

**DESIGN OF DOWELS FOR SHEAR TRANSFER AT THE
INTERFACE BETWEEN CONCRETE CAST AT
DIFFERENT TIMES: A CASE STUDY**

Samayamanthre Mudiyansele Premasiri Karunaratna

118614J



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Degree of Master of Engineering in Structural Engineering Design

Department of Civil Engineering


University of Moratuwa
Sri Lanka

December 2015

**DESIGN OF DOWELS FOR SHEAR TRANSFER AT THE
INTERFACE BETWEEN CONCRETE CAST AT
DIFFERENT TIMES: A CASE STUDY**

Samayamanthre Mudiyansele Premasiri Karunaratna

118614J

 University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
A Thesis submitted in partial fulfillment of the requirement for the degree of
www.lib.mrt.ac.lk
Master of Engineering in Structural Engineering Design

Department of Civil Engineering

University of Moratuwa
Sri Lanka

December 2015

DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

.....

Signature:



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

.....

Date

The above candidate has carried out research for the Masters of Engineering in Design Dissertation under my supervision.

.....

Signature of the supervisor

.....

Date

ABSTRACT

Enlargement of original cross-sections or replacement of defective concrete layers with new concrete are usual situations in strengthening operations of reinforced concrete structures. In these situations, the shear strength between concrete cast at different times is crucial for the monolithic behavior of the strengthened members. Most design standards for concrete structures present design procedure for estimating the shear resistance between concrete layers based on the shear friction theory.

The study includes three-dimensional and two-dimensional finite element model (FEM) analysis for calculation of shear stresses and comparison of three different code approaches, i.e. BS8110, ACI 318 and EN 1992, for determination of design shear resistance at an interface between concrete cast at different ages of a pile cap supported on precast concrete piles.

Based on the results of the analysis carried out, it can be stated that complicated three dimensional finite element model analysis is not always essential for analysis of structures, which are having complex geometrical shapes. It is possible to transform three-dimensional problems to a simplified two-dimensional problem based on the level of accuracy required.

For the selected surface characteristics and r/f percentage, the estimated design shear resistance based on recommendations of EN-1992-1-1-2004 was found be lower than the corresponding estimated value based on ACI 318M-11 recommendations. It was further observed that BS 8110-1-1997 recommendations gives the highest value for the design shear resistance independent of r/f percentage provided.

EN-1992-1-1-2004 can be used to compare contribution of concrete interface roughness and interface reinforcement on design shear resistance without any limitation of design shear stress as specified in ACI 318M-11. Furthermore, the EN-1992-1-1-2004 recommends a conservative value for design shear resistance compared to other two standards.

ACKNOWLEDGEMENT

First, I would like to give my heartfelt thanks to Prof. S.M.A.Nanayakkara for his advice, guidance, invaluable input, and excellent interaction throughout the duration of this study. In addition to that, his academic input, thought provoking comments and help throughout the duration of my M-Eng. studies corroborated to develop my professional career.

I would like to express sincere appreciation to Eng.Mr. H.Abayaruwan for his earnest efforts on collection of very important and useful literature for my study. I would also like to thank Dr. K.K.Wijesundara for his comments, and assistance throughout the duration of my Finite Element Analysis studies of this case study. Thanks also go to Eng.Mr. K.K.Nanayakkara for his dedicated time on furnishing necessary information belongs to my study to make the task successful.

I would like to express tremendous gratitude to my wife, Chalini for her constant support in my life and for providing me the opportunity to continue my education further. Even though my son was two years old, he was able to bring me happy and strength throughout the time I dedicated on this study, so I would like to give my thanks to my son.

I would also like to give my sincere thanks to my father in law and mother in law for their hard work and invaluable help towards my success. Thanks also go to my fellow students who were so helpful along the way.



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

TABLE OF CONTENTS

	Page
DECLARATION	i
LIST OF FIGURES	vii
LIST OF TABLES	viii
LIST OF ABBREVIATIONS	ix
CHAPTER 1 : INTRODUCTION	1
1.1. General	2
1.2. Background of the problem	2
1.3. Objective of the study	6
1.4. Scope of the study	6
1.5. Methodology	7
CHAPTER 2 : LITERATURE REVIEW	8
2.1. Factors affecting interface shear resistance	9
2.1.1. Effect of reinforcement crossing the interface	9
2.1.2. Effect of interface surface preparation	11
2.1.3. Compressive strength of existing and new concrete members	15
2.2. Design considerations	16
2.2.1. Accuracy of design code expressions	16
2.2.2. EN-1992-1-1-2004 [11] Approach for horizontal shear	18
2.2.3. ACI 318M-2011 [12] Approach for horizontal shear	21
2.2.4. BS 8110-1-1997 [13] Approach for horizontal shear	23
2.2.5. Other proposed equations	25
2.2.5.1. Linear shear friction equation	25
2.2.5.2. Mattock's and Hawkins's equations	26
2.2.5.3. Loov's Equation	26
2.2.5.4. Walraven's Equations	26
2.2.5.5. Randl's Equation	26

CHAPTER 3 : FINITE ELEMENT MODELING AND ANALYSIS	27
3.1 Analysis of the pile cap by simplified 2D-model	28
3.1.1 Model Geometry	28
3.1.2 Applied Loads	28
3.1.3 Finite Elements Used	30
3.1.4 Boundary conditions	30
3.1.5 Output Results	30
3.2 Analysis of the pile cap by 3d-model	32
3.2.1 Model Geometry	32
3.2.2 Finite Elements Used	33
3.2.3 Applied Loads	33
3.2.4 Boundary conditions	33
3.2.5 Output results	33
3.3 Comparison of FE model analysis results	34
CHAPTER 4 : DESIGN OF DOWELS FOR INTERFACE SHEAR	36
4.1 Design shear stress at the interface	37
4.1.1 EN-1992-1-1-2004 Approach	37
4.1.2 ACI 318M-2011 [12] Approach	39
4.1.3 BS 8110-1-1997 [13] Approach	40
4.2 Design shear resistance at the interface	41
4.2.1 EN-1992-1-1-2004 Approach	41
4.2.2 ACI 318M-11 Approach	49
4.2.3 BS 8110-1-1997 Approach	52
4.3 Comparison and recommendations given in EN-1992-1-2004, ACI 318M-2011 and BS 8110-1-1997	53
4.3.1 Design shear resistance	55
4.3.2 Minimum area of dowel bars	55

4.3.3	Maximum spacing of dowel bars	55
4.4	Recommendation for repairing the pile cap	56
CHAPTER 5 : CONCLUSIONS AND RECOMMENDATIONS		57
REFERENCES		59



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

LIST OF FIGURES

	Page
Figure 1: Layout of the piles and pile caps of Bridge B20A	3
Figure 2: Core sample locations	4
Figure 3: Defects in core samples A, B, & C	4
Figure 4: Defects in core samples D, F, G, H & J	5
Figure 5: Flow chart for methodology	7
Figure 6: The mechanisms of dowel action [2]	11
Figure 7: Load-slip curves of concrete shear transfer for various	14
Figure 8: Experimental /numerical versus analytical ratios “shear strength/normal stress,” according to different codes [3]	17
Figure 9: Determination of β	19
Figure 10: Horizontal shear force	23
Figure 11: Details of the existing pile cap	29
Figure 12: Model No: 2D-L	29
Figure 13: Model No: 2D-V	29
Figure 14: Shear force, Bending Moment variation along the	31
Figure 15: Shear force, Bending Moment variation along the	31
Figure 16: 3D Finite element solid model (Half of the pile cap)	32
Figure 17: Shear stress distribution over the depth of the pile cap	34
Figure 18: Shear stress distribution over the depth of the pile cap	34
Figure 19: Stress distribution of cracked concrete section	37
Figure 20: Details of reinforcement at the bottom of the existing pile-cap	43
Figure 21: Details of reinforcement at the top of the existing pile-cap	44
Figure 22: Details of reinforcement at sections, elevations of the existing pile-cap	45
Figure 23: r/f bars which considered in calculating design shear resistance	46

LIST OF TABLES

	Page
Table 1: c and μ factors for interfaces of concrete elements cast at different times	20
Table 2: Design ultimate horizontal shear stresses at interface [13]	25
Table 3: Characteristics of 2D-FE Models	30
Table 4: Characteristic of 3D-FE Model	33
Table 5: Shear force obtained from model analysis	35
Table 6: Design shear resistance, minimum area of r/f and dowel spacing at interface	54
Table 7: Contribution of concrete and reinforcement on design interface shear resistance	54



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

LIST OF ABBREVIATIONS

EN-1992-1-1-2004	ACI 318M-2011
V_{Edi} = Design value of shear stress	V_u = Factored shear force
V_{Rdi} = Design shear resistance	ϕ = Strength reduction factor
β = Ratio of the longitudinal forces	V_{nh} = Nominal horizontal shear strength
V_{Ed} = Design value of applied shear force	b_v = Width of the cross section
z = Lever arm of composite section	d = Distance from extreme compression fiber to centroid of longitudinal tension reinforcement
b_i = Width of the interface	A_{vf} = Area of shear friction reinforcement
c = Factor related to adhesion	f_y = Yield strength of reinforcement
μ = Coefficient of friction	μ = Coefficient of friction
ρ = Ratio (A_s/A_i)	f'_c = Specified compressive strength of concrete
f_{ctd} = Design value of concrete tensile strength	A_c = Area of concrete section resisting shear transfer
σ_n = Stress per unit area caused by external normal force	λ = Modification factor
f_{yd} = Design yield strength of reinforcement	s = Spacing of shear links
α = Angle	ρ_v = Ratio of tie reinforcement area to contact surface area
v = Strength reduction factor	f_{yt} = Yield strength of transverse reinforcement
f_{cd} = Design value of concrete compressive strength	b_w = Web width, wall thickness
f_{ctk} = Characteristic axial tensile strength of concrete	v_u = Design shear stress
γ_c = Partial factor for concrete	
A_s = Area of the reinforcement crossing the interface	
	BS 8110-1-1997
A_i = Area of the joint	V_h = Horizontal shear force
f_{ck} = Characteristic compressive cylinder strength of concrete at 28 days	C = Compressive force
α_{cc} = Coefficient	T = Tensile force
α_{ct} = Coefficient	v_h = Horizontal shear stress
b_w = Breadth of the web of the member	l = Length between points of maximum moment and zero moment
$\rho_{w.min}$ = Nominal shear reinforcement ratio	A = Cross sectional area of nominal links
A_{sw} = Area of nominal shear reinforcement	b_v = Width of the contact surface

$S_{l,max}$ = Maximum longitudinal spacing between links

$S_{t,max}$ = Maximum transverse spacing between links

f_{yk} = Characteristic yield strength of reinforcement

S_v = Spacing of shear links

h_f = Minimum thickness of the in-situ concrete

A_h = Total area of shear reinforcement

M = Bending Moment

b = Width of the section

d = Effective width of the tension reinforcement

f_{cu} = Characteristic cube strength of concrete

FEM = Finite Element Model

2D = Two Dimensional

3D = Three Dimensional

2D-L = Two Dimensional-Longitudinal

2D-T = Two Dimensional-Transverse

ULS = Ultimate Limit State

RC = Reinforced Concrete

SFD = Shear Force Diagram

BMD = Bending Moment Diagram



University of Moratuwa, Sri Lanka.

Electronic Theses & Dissertations

www.lib.mrt.ac.lk