



Ain Shams University
Faculty of Engineering

BEHAVIOUR OF CONNECTION BETWEEN PRECAST HIGH STRENGTH CONCRETE BEAMS AND DECK SLABS

By
Eng. Karim Atef Hassan Sayed

B.Sc. (٢٠٠٦)
Structural Division – Civil Engineering Departement
Faculty of Engineering – Ain Shams University

A Thesis
Submitted in Partial Fulfillment of the Requirements
of the Degree of Master of Science in Civil Engineering (Structural)

Under the supervision of:

Prof. Dr. Amr Ali Abdelrahman
Professor of Concrete Structures
Structural Engineering Dept.
Ain Shams University, Egypt.

Dr. Khaled Mohammed Hilal
Assistant Professor
Structural Engineering Department,
Ain Shams University, Egypt.

November – ٢٠١٣
Cairo – Egypt

STATEMENT

This thesis is submitted to Ain Shams University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Structural).

The work included was carried out by the author at reinforced concrete laboratory of the faculty of engineering, Ain Shams University.

No part of this thesis has been submitted for a degree or a qualification at any other university or institution.

Date : ٢١/٠٤/٢٠١٣
Name : **Karim Atef Hassan Sayed**
Signature : *Karim Atef*

AUTHOR

Name : Karim Atef Hassan Sayed
Date of birth : ٢٩ May ١٩٨٣
Place of birth : Cairo, Egypt.
Academic Degree : B.Sc. in Structural Engineering
University : Ain Shams University
Date : July ٢٠٠٦
Grade : Good
Current job : Civil / Structural Engineer at PARSONS.

EXAMINERS COMMITTEE

Name and Affiliation

Signature

Prof. Dr. Amr Ali Abdelrahman

Professor of Concrete Structures
Structural Engineering Dept.
Ain Shams University, Egypt.

Prof. Dr. Ibrahim Galal Shaban

Professor of Concrete Structures
Executive Projects Manager
High Education Authority, Egypt.

Dr. Ahmad Hassan Galab

Professor of Concrete Structures
Structural Engineering Department,
Ain Shams University, Egypt.

Dr. Khaled Mohammed Hilal

Assistant Professor
Structural Engineering Department,
Ain Shams University, Egypt.

ACKNOWLEDGEMENT

First of all, I thank ALLAH who guided and helped me to finish this work in the proper shape.

I would like to thank my father, mother, my wife and my whole family for their continuous support. I would like to express my deep appreciation to Prof. Dr. Amr Ali Abd El-Rahman, professor of concrete structures, faculty of engineering, Ain Shams University, for his experienced advice, continuous support and deep encouragement through all phases of the work.

I am also extremely grateful to Dr. Khaled Mohammed Hilal, Assistant Professor at the Structural Engineering Department, Faculty of Engineering, Ain Shams University, for his experienced advice, continuous support and deep encouragement through all phases of the work.

I would like to thank the technicians of the reinforced concrete laboratory, Ain Shams University.

Finally, I would like to thank my dear friends and colleagues Medhat Tawfik and Moataz Mostafa, who helped and supported me in the completion of this work.



**Ain Shams University,
Faculty of Engineering
Structural Department**

ABSTRACT

Title of the thesis:

**“BEHAVIOUR OF CONNECTIONS BETWEEN PRECAST
HIGH STRENGTH CONCRETE BEAMS AND DECK
SLABS”**

Submitted by: Eng. Karim Atef Hassan Sayed

**Supervised by: Prof. Dr. Amr Ali Abdelrahman
Dr. Khaled Mohammed Hilal**

Over the past three decades, bridge deck construction using precast components has become the system of choice for contractors and transportation officials. The choice for precast concrete is due to the rapid erection of its lightweight components, reduction in overall mobilization and equipment costs and its structural durability. Several precast elements are available to meet with all construction requirements. It is often preferable to transport beams and deck slabs separately to reduce the weight of each element. While precast panels perform well under large and highly repetitive loading, the transversal grouted connection between precast beams and deck slabs can become problematic.

The research program included in thesis, evaluate the structural performance of the different types of the connection between precast high strength concrete beams and deck slabs. The main variable in the study was the shear connectors' distribution along the transversal connection between the beams and deck slabs. The research also evaluates the chemical adhesion between the beams and deck slabs using epoxy resins and grout to connect the beams with the deck slabs without using shear connectors.

Six high strength concrete beam specimens with different shear connector's distribution were tested under static loading conditions, flexural tests were performed to study the parameters mentioned previously and to quantify peak and post-peak behavior of the interface between beams and deck slabs. The different series of tests investigated the surface treatment of the bottom of the slab, the distribution and amount of shear connector and several pocket details. In addition, the effect of chemical adhesion on the behavior of the connection was investigated by using epoxy resin without shear connectors at one of the six beam specimens.

The thesis also presents the analytical program that evaluates the different design approaches of the international standards like ACI-318M 2008, BS8110, ECP-203 2007 and AASHTO LRFD 2007 and comparing these approaches with the test results.

The research findings indicated that the studied shear connectors' distribution patterns; i.e. concentrated at beam edge or distributed along the beam length; had no significant effect on the load – deflection behavior or the ultimate capacity of the tested beam specimens. The beam specimens interface shear reinforcement was designed by the shear friction equation of the Egyptian code.

The research also indicated that Specimens with Dense shear connectors distribution achieved the full capacity as the monolithic control beam specimen, Specimens with light shear connectors distribution achieved 90% of the full capacity of the monolithic control beam specimen. While The failure load of beam specimen without using mechanical connectors was 80% of the monolithic control beam capacity.

Finally, the research indicated that, the grouted pockets technique is a promising alternative to the conventional cast-in-place concrete deck. They afford reduced construction time and fewer burdens on the motoring public. In addition, using high strength concrete has given smaller composite sections with the ability to carry larger loads.

Beam specimen B₇ give promising results for using epoxy resin only at the interfacial surface without using mechanical shear connectors. More

researches are needed to evaluate this type of connection depending on epoxy only under cyclic loading. In addition, more researches are needed to evaluate and enhance the grouted pockets technique under cyclic loading.

TABLE OF CONTENTS

Table of contents	1
Notations	13
Chapter (1) Introduction	15
1.1 General.....	15
1.2 Research Objective.....	16
1.3 Research Scope And Contents.....	17
Chapter (2) Literature Review	21
2.1 general.....	21
2.2 Precast Concrete Bridge Deck Panel System Background	21
2.3 Horizontal Shear Stress in Composite Members.....	22
2.3.1 Classical Elastic Method.....	23
2.3.2 Simplified Elastic Beam Behavior.....	25
2.3.3 Summary Of Shear Demand Methods	26
2.4 Shear Friction Model	27
2.5 Horizontal Shear Strength Research For Cast-In-Place Decks.....	28
2.5.1 Hanson.....	29
2.5.2 Mast	29
2.5.3 Saemann and Washa.....	31
2.5.4 Birkeland	32
2.5.5 Shaikh	32
2.5.6 Loov	33
2.5.7 Walraven.....	33
2.5.8 Mattock.....	33
2.5.9 Mau and Hsu	34
2.5.10 Loov and Patnaik.....	34
2.6 Horizontal Shear Strength Research For Precast Deck Systems.....	35
2.6.1 Menkulasi.....	35
2.6.2 Scholz.....	36
2.7 Headed Stud Connectors for Composite Action.....	36

Table of contents

۲.۸ AASHTO Standard Specification Provisions	۳۸
۲.۹ AASHTO LRFD-۲۰۰۷ Bridge Design Specifications for Horizontal Shear	۳۹
۲.۹.۱ Cohesion and friction factors for AASHTO LRFD ۲۰۰۷	۴۲
۲.۹.۲ Maria Lang, ۲۰۱۱	۴۴
۲.۱۰ ECP ۲۰۳ -۲۰۰۷ Design Provisions.....	۴۴
۲.۱۱ British standard – BS ۸۱۱۰-۱:۱۹۹۷	۴۵
۲.۱۱.۱ Horizontal Shear Force Due To Design Ultimate Loads	۴۵
۲.۱۱.۲ Average Horizontal Design Shear Stress.....	۴۶
۲.۱۱.۳ Links In Excess Of Minimum	۴۶
۲.۱۲ Effectiveness of Chemical Adhesion And Cohesion On The Horizontal Shear Transfer	۴۷
۲.۱۲.۱ Tanaka and Nakamura, ۲۰۱۰	۴۷
۲.۱۲.۲ A.elmahdy, ۲۰۱۰	۴۷
۲.۱۲.۳ Jonathan D.Kovach, ۲۰۰۸.....	۴۹
۲.۱۳ horizontal shear connection.....	۵۰
۲.۱۴ Summary Of Horizontal Shear Strength Researches For Cast In Place Decks.....	۵۱
۲.۱۵. Material Review – High Strength Concrete HSC	۵۱
۲.۱۵.۱. Definition	۵۱
۲.۱۵.۲. Characteristics of High-Strength Concrete	۵۲
Chapter (۳) Experimental Program	۵۳
۳.۱ General.....	۵۳
۳.۲ Specimen Design Concept And Methodology	۵۴
۳.۳ Horizontal Shear Connection.....	۵۴
۳.۳.۱ Fully Composite Connection (Rigid Connection).....	۵۴
۳.۳.۲ Partially Composite Connection (Semi Rigid Connection)	۵۵
۳.۴ Design Of Test Specimens	۵۵
۳.۴.۱ Flexure Capacity.....	۵۵
۳.۴.۲ Vertical Shear Capacity	۵۶
۳.۴.۳ Horizontal Shear Strength For Fully And Partially Composite Specimens B۲, B۳, B۴ And B۵	۵۶

Table of contents

۳.۴.۳.۱ Beam specimen B۲.....	۵۷
۳.۴.۳.۲ Beam specimen B۳.....	۵۸
۳.۴.۳.۳ Beam specimen B۴.....	۵۸
۳.۴.۳.۴ Beam specimen B۵.....	۵۸
۳.۵ Test Specimen.....	۵۹
۳.۶ Fabrication Of Test Specimen.....	۶۵
۳.۶.۱ Fabrication Of Control Specimen And Five R-Section Concrete Beams (Stage ۱).....	۶۶
۳.۶.۲ Fabrication Of Slab Panels With Different Pockets Patterns (Stage ۲).....	۶۹
۳.۶.۳ Application Of The Grout And The Epoxy Resin (Stage ۳).....	۷۱
۳.۶.۳.A Application Of The Grout.....	۷۱
۳.۶.۳.B Application Of The Epoxy Resin.....	۷۳
۳.۷ Material Properties.....	۷۴
۳.۷.۱ Concrete.....	۷۴
۳.۷.۲ Reinforcing Steel.....	۷۶
۳.۷.۳ Grouting Mortar (SIKAGROUT-۲۱۴).....	۷۷
۳.۷.۴ Epoxy resin (SIKADURE-PF).....	۷۷
۳.۸ Instrumentation.....	۷۸
۳.۸.۱ Load Measurements.....	۷۸
۳.۸.۲ Vertical Deflection And Horizontal Slip Measurements.....	۷۹
۳.۸.۳ Steel Strain Measurements.....	۸۰
۳.۸.۴ Concrete Strain Measurements.....	۸۳
۳.۹ Test Set-Up.....	۸۳
۳.۹.۱ Loading.....	۸۴
۳.۹.۲ Supports.....	۸۵
۳.۹.۳ Preparation Of Test.....	۸۵
۳.۹.۴ Testing Procedure.....	۸۶
Chapter (۴) Results of the experimental program.....	۸۷
۴.۱ General.....	۸۷
۴.۲ Test Results.....	۸۸
۴.۲.۱ Specimen B۱ (Control Specimen):.....	۹۲
۴.۲.۲ Specimen B۲:.....	۹۷

Table of contents

٤.٢.٣ Specimen B٣:	١٠٢
٤.٢.٤ Specimen B٤:	١٠٨
٤.٢.٥ Specimen B٥:	١١٣
٤.٢.٦ Specimen B٦:	١٢٠
٤.٢.٧ Horizontal Slip	١٢٤
Chapter (٥) Discussion Of The Experimental Results	١٢٨
٥.١ General	١٢٨
٥.٢ Discussion Of The Experimental Results	١٢٨
٥.٢.١ Effect Of The Different Shear Connectors' Distribution.....	١٢٨
٥.٢.٢ Effect Of The Chemical Adhesion By Using Epoxy Resin.....	١٣٧
٥.٣ Conclusion Of The Experimental Work.....	١٤٠
Chapter (٦) Analytical Study	١٤١
٦.١ General	١٤١
٦.٢ Different Design Provisions For Horizontal Shear strength	١٤١
٦.٢.١ ACI -٣١٨ Design Provisions.....	١٤٢
٦.٢.١.١ MAST	١٤٢
٦.٢.١.٢ Birkeland's Equation	١٤٣
٦.٢.١.٣ Shaikh's Equation	١٤٤
٦.٢.١.٤ Loov's Equation	١٤٥
٦.٢.١.٥ Walraven 's Equation	١٤٦
٦.٢.٢ ECP ٢٠٣ -٢٠٠٧ Design Provisions.....	١٤٧
٦.٢.٣ AASHTO LRFD Design Specifications - ٢٠٠٧	١٤٨
٦.٢.٤ British standard – BS ٨١١٠-١:١٩٩٧	١٤٩
٦.٢.٥ Mattock and Hawkins (١٩٧٢)	١٥٠
٦.٢.٦ Patnaik (٢٠٠١).....	١٥١
٦.٣ Parametric Study For The Available Analytical Models	١٥٢
٦.٤ Experimental Longitudinal Shear Stress (experimental shear stress) ...	١٥٤
٦.٥ Comparison Between Experimental And Analytical Results.....	١٥٥
٦.٦. Comparison Between Different Analytical Models Based On Experimental Data	١٦٩
٦.٧. Summary Of The Analytical Models And Experimental Results	١٧٠

Table of contents

٦.٨. Experimental Results Compared To The Existing Analytical Models ..	١٧١
٦.٨.١ Linear Equations.....	١٧١
٦.٨.٢ Non- Linear Equations.....	١٧٣
٦.٨.٣ Looove And Walraven Equations.....	١٧٥
٦.٩. Cohesion Effectiveness On The Horizontal Shear – Beam Specimen B٦	
.....	١٧٨
٦.٩.١ Tanaka And Nakamura	١٧٨
٦.٩.٢ AASHTO LRFD ٢٠٠٧.....	١٧٨
٦.٩.٣ Mattock and Hawkins.....	١٧٨
٦.٩.٤ Patnaik (٢٠٠١).....	١٧٩
٦.٩.٥ Test Result Compared To The Existing Analytical Models.....	١٧٩
٦.١٠. Strut And Tie Models.....	١٨١
٦.١٠.١ Strut And Tie Model For The Grouted Pockets Specimens	١٨١
٦.١٠.٢ Strut And Tie Model For Beam Specimen B٦.....	١٨٢
٦.١١. Summary And Conclusion For The Analytical Work.....	١٨٦
Chapter (٧) Summary, Conclusions And Recommendations	١٨٧
٧.١ Summary.....	١٨٧
٧.٢ Conclusions	١٨٨
Future Work.....	١٩٠
references	١٩١
Appendix A / Calculations	١٩٣
Appendix B / Experimental Results Photos	٢١٩

LIST OF FIGURES

Fig. 1.1: Typical system for full-depth precast concrete bridge consisting of precast concrete deck on precast concrete I-girder	16
Fig. 2.1: Free Body Diagram from (AASHTO Figure C 9.4.4.1-1).....	23
Fig. 2.2: segment represents the horizontal shear stress between web and slab panel.....	24
Fig. 2.3: Aggregate Interlock	28
Fig. 2.4: Basis of shear friction design method: (a) applied shear; (b) enlarged representation of crack surface; (c) free body diagram of concrete above crack.	30
Fig. 2.5: Free body diagram.....	40
Fig. 2.6: Cross-section of the hybrid FRP-concrete section.	48
Fig. 3.1: Typical cross section for specimen (B 1)-Control specimen	59
Fig. 3.2: Typical cross section for specimen (B 2, B 3, B 4 and B 5) with different shear connector's distributions and pocket details	60
Fig. 3.3: Typical cross section for specimen (B 6)-Using epoxy resin only.....	61
Fig. 3.4: Typical reinforcement details for the web of all specimens.....	62
Fig. 3.5: Typical reinforcement details for the flange (slab panel) of all specimens	62
Fig. 3.6: Shear connectors' distribution and pockets details for specimen B 2	63
Fig. 3.7: Shear connectors' distribution and pockets details for specimen B 3	63
Fig. 3.8: Shear connectors' distribution and pockets details for specimen B 4	64
Fig. 3.9: Shear connectors' distribution and pockets details for specimen B 5	64
Fig. 3.10: Reinforcement preparation	66
Fig. 3.11: Plywood forms	67
Fig. 3.12: Steel reinforcement placed in the plywood forms.....	67
Fig. 3.13: Casting concrete and compacting with electrical vibrator	68

List of figures

Fig. ٢.١٤: Steel reinforcement placed in the plywood forms of the slab panels- and installed steel pockets	٧٠
Fig. ٢.١٥: Casting concrete for the slab panels	٧٠
Fig. ٢.١٦: Casting concrete for the slab panels	٧١
Fig. ٢.١٧: Placing the slab panels over the R-section beams.....	٧٢
Fig. ٢.١٨: Pouring non-shrink grout in the pockets	٧٣
Fig. ٢.١٩: Epoxy past preparation.....	٧٤
Fig. ٢.٢٠: The standard ١٠٠(mm) x ١٠٠(mm) x ١٠٠(mm) cubes	٧٥
Fig. ٢.٢١: Details of the load cell	٧٩
Fig. ٢.٢٢: Location of LVDTs to measure vertical deflection	٨٠
Fig. ٢.٢٣: Location of LVDTs to measure relative slip between slab panel and beam's web	٨٠
Fig. ٢.٢٤: Typical locations of strain gauges of the longitudinal main steel reinforcement for beam specimens B ١ to B ٦	٨١
Fig. ٢.٢٥: Locations of strain gauges of shear connectors for beam specimen B ٢	٨١
Fig. ٢.٢٦: Locations of strain gauges of shear connectors for beam specimen B ٣	٨٢
Fig. ٢.٢٧: Locations of strain gauges of shear connectors for beam specimen B ٤	٨٢
Fig. ٢.٢٨: Locations of strain gauges of shear connectors for beam specimen B ٥	٨٢
Fig. ٢.٢٩: locations of strain gauges of corresponding stirrups for beam specimen B ١ and B ٦.....	٨٣
Fig. ٢.٣٠: Concrete strain gauges	٨٣
Fig. ٢.٣١: Test Set-Up.....	٨٤
Fig. ٢.٣٢: Distributing steel I-beam supported on two steel rods rested on neoprene plates	٨٥
Fig. ٢.٣٣: Pin Support	٨٥
 Fig. ٤. ١: Failure loads for all beam specimens.....	 ٨٩
Fig. ٤. ٢: Pockets cracking loads for specimens B ٢ to B ٥.....	٩٠
Fig. ٤. ٣: Interfacial surface separation load for specimens B ٢ to B ٦.....	٩٠
Fig. ٤. ٤: Vertical deflection at failure load for specimens B ١ to B ٦.....	٩١