



Effect of interface position with different concrete compressive strength and shear connector shapes on the behavior of one-way composite pre-slabs

BY

ENG. AHMED ADEL ALY AFIFI

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

CAIRO UNIVERSITY, FACULTY OF ENGINEERING
GIZA, EGYPT
2016

Effect of interface position with different concrete compressive strength and shear connector shapes on the behavior of one-way composite pre-slabs

BY

ENG. AHMED ADEL ALY AFIFI

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.
MOHAMED EL-SAID ISSA
Professor of Reinforced concrete
Faculty of Engineering
Cairo University

PROF. DR.
MOHAMED TALAT MOSTAFA
Professor of Reinforced concrete
Faculty of Engineering
Cairo University

PROF. DR.
MOHAMED RABIE MAHMOUD
Professor of Reinforced concrete
Faculty of Engineering
Cairo University

ASS.PROF. DR.
SHERIF AHMED MOSTAFA
Associate Professor
Faculty of Engineering
October 6 University

CAIRO UNIVERSITY, FACULTY OF ENGINEERING
GIZA, EGYPT
2016

Effect of interface position with different concrete compressive strength and shear connector shapes on the behavior of one-way composite pre-slabs

BY
ENG. AHMED ADEL ALY AFIFI

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. Mohamed El-Said Issa,	Main Advisor
Prof.Dr. Mohamed Talat Mostafa,	Member
Prof.Dr. Mohamed Rabie Mahmoud,	Member
ASS.Prof.Dr. Sherif Ahmed Mostafa, Associate prof. Faculty of Engineering, October 6 University	Member
Prof.Dr. Mostafa Foad El Kafrawy,	Internal Examiner
Prof.Dr. Amr H. Abdel-azim Zaher, Professor of Reinforced Concrete, Faculty of Engineering, Ain-Shams University	External Examiner

**CAIRO UNIVERSITY, FACULTY OF ENGINEERING
GIZA, EGYPT
2016**

Engineer: Ahmed Adel Aly Afifi
Date of Birth: 27 / 5 / 1980
Nationality: Egyptian
E-mail: A7med_Afifi@yahoo.com
Phone: 01001566606
Address: Villa (8) El-wrood street 6 October city
Registration Date: 1 / 10 / 2009
Awarding Date: / / 2016
Degree: PH.D
Department: Structural Engineering



Supervisors: **Prof. Dr.** Mohamed El-Said Issa
Prof. Dr. Mohamed Talat Mostafa
Prof. Dr. Mohamed Rabie Mahmoud
Ass. Prof. Dr. Sherif Ahmed Mostafa – October 6

University

Examiners: **Prof. Dr.** Mohamed El-Said Issa
Prof. Dr. Mohamed Talat Mostafa
Prof. Dr. Mohamed Rabie Mahmoud
Ass. Prof. Dr. Sherif Ahmed Mostafa – October 6

University

Prof. Dr. Mostafa Foaad El Kafrawy
Prof. Dr. Amr H. Abdel-azim Zaher – Ain-Shams

University

Title of Thesis:

"Effect of interface position with different concrete compressive strength and shear connector shapes on the behavior of one-way composite pre-slabs"

Key Words: (Composite, Interface, Shear connector, Pre-slabs)

Summary:

Composite pre-slabs are one of the most common types of composite elements. There are many factors effected in the behavior of the pre-slab, the main governing factor is the shear transfer along the interface to achieve the composite action between the two layers. This research presents as investigation of one-way composite pre-slabs behavior for many specimens have a different interface positions with two alternative concrete compressive strengths and different shapes of shear connector.

ACKNOWLEDGEMENTS

The writer wants to express his deepest thanks to **Prof. Dr. MOAHMED EL-SAID ISSA**, Professor of Reinforced concrete, Faculty of Engineering, Cairo University for his constant supervision, planning, guidance, valuable suggestions, precise advice and for being like a father during all faces of this research work.

The writer wishes to express his sincere appreciation to **Prof. Dr. MOHAMED TALAT MOSTAFA**, Professor of Reinforced concrete, Faculty of Engineering, Cairo University, for his kind and constant supervision, for his sincere help, encouragement, and cooperation to the fullest degree during all phases of his work.

The writer wishes to express his deepest gratitude and appreciation to **Prof. Dr. MOHAMED RABIE MAHMOUD**, Professor of Reinforced concrete, Faculty of Engineering, Cairo University, for his kind supervision, guidance, generous support and patience during the course of this research work.

The writer would like to express his thanks to **Dr. SHERIF AHMED MOSTAFA**, Assistant Professor, Faculty of Engineering, October 6 University.

Thanks should also go to **Dr. Heba Mohamed Issa** for her guidance throughout the theoretical study of this research.

Further more, the writer is grateful to all members of the **Reinforced Concrete Laboratory Staff**, Faculty of Engineering, Cairo University for their kind help during the experimental phase of this study

Finally, I dedicate this thesis to my **FATHER, MOTHER, BROTHER, SISTERS, SONS (ANAS AND ASER) AND FINALY MY WIFE** for their continuous encouragement and fruitful care.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENT.....	i
TABLE OF CONTENTS.....	ii
LIST OF TABLES.....	vi
LIST OF FIGURES.....	vii
ABSTRACT.....	xiii

CHAPTER (1): INTRODUCTION

1.1. General.....	1
1.2. Objectives.....	1
1.3. Scope and contents.....	2

CHAPTER (2): REVIEW OF PREVIOUS WORK

2.1 General.....	3
2.2 Factors affecting shear strength.....	3
2.2.1. Concrete compressive strength.....	4
2.2.2 Slippage.....	5
2.2.3. Types of loading.....	5
2.2.4. Interface position with respect to neutral axis.....	6
2.2.5. Aggregate size and shape.....	6
2.2.6 Casting position.....	6
2.2.7. Concrete placement method.....	7
2.2.8. Concrete age and curing method.....	7
2.2.9. Type of stress acting parallel to the shear plane.....	7
2.2.10. Differential shrinkage.....	8
2.2.11. Dimensions and reinforcement of the tested specimens.....	9
2.2.12. Ratio of shear span to effective depth.....	10
2.3. Composite section.....	11
2.3.1. Examples of composite sections.....	11
2.3.2. Structural behavior of composite flexural members.....	12
2.4. Shear transfer mechanism in composite members.....	13
2.4.1. The shear friction theory.....	13
2.4.2. General theory for shear transfer mechanism of concrete.....	15
2.4.3. Truss action model of shear transfer.....	17
2.5. Shear transfer tests.....	20
2.6. Types of composite slabs.....	21

2.6.1. Composite slabs with prefabricated beams.....	21
2.6.2. Conventional steel deck slab system.....	21
2.6.3. Composite concrete-concrete slabs.....	21
2.7. Different types of shear connection between two concrete surfaces.	22
2.7.1 Rough surface connection.....	22
2.7.2. Shear keyed connection.....	27
2.7.3. Steel doweled shear connection.....	30
2.7.3.1. Effect of percentage area and embedded length of dowels....	30
2.7.3.2. Effect of steel strength, bar size and spacing.....	32
2.7.3.3. Distribution and shapes of the steel dowels over the span...	32
2.7.4. Epoxy binding materials.....	34
2.8. Theoretical analysis of the composite concrete members.....	34
2.9. Prediction of shear transfer capacity.....	35
2.9.1. Empirical formulas.....	35
2.9.2. Semi-empirical formulas.....	36
2.10. Code requirements.....	37
2.10.1. ACI Committee 318-95 (5).....	37
2.10.2. BS 8110 1995 (8).....	41
2.10.3. DIN 1045 1978 (9).....	42
2.10.4. Japanese standard specification (27).....	42
2.10.5. ECP 203-2007 (14).....	43

CHAPTER (3): EXPERIMENTAL PROGRAM

3.1. Introduction	74
3.1.1. Purpose of the study.....	74
3.2. Details of test specimens.....	75
3.2.1. Monolithic slabs specimens.....	75
3.2.2. Composite pre-slabs specimens.....	75
3.2.3. Shear connectors.....	76
3.3. Characteristics of used materials.....	86
3.3.1. Aggregates.....	86
3.3.2. Cement.....	88
3.3.3. Water.....	88
3.3.4. Silica fume.....	88
3.3.5. Super-plasticizer.....	89
3.3.6. Reinforcing steel.....	90
3.4. Mix proportions.....	90
3.5. Preparation of specimens.....	91
3.5.1. Mixing and curing.....	95
3.5.2. Properties of hardened concrete.....	97
3.5.2. Interface of pre-slab specimens.....	99

3.6. Loading of specimens.....	100
3.7. Measurement instruments.....	100
3.7.1. Loads.....	101
3.7.2. Deflection.....	101
3.7.3. Slippage.....	101
3.7.4. Concrete strain.....	101
3.7.5. Shear connectors strain.....	101
3.8. Test procedure.....	104

CHAPTER (4): ANALYSIS AND DISCUSSION OF TEST RESULTS

4.1. General	106
4.2. Deflection.....	106
4.3. Crack width.....	118
4.4. Steel strain.....	124
4.5. Cracking behavior.....	129
4.5.1. Cracking behavior for monolithic group.....	129
4.5.2. Cracking behavior for group G1.....	129
4.5.3. Cracking behavior for group G2.....	130
4.5.4. Cracking behavior for group G3.....	130
4.5.5. Cracking behavior for group G4.....	131
4.6. Mode of failure.....	146
4.6.1. Mode of failure for group G1.....	146
4.6.2. Mode of failure for group G2.....	146
4.6.3. Mode of failure for group G3.....	147
4.6.4. Mode of failure for group G4.....	147
4.7. Summary of results.....	148

CHAPTER (5): ANALYSIS EXPERIMENTAL PROGRAM

5.1. Introduction.....	150
5.2. Finite element program (ANSYS).....	150
5.3. Main steps for modeling pre-slab using ANSYS (16.0).....	151
5.3.1. Elements types.....	151
5.3.1.1. Concrete element.....	151
5.3.1.2. Steel reinforcement element.....	152
5.3.1.3. Interface element.....	154
5.3.2. Real constants.....	154
5.3.2.1. Concrete elements.....	154
5.3.2.2. Steel reinforcement element.....	155

5.3.3. Material properties.....	156
5.3.3.1. Concrete elements.....	156
5.3.3.2. Steel reinforcement element.....	159
5.3.3.3. Lead plates and supports.....	160
5.3.4. Modeling.....	161
5.3.4.1. Solid65.....	161
5.3.4.2. Link180.....	161
5.3.5. Numbering controls.....	162
5.3.6. Loads and boundary conditions.....	162
5.3.7. Analysis type.....	162
5.3.8. Analysis process for the finite element model.....	165
5.3.9. Load stepping and failure definition for F.E models.....	166
5.4. ANSYS Finite element model.....	166
5.4.1. Elements types for all slabs	166
5.4.1.1. Reinforced concrete.....	166
5.4.2. Real constants.....	167
5.4.3. Material properties.....	168
5.4.3.1. Material model number 1	168
5.4.3.2. Material model number 2.....	168
5.4.3.3. Material model number 3.....	168
5.4.4. Detailing of the model	171
5.4.4.1. Solid65	171
5.4.4.2. Link180	172
5.4.5. Numbering controls.....	174
5.4.6. Loads and boundary conditions.....	174
5.4.7. Analysis type.....	175
5.4.8. Analysis process for the finite element mode.....	175

CHAPTER (6): ANALYSIS CORRELATION BETWEEN THEORETICAL AND EXPERIMENTAL RESULTS

6.1. General.....	176
6.2. Deflection.....	176
6.3. Mode of failure.....	183

CHAPTER (7): CONCLUSION

7.1. General.....	184
7.2. Conclusion.....	184
7.3. Recommendations for future study	185
<i>REFERENCES</i>	186

LIST OF TABLES

<i>CHAPTER (2)</i>	PAGE
Table 2.1: Empirical formulas of previous work	44
Table 2.2: Design ultimate horizontal shear stress at interface according to BS 8110 (8).....	45
Table 2.3: Limits of basic values of the shear stress for the design of shear reinforcement in kg/cm ² under service load according to DIN 1045.....	46
<i>CHAPTER (3)</i>	
Table 3.1: Designation of experimental testing groups.....	77
Table 3.2: Material quantities in kg/m ³ for the cube strength specimens.....	91
Table 3.3: Compressive strength of concrete cubes.....	99
<i>CHAPTER (5)</i>	
Table 5.1: Real constants for Solid65.....	155
Table 5.2: Real constants for Link 180.....	156
Table 5.3: Material properties for the concrete element.....	157
Table 5.4 :Material properties for the steel reinforcement element	160
Table 5.5: Material properties for the lead plates and supports element.....	160
Table 5.6: Commands used to control nonlinear analysis.....	163
Table 5.7: Commands used to control output.....	163
Table 5.8: Nonlinear algorithm and convergence criteria parameters.....	164
Table 5.9: Advanced nonlinear control settings used.....	164
Table 5.10: Real constants.....	167
Table 5.11: Material properties	169
Table 5.12: Element attributes for the model.....	174

LIST OF FIGURES

CHAPTER (2)	PAGE
Figure 2.1.a: Effect of compressive strength of old concrete.....	48
Figure 2.1.b: Effect of compressive strength of new concrete....	48
Figure 2.2: Ultimate shear strength against concrete compressive strength.....	49
Figure 2.3: Effect of concrete strength on shear transfer of initially cracked push-off specimens.....	49
Figure 2.4: Effect of compressive strength and ρf_y on shear strength.....	50
Figure 2.5: Strain distribution showing two-beam action.....	50
Figure 2.6: Shear stress-slip curve for shear across construction joint subjected to reversed cyclic loading.....	51
Figure 2.7: Test specimen dimensions.....	51
Figure 2.8: Casting position.....	52
Figure 2.9: Effect of casting position.....	52
Figure 2.10: Effect of method of placement.....	53
Figure 2.11: Effect of direct stress acting parallel to shear plane	53
Figure 2.12: Effect of K ratio on calculated maximum shear strength.....	54
Figure 2.13: Effect of transverse steel on shear strength.....	54
Figure 2.14: Effect of shear span/effective depth and steel across joint on ultimate strength.....	55
Figure 2.15.a: Distribution of stresses in horizontal section of composite member.....	56
Figure 2.15.b: Test arrangement.....	56
Figure 2.16: Details of tested specimens.....	56
Figure 2.17: Details of tested slabs.....	57
Figure 2.18: Bending stress and shear stress distribution of composite beam.....	58
Figure 2.19: Shear friction model.....	58
Figure 2.20: Shear friction model.....	59
Figure 2.21: Zia's failure envelope.....	60
Figure 2.22: Comparison of test result with Zia's failure envelope.....	60
Figure 2.23.a, b: Shear transfer of initially uncracked concrete.	61
Figure 2.23.c: Comparison of calculated and tested shear transfer strength of initially uncracked push-off specimens.....	61

Figure 2.24: Comparison of shear transfer strength calculated by mattock and Neil approach with the measured strengths of initially cracked push-off and pull-off specimens.....	62
Figure 2.25: Shear stress against shear strain given by Thomas..	63
Figure 2.26: Strut and tie model for shear transfer across interface.....	63
Figure 2.27.a: Effect of concrete strength on prediction of shear transfer capacity.....	64
Figure 2.27.b: Effect of normal stress on prediction of shear transfer capacity.....	64
Figure 2.28: Details of push-off specimens.....	65
Figure 2.29: Details of push-off specimens tested by Dong.....	65
Figure 2.30: Details of beams tested by Grossfield.....	66
Figure 2.31: Section of beams tested by Saemann.....	66
Figure 2.32: Effect of shear keys on shear strength.....	67
Figure 2.33: Details of theoretical test specimen.....	68
Figure 2.34: Effect of dowels area on shear transfer strength.....	69
Figure 2.35: Section of tested specimens.....	69
Figure 2.36.a: Shear stress at 0.005 inch slip against steel across joint.....	70
Figure 2.36.b: Ultimate shear strength against steel across joint.	71
Figure 2.37: Effect of dowels diameter.....	72
Figure 2.38: Details of specimens with steel trusses shear connectors.....	72
Figure 2.39: Shear stud in favorable, central and un favorable position.....	73

CHAPTER (3)

Figure 3.1: Typical dimensions and reinforcement of monolithic slabs (M1, M2)	78
Figure 3.2: Typical dimensions and reinforcement of composite pre-slabs (S11, S31).....	79
Figure 3.3: Typical dimensions and reinforcement of composite pre-slabs (S12, S32).....	80
Figure 3.4: Typical dimensions and reinforcement of composite pre-slabs (S13, S33).....	81
Figure 3.5: Typical dimensions and reinforcement of composite pre-slabs (S21, S41).....	82
Figure 3.6: Typical dimensions and reinforcement of composite	

pre-slabs (S22, S42).....	83
Figure 3.7: Typical dimensions and reinforcement of composite pre-slabs (S23, S43)	84
Figure 3.8: Typical dimensions of shear connector shapes.....	85
Figure 3.9: Fine aggregates natural sand.....	86
Figure 3.10: Course aggregates crushed lime stone size number1	87
Figure 3.11: Course aggregates Cleaning process.....	87
Figure 3.12: Ordinary Portland cement packing.....	88
Figure 3.13: Silica fume packing.....	89
Figure 3.14: Super-plasticizer packing.....	90
Figure 3.15: Preparing of wooden form of thespecimens.....	92
Figure 3.16: Preparing of steel bars with shear connectors.....	92
Figure 3.17: Placing of steel mesh in wooden form (Shape1)....	93
Figure 3.18: Placing of steel mesh in wooden form (Shape2)....	93
Figure 3.19: Placing of steel mesh in wooden form (Shape3)....	94
Figure 3.20: Placing of electrical strain gauges in dowels.....	94
Figure 3.21: Concrete mechanical mixer.....	95
Figure 3.22: Concrete compaction.....	96
Figure 3.23: Smoothing of the final concrete surface.....	96
Figure 3.24: Concrete curing.....	97
Figure 3.25: cubes specimen.....	98
Figure 3.26: Investigation of concrete compressive strength.....	98
Figure 3.27: cubes specimen after testing.....	99
Figure 3.28: Surface cleaning.....	100
Figure 3.29: vertical deflection points.....	102
Figure 3.30: Specimen paint and demec points distribution.....	103
Figure 3.31: positions of dial gauge to measure the slippage....	104
Figure 3.32: General view of test setup.....	105

CHAPTER (4)

Figure 4.1: Deflection profile at cracking load of M1 and G1	107
Figure 4.2: Deflection profile at cracking load of M1 and G2...	108
Figure 4.3: Deflection profile at cracking load of M2 and G3...	108
Figure 4.4: Deflection profile at cracking load of M2 and G4...	109
Figure 4.5: Deflection profile at ultimate load of M1 and G1...	109
Figure 4.6: Deflection profile at ultimate load of M1 and G2...	110
Figure 4.7: Deflection profile at ultimate load of M2 and G3...	110
Figure 4.8: Deflection profile at ultimate load of M2 and G4...	111

Figure 4.9: Load-Deflection curves at left side of M1 and G1...	111
Figure 4.10: Load-Deflection curves at middle of M1 and G1..	112
Figure 4.11: Load-Deflection curves at right side of M1 and G1.....	112
Figure 4.12: Load-Deflection curves at left side of M1 and G2..	113
Figure 4.13: Load-Deflection curves at middle of M1 and G2	113
Figure 4.14: Load-Deflection curves at right side of M1 and G2	114
Figure 4.15: Load-Deflection curves at left side of M2 and G3..	114
Figure 4.16: Load-Deflection curves at middle of M2 and G3...	115
Figure 4.17: Load-Deflection curves at right side of M2 and G3	115
Figure 4.18: Load-Deflection curves at left side of M2 and G4..	116
Figure 4.19: Load-Deflection curves at middle of M2 and G4...	116
Figure 4.20: Load-Deflection curves at right side of M2 and G4	117
Figure 4.21: Cracking and ultimate loads for tested slabs.....	117
Figure 4.22: Load – Crack width curves at left side of M1 and G1.....	118
Figure 4.23: Load – Crack width curves at middle of M1 and G1.....	119
Figure 4.24: Load – Crack width curves at right side of M1 and G1.....	119
Figure 4.25: Load – Crack width curves at left side of M1 and G2.....	120
Figure 4.26: Load – Crack width curves at middle of M1 and G2.....	120
Figure 4.27: Load – Crack width curves at right side of M1 and G2.....	121
Figure 4.28: Load – Crack width curves at left side of M2 and G3.....	121
Figure 4.29: Load – Crack width curves at middle of M2 and G3.....	122
Figure 4.30: Load – Crack width curves at right side of M2 and G3.....	122
Figure 4.31: Load – Crack width curves at left side of M2 and G4.....	123
Figure 4.32: Load – Crack width curves at middle of M2 and G4.....	123
Figure 4.33: Load – Crack width curves at right side of M2 and G4.....	124
Figure 4.34: Load-Steel strain curve in left dowels of G1.....	125
Figure 4.35: Load-Steel strain curve in right dowels of G1.....	125
Figure 4.36: Load-Steel strain curve in left dowels of G2.....	126

Figure 4.37: Load-Steel strain curve in right dowels of G2.....	126
Figure 4.38: Load-Steel strain curve in left dowels of G3.....	127
Figure 4.39: Load-Steel strain curve in right dowels of G3.....	127
Figure 4.40: Load-Steel strain curve in left dowels of G4.....	128
Figure 4.41: Load-Steel strain curve in right dowels of G4.....	128
Figure 4.42: Cracks pattern of specimen M1.....	132
Figure 4.43: Shear cracks of specimen M1.....	132
Figure 4.44: Cracks pattern of specimen M2.....	133
Figure 4.45: Shear cracks of specimen M2.....	133
Figure 4.46: Cracks pattern of specimen S11.....	134
Figure 4.47: Shear cracks of specimen S11.....	134
Figure 4.48: Cracks pattern of specimen S12.....	135
Figure 4.49: Shear cracks of specimen S12.....	135
Figure 4.50: Cracks pattern of specimen S13.....	136
Figure 4.51: Shear cracks of specimen S13.....	136
Figure 4.52: Cracks pattern of specimen S21.....	137
Figure 4.53: Shear cracks of specimen S21.....	137
Figure 4.54: Cracks pattern of specimen S22.....	138
Figure 4.55: Shear cracks of specimen S22.....	138
Figure 4.56: Cracks pattern of specimen S23.....	139
Figure 4.57: Shear cracks of specimen S23.....	139
Figure 4.85: Cracks pattern of specimen S31.....	140
Figure 4.59: Shear cracks of specimen S31.....	140
Figure 4.60: Cracks pattern of specimen S32.....	141
Figure 4.61: Shear cracks of specimen S32.....	141
Figure 4.62: Cracks pattern of specimen S33.....	142
Figure 4.63: Shear cracks of specimen S33.....	142
Figure 4.64: Cracks pattern of specimen S41.....	143
Figure 4.65: Shear cracks of specimen S41.....	143
Figure 4.66: Cracks pattern of specimen S42.....	144
Figure 4.67: Shear cracks of specimen S42.....	144
Figure 4.68: Cracks pattern of specimen S43.....	145
Figure 4.69: Shear cracks of specimen S43.....	145
Figure 4.70: Relation between shear connector shapes and ratio of increasing in ultimate load.....	149