel Latif Attia


.....

Professor of Structural Analysis and
Mechanics
Structural Engineering Department
Faculty of Engineering, Cairo University

Prof. Dr. Ahmed Hassan Amer


.....

Professor of Structural Analysis and
Mechanics
Structural Engineering Department
Faculty of Engineering, Cairo University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2021

INVESTIGATION OF OUT-OF-PLANE BENDING BEHAVIOR OF PRECAST CONCRETE SANDWICH PANELS

By
Mohamed Fawzy Abdel Aziz Gomaa

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
in
Structural Engineering

Approved by the
Examining Committee

Prof. Dr. Walid Abdel Latif Attia,
- Professor of Structural Analysis and Mechanics



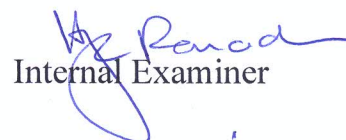
Thesis Main Advisor

Prof. Dr. Ahmed Hassan Amer,
- Professor of Structural Analysis and Mechanics



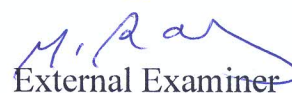
Advisor

Prof. Dr. Hazem Mostafa Ramadan,
- Professor of Steel Structures and Bridges



Internal Examiner

Prof. Dr. Mohamed Ragaei Badr,
- Professor of Structural Engineering
Housing and Building National Research Center



External Examiner

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2021

Engineer's Name: Mohamed Fawzy Abdel Aziz
Date of Birth: 05/05/1985
Nationality: Egyptian
E-mail: mfgomha@gmail.com
Phone: 00201223594059
Address: 6th October City, Giza, Egypt.
Registration Date: 01/03/2015
Awarding Date:/....../2021.
Degree: Doctor of Philosophy
Department: Structural Engineering



Supervisors:

Prof. Walid Abdel Latif Attia
Prof. Ahmed Hassan Amer

Examiners:

Prof. Walid Abdel Latif Attia (Thesis main advisor)
Prof. Ahmed Hassan Amer (advisor)
Prof. Hazem Mostafa Ramadan (Internal examiner)
Prof. Mohamed Ragaei Badr (External examiner)
Prof. of Structural Engineering
Housing and Building National Research Center

Title of Thesis:

Investigation of out-of-Plane Bending Behavior of Precast Concrete Sandwich Panels

Key Words:

Concrete; Sandwich Panels; Insulated Panels; Precast Panels; Flexural Capacity of Precast Concrete Panels

Summary:

Precast concrete sandwich panel (PCSP) is composed of two concrete layers, known as wythes, separated by a rigid layer of insulation. The out-of-plane bending behavior of sandwich panel heavily depends on the shear force transferred between the wythes through elements known as shear connectors. Fully composite and non-composite panels can be readily analyzed, but there is uncertainty between designers in evaluating of partially composite panels because their behavior is much more complex and typically rely on test results. In this research a 3D non-linear finite element model utilizing ANSYS software, V19.3, was developed and validated against published test data, then a parametric study followed. The parametric considered some parameters that believed to impact the out-of-plane bending such as: shear connectors shape and distribution, connectors area, panel length, effect of foam core bond in composite action, concrete grade, wythes thickness, adding ribs to the structural wythe, and use of GFRP material in the shear connectors. The results of the developed model were in a good agreement with the test results and this was sufficient to employ the model to capture the variation effect of the parameters presented in this study.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the references section.

Name: Mohamed Fawzy Abdel Aziz Gomaa

Date: / / 2021

Signature:

Acknowledgments

All praise belongs to Allah, Almighty, for the countless graces I have and the continuous support I receive from Allah along with supporting me to achieve my targets from the postgraduate studies of learning new issues and increasing my knowledge.

The author wishes to express his most heartfelt thanks to prof. Dr. Walid Abdel Latif Attia and Prof. Dr. Ahmed Hassan Amer for their wise sincere supervision, guidance, interest, patience, and recommendations.

The author wants to dedicate this research to his father's soul, his mother, his wife, and his daughters Laila and Karma.

Table of Contents

DISCLAIMER.....	I
ACKNOWLEDGMENTS	II
TABLE OF CONTENTS.....	III
LIST OF TABLES	VI
LIST OF FIGURES	VIII
ABSTRACT	XII
CHAPTER 1 : INTRODUCTION	1
1.1. GENERAL	1
1.2. PROBLEM STATEMENT	1
1.3. METHODOLOGY AND OBJECTIVES	2
1.4. SCOPE OF WORK.....	2
1.5. CONTENTS	2
CHAPTER 2 :LITERATURE REVIEW	4
2.1. INTRODUCTION	4
2.2. HISTORY	4
2.3. ADVANTAGES	5
2.4. SANDWICH PANEL COMPONENTS	5
2.4.1. Concrete wythes and flexural reinforcement	6
2.4.2. Shear connectors.....	7
2.4.3. Insulation layer	9
2.4.3.1. Expanded polystyrene	10
2.4.3.2. EPS geo-foam manufacturing.....	10
2.4.3.3. EPS density	10
2.4.3.4. EPS compressive strength and stress strain curve	10
2.4.3.5. EPS initial elastic modulus.....	11
2.4.3.6. EPS Poisson’s ratio	12
2.4.3.7. EPS tensile strength.....	12
2.4.3.8. EPS flexural strength.....	13
2.4.3.9. EPS interface friction	13
2.5. FIBER REINFORCED POLYMERS IN SANDWICH PANELS.....	14
2.6. STRUCTURAL DESIGNATIONS	15
2.6.1. Fully composite walls	16
2.6.2. Non-composite Panels	17
2.6.3. Partially composite panels	17
2.6.4. Evaluating of composite action	18
2.7. THEORETICAL METHODS TO ESTIMATE THE SANDWICH PANEL BEHAVIOR	19
2.7.1. Numerical methods.....	19
2.7.2. Finite element analysis methods.....	19
2.8. PREVIOUS STRUCTURAL TESTING PROGRAMS.....	20

2.8.1.	Direct shear push through tests.....	20
2.8.2.	Flexural testing	23
CHAPTER 3 : FINITE ELEMENT ANALYSIS OF OUT-OF-PLANE BENDING OF PRECAST CONCRETE SANDWICH PANELS.....		25
3.1.	INTRODUCTION	25
3.2.	FUNDAMENTAL CHARACTERISTICS OF ANSYS	25
3.3.	PUBLISHED DATA FOR THE EXPERIMENTAL TESTING OF PRECAST CONCRETE SANDWICH PANEL, PCI, 2015 (48).....	25
3.4.	FINITE ELEMENT MODEL	27
3.4.1.	Element types	27
3.4.1.1.	SOLID 65 for concrete wythes.....	27
3.4.1.2.	SOLID 185 for insulation layer and leveling pads	28
3.4.1.3.	LINK180 for flexure reinforcing bars and shear connectors	29
3.4.1.4.	BEAM188 for shear connectors	30
3.4.1.5.	CONTA174 and TARGE170 elements for interface between concrete and insulation layer	30
3.4.2.	Real constant for SOLID65	31
3.4.3.	Geometry, meshing, and boundary conditions of the first validation model	32
3.4.4.	Materials	33
3.4.4.1.	Concrete material	33
3.4.4.2.	Steel reinforcement material.....	34
3.4.4.3.	Expanded polystyrene for insulation layer (EPS).....	34
3.4.5.	Load stepping	35
3.4.6.	Non-linear analysis in ANSYS.....	36
3.4.7.	Non-linear solution and convergence criteria.....	37
3.5.	RESULTS OF THE FIRST VALIDATION FINITE ELEMENT MODEL	37
3.6.	CONCLUSIONS FOR THE FIRST VALIDATION MODEL.....	39
3.7.	SECOND VALIDATION MODEL.....	41
3.7.1.	Finite element geometry for second validation model.....	43
3.7.2.	Results of the second validation model.....	45
CHAPTER 4 : PARAMETRIC STUDY OF FLEXURAL CAPACITY OF PRECAST CONCRETE SANDWICH PANELS (INPUTS DATA).....		46
4.1.	INTRODUCTION	46
4.2.	PARAMETRIC STUDY	46
4.2.1.	Materials	55
4.2.1.1.	Concrete material	55
4.2.1.2.	Steel materials	56
4.2.1.3.	Insulation material.....	56
4.2.1.4.	Glass fiber reinforced polymers material (GFRP).....	57
4.2.2.	Geometry inputs in ANSYS	58
CHAPTER 5 : PARAMETRIC STUDY OF FLEXURAL CAPACITY OF PRECAST CONCRETE SANDWICH PANELS (RESULTS).		67
5.1.	INTRODUCTION	67
5.2.	FULLY COMPOSITE VOIDED PANEL AGAINST SOLID PANEL	67
5.3.	HORIZONTAL SHEAR AND GLOBAL FLEXURE FAILURES.....	69

5.3.1.	Shear connectors stresses.....	69
5.3.2.	Load deflection relationships.....	71
5.3.3.	Normal stresses of concrete wythes due to flexure.....	73
5.3.4.	Flexural reinforcement stresses (top and bottom)	79
5.3.5.	Key results	79
5.3.6.	Discussion of results regarding the study of horizontal shear and global flexure failures.....	83
5.4.	EFFECT OF SHEAR CONNECTORS SHAPE AND DISTRIBUTION ON OUT-OF-PLANE BENDING BEHAVIOR.....	84
5.4.1.	Discussion.....	88
5.5.	EFFECT OF SHEAR CONNECTORS AREA ON OUT-OF-PLANE BENDING BEHAVIOR	88
5.5.1.	Discussion.....	89
5.6.	EFFECT OF FOAM CORE BOND ON OUT-OF-PLANE BENDING BEHAVIOR...	91
5.7.	EFFECT OF STRUCTURAL WYTHE THICKNESS ON OUT-OF-PLANE BENDING BEHAVIOR	95
5.8.	EFFECT OF CONCRETE GRADE ON OUT-OF-PLANE BENDING BEHAVIOR ..	97
5.9.	USE OF GFRP MATERIAL IN TRUSS SHEAR CONNECTORS	99
5.10.	EFFECT OF ADDING RIBS TO THE STRUCTURAL WYTHE IN SANDWICH PANELS	101
5.11.	SERVICE LOAD	103
5.12.	ASSESSMENT OF COMPOSITE ACTION LEVEL	103
CHAPTER 6 : CONCLUSIONS.....		109
6.1.	CONCLUSIONS.....	109
6.2.	RECOMMENDATION FOR FUTURE STUDIES	111
REFERENCES.....		112

List of Tables

Table 2.1: Insulation types commonly used in concrete sandwich panels (adapted by Al-Hamoud, 2005) (4)).....	10
Table 2.2: EPS geofoam interface friction factors (46).....	14
Table 2.3: Typical tensile properties of the reinforcing materials (4).....	15
Table 2.4: Typical densities of reinforcing bars lb/ft ³ (g/cm ³) (2)	15
Table 3.1: Key results of the analytical and experimental results.....	40
Table 3.2: Ultimate tensile strength of wire mesh and elongation.	43
Table 4.1: Characteristics of sandwich panels in the parametric study.....	48
Rest of table 4.1: Characteristics of sandwich panels in the parametric study.....	49
Table 4.2: Panel type details (Typical Details)	49
Rest of table 4.2: Panel type details (Typical Details)	50
.....	50
Rest of table 4.2: Panel type details (Typical Details)	51
Rest of table 4.2: Panel type details (Typical Details)	52
Table 4.3: Objectives table (all items studied the out-of-plan bending)	55
Table 4.4: Cracking and crushing stresses of concrete grades	56
Table 5.1: Key results of short panels presented in study of HZ. Shear and global flexure failure	83
Table 5.2: Key results of long panels presented in study of HZ. Shear and global flexure failure.....	83
Table 5.3: Key results of short panels presented in the study of the effect of shear connectors shape and distribution on flexural behavior of sandwich panels	87
Table 5.4: Key results of long panels presented in the study of the effect of shear connectors shape and distribution on flexural behavior of sandwich panels	88
Table 5.5: key results of short panels presented in the study of the effect of shear connectors area on flexural behavior of sandwich panels.....	90
Table (5-6) key results of long panels presented in the study of the effect of shear connectors area on flexural behavior of sandwich panels.....	90
Table 5.7: key results of the short panels presented in the study of the effect of foam bond on flexural behavior of sandwich panels.....	92
Table 5.8: key results of the long panels presented in the study of the effect of foam bond on flexural behavior of sandwich panels	92
Table 5.9: key results of the short panels presented in the study of the effect of structural wythe thickness on flexural behavior of sandwich panels	96
Table 5.10: key results of the long panels presented in the study of the effect of structural wythe thickness on flexural behavior of sandwich panels	96
Table 5.11: key results of the short panels presented in the study of the effect of concrete grade on flexural behavior of sandwich panels.....	98
Table 5.12: key results of the long panels presented in the study of the effect of concrete grade on flexural behavior of sandwich panels.....	98
Table 5.13: key results of the panels presented in the study of use GFRP material against steel material in the truss shear connectors of the sandwich panels	100
Table 5.14: key results of the short panels presented in the study of adding concrete ribs in sandwich panels.....	103
Table 5.15: key results of the long panels presented in the study of adding concrete ribs in sandwich panels.....	103

Table 5.16: Summary of service loads for the short panels of 3.0m span.....	105
Table 5.17: Summary of service loads for the long panels of 9.0m span.....	106
Table 5.18: Summary of results along with composite actions degrees for the short panels of 3.0m span	107
Table 5.19: Summary of results along with composite actions degrees for the long panels of 9.0 m span	108

List of Figures

Figure 2.1: Precast concrete sandwich panel components	6
Figure 2.2: One-way shear connectors, stiff in one direction only (40).....	8
.....	8
Figure 2.3: Two-way shear connectors, stiff in two directions (40)	8
Figure 2.4: Flexible connectors for non-composite behavior (40)	9
Figure 2.5: EPS uniaxial compressive stress strain curves (16)	11
Figure 2.6: Initial tangent modulus for EPS geo-foam (16)	12
Figure 2.7: EPS geo-foam tensile strength (16)	13
Figure (2-8): EPS interface friction (46)	14
Figure 2.9: Panel structural designations (48)	16
Figure 2.10: Sample push-through test setup, presented by Woltman (2013) (53).....	22
Figure 2.11: Push-through test results showing difference between EPS and XPS insulation as presented by Bunn (2011) (10)	23
Figure 3.1: Geometry of the tested panel and its details (48)	26
Figure 3.2: Steel connectors details (48)	26
Figure 3.3: Loading setup (48)	27
Figure 3.4: Geometry of element type SOLID65 (5)	28
Figure 3.5: SOLID65 Stress output (5)	28
Figure 3.6: Geometry for element type SOLID185 (5)	29
Figure 3.7: SOLID185 Stress output (5)	29
Figure 3.8: Geometry for element type LINK180 (5)	30
Figure 3.9: LINK180 Stress Output (5)	30
Figure 3.10: Geometry for element type BEAM188 (5)	31
Figure 3.11: Geometry configuration for elements type CONTA174 and TARGE170 (5)	31
Figure 3.12: 3D view of the calibration model	32
Figure 3.13: Elevation view of the calibration model.	33
Figure 3.14: Part of 3D view of the calibration model	33
Figure 3.15: Uniaxial compressive stress- strain curve for concrete with $f_c' = 60$ MPa (validation model)	34
Figure 3.16: Simplified uniaxial stress- strain relationship for insulation material	34
Figure 3.17: Solution control of the 1st validation model	36
Figure 3.18: Newton-Raphson iterative solution	37
Figure 3.19: Stresses in reinforcement at ultimate load, MPa	38
Figure 3.20: Normal stresses of top concrete wythe at ultimate load, MPa	38
Figure 3.21: Normal stresses of bottom concrete wythe at ultimate load, MPa	38
Figure 3.22: Ultimate deformed shape for the 1st validation model, mm	39
Figure 3.23: Analytical and experimental load-deflection relationships for the 1st validation model	39
Figure 3.24: Comparison between analytical and experimental results	40
Figure 3.25: Concrete Dimension of the tested panel	41
Figure 3.26: Reinforcement details of the tested panel	42
Figure 3.27: Loading configuration of the tested panel	42
Figure 3.28: Loading and boundary conditions as defined in ANAYS	43
Figure 3.29: Geometry as defined in ANSYS for the second validation FEM	44