

**Sirindhorn International Institute of Technology
Thammasat University**

Thesis CE-MS-2009-03

**STRENGTHENING LAP SPLICE IN SUB-STANDARD REINFORCED
CONCRETE COLUMN BY FRP WRAPPING**

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A Thesis Presented

by

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Master of Science
School of Civil Engineering and Technology
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Thammasat University

May 2010

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Submitted to

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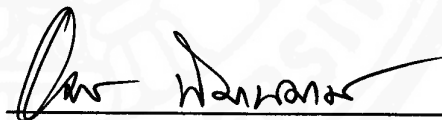
Thammasat University

In partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE IN ENGINEERING

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Dedication

This work is dedicated to my son “little Mốc”, my wife, and my family.

สำนักหอสมุด

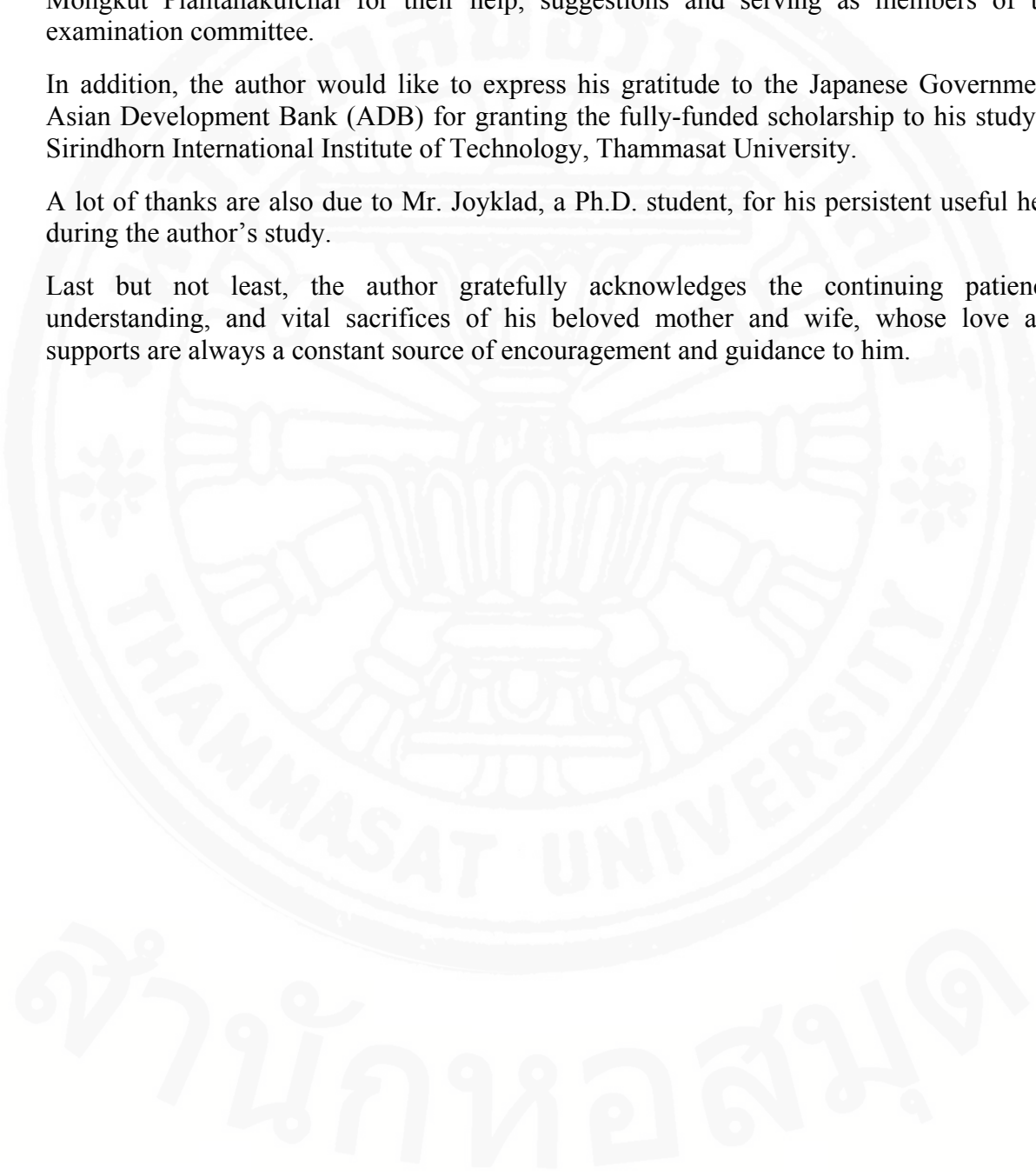
Acknowledgement

The author would like to express his appreciation of gratitude to his advisor, Dr. Amorn Pimanmas, for his enthusiastic guidance, valuable suggestions, constructive criticism, friendly discussion and persistent supervision, which are indispensable for completion of this thesis. The sincere appreciation is also due to Dr. Virote Boonyapinyo and Dr. Mongkut Piantanakulchai for their help, suggestions and serving as members of the examination committee.

In addition, the author would like to express his gratitude to the Japanese Government, Asian Development Bank (ADB) for granting the fully-funded scholarship to his study at Sirindhorn International Institute of Technology, Thammasat University.

A lot of thanks are also due to Mr. Joyklad, a Ph.D. student, for his persistent useful help during the author's study.

Last but not least, the author gratefully acknowledges the continuing patience, understanding, and vital sacrifices of his beloved mother and wife, whose love and supports are always a constant source of encouragement and guidance to him.



Abstract

The old reinforced concrete (RC) building structures (pre 1970s or sub-standard) were brittle and susceptible to collapse under seismic actions. They have been addressed as the main reason to cause death and casualty in natural catastrophes, especially during earthquakes. In these columns, lap splice, or the zone in which two reinforcing (steel) bars overlap to form a continuous line, was relatively short and less than that is required in modern earthquake design standard. This causes the failure of lap splice to occur before the yielding of reinforcing bar, and no apparent ductility in column's and structure's behavior, as a consequence. To strengthen the sub-standard column, there are some methods that applied the jacketing around the lap spliced zone, for example, steel-plate jacketing, ferrocement jacketing, and Fiber Reinforced Polymer (FRP) wrapping.

The application of FRP on confining the lap splice zone in sub-standard RC columns is the goal of this study. Firstly, the study proposed a tri-uniform bond stress distribution along starter bars at the critical state (lap splice failure state) since starter bar works in either elastic (pre-yield) or plastic (post-yield) range. Secondly, the parametric investigation was conducted to explore the effectiveness of FRP confinement on lap splice strength. Additionally, a dynamic analysis was also conducted to apply the proposed model on some existing experiments in order to verify the proposed tri-uniform bond stress model. Through this verification, a good agreement was found between the analytical and experimental results. Finally, an experiment was conducted to investigate the effectiveness of FRP confinement on improving the lap splice strength in reinforced concrete columns.

The experimental program consisted of 16 reinforced concrete beam specimens tested under static load. The beams were divided into 4 series with different lap splice lengths: $30d_b$, $25d_b$, $20d_b$, and $15d_b$ (where d_b is the bar diameter). It is found that the confinement by FRP significantly strengthens the lap splice zone and sub-standard RC column. The confined specimens show the great increase in strength and ductility in comparison to the unconfined ones. Especially by wrapping FRP, the short lap splice was protected from brittle pre-yield failure and the starter bar can finally reach yielding. Consequently, FRP confinement improves the lap splice strength from pre-yielding to post-yielding, and increase ductility from none to high ductility. The verification of the proposed tri-bond stress model was also good. The failure modes of specimens were predicted by the proposed tri-uniform bond stress distribution and verified in the experiment. The experimental results closely agree with the predicted ones. The slip measured in experiment also agreed well with the proposed ones. Strain values recorded by strain-gages along lap splice zone were laid around the predicted strain-distribution.

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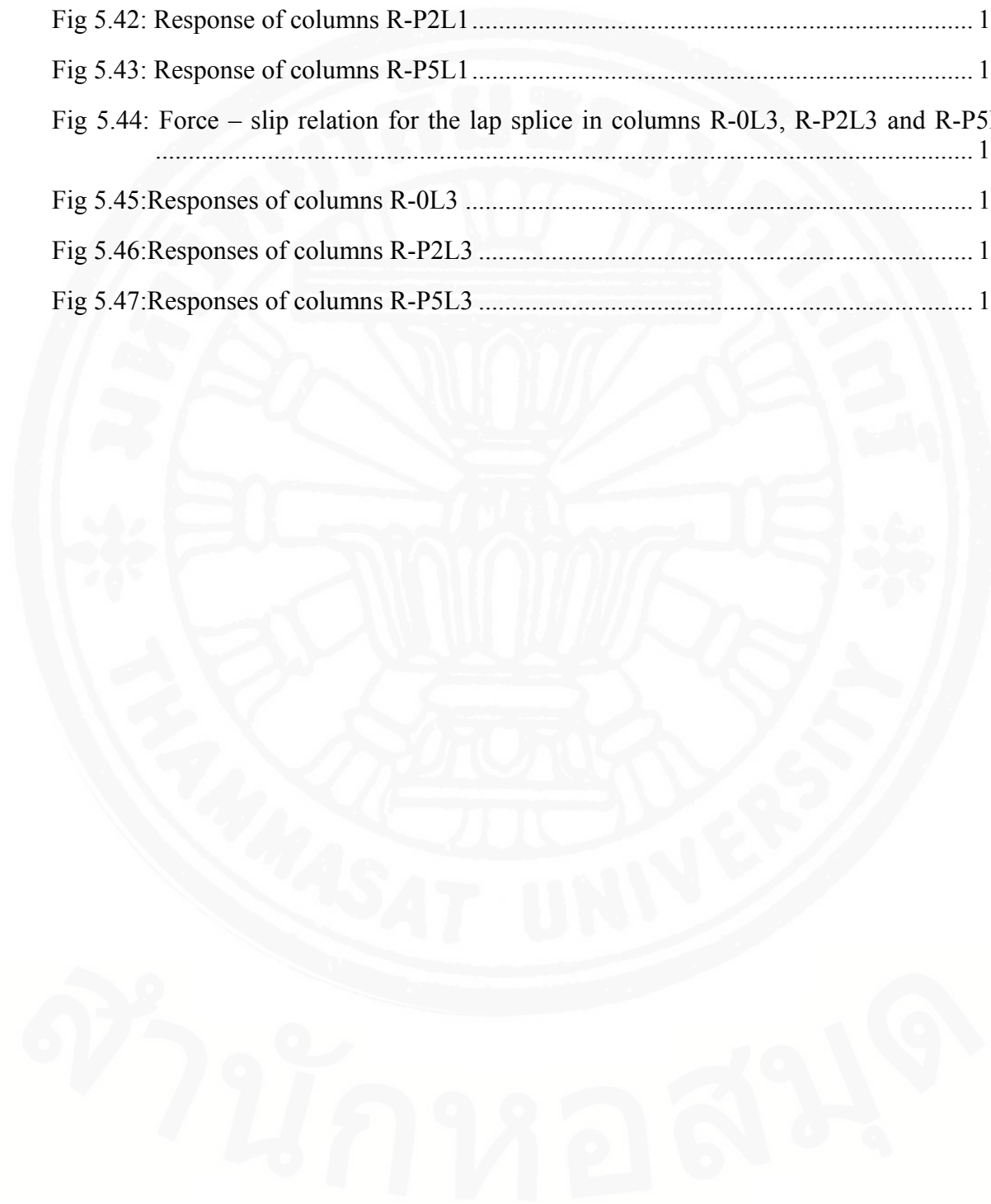
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(2.18).....	9	(3.22).....	32	(5.19).....	143
(2.19).....	9	(3.23).....	32	(5.20).....	143
(2.20).....	10	(3.24).....	33	(5.21).....	143
(2.21).....	10	(3.25).....	33	(5.22).....	143
(2.22).....	12	(3.26).....	33	(5.23).....	143
(2.23).....	12	(3.27).....	34	(5.24).....	143
(2.24).....	12	(4.1).....	59	(5.25).....	143
(2.25).....	13	(4.2).....	120	(5.26).....	144
(2.26).....	13	(4.3).....	120	(5.27).....	144
(3.1).....	25	(4.4).....	120	(5.28).....	144
(3.2).....	27	(4.5).....	120		
(3.3).....	27	(4.6).....	121		
(3.4).....	27	(5.1).....	139		

Nomenclature

A_{fap}	Area of transverse FRP reinforcement	K	confined strength ratio
A_{fa}	Area of longitudinal FRP reinforcement	k_1	Confinement effectiveness coefficient
A_g	Gross area of section	k_e, k_v	Confinement effectiveness parameters
A_{cc}	Area of concrete core	n_f	Number of transverse FRP layers
A_e	Area of effectively confined concrete	N_f	Number of equally spaced discrete bands
A_s	Area of column longitudinal reinforcement	P	Applied axial load
A_{st}	Area of column transverse reinforcement	r	Corner radius
b	Section width	s'	Clear spacing between transverse hoops or spirals
b_f	Width of discrete bands of FRP	t_f	Thickness of one FRP layer
c	Minimum concrete cover	w	Clear distance between adjacent longitudinal bars
D	Diameter of circular section	w_{xi}, w_{yi}	The i^{th} clear distance between adjacent longitudinal bars along the horizontal x and y dimensions respectively
d	effective depth of column section	x, y	Concrete core dimensions to center line of peripheral hoop
d_s	Diameter of spiral or hoop	ε_c	Concrete strain
d_b	Diameter of reinforced bar	ε_{cc}	Concrete strain for confined concrete
E_c	Modulus of elasticity of concrete	ε_{co}	Concrete strain at the intersection point between the 1st and 2nd stage of the stress-strain curve
E_f	Modulus of elasticity of transverse FRP	ε_{cu}	Limiting concrete strain
E_{fa}	Modulus of elasticity of longitudinal FRP	ε_{fu}	Fracture strain of the FRP
E_{lf}	Lateral modulus of elasticity of FRP	ε_l	Lateral concrete strain
E_{ls}	Lateral modulus of elasticity of steel	ε_{lo}	Lateral concrete strain at intersection point between the 1 st and 2 nd stage of the stress strain curve
E_s	Modulus of elasticity of steel	ε_o	Strain at maximum stress for unconfined concrete
f_c	Concrete stress	ε_{yt}	Yield strain of transverse hoops
f'_c	Compressive strength of unconfined concrete	ρ_{cc}	Steel ratio relative to the concrete core section
f_{cc}	Stress in confined concrete	ρ_f	Volumetric ratio of FRP reinforcement
f'_{cc}	Compression strength of confined concrete	ρ_s	Ratio of column longitudinal reinforcement
f_{co}	Stress at the intersection point between the 1 st and 2 nd stage of the stress-strain curve	ρ_{st}	Volumetric ratio of hoop reinforcement
f_{cu}	Stress corresponding to a limiting strain ε_{cu}	L	Height of column
f_l	Effective lateral confining pressure	L_p	Length of plastic hinge zone
f'_l	Hydrostatic confining pressure	L_s	Length of lapslice
f_s	Steel stress	a	Shear span of column
f_y	Yield stress of longitudinal column reinforcement	V_s	Shear strength of column
f_{yt}	Yield stress of transverse steel ties or hoops	V_r	Residual shear strength of column
h	Section depth		