

**POST TENSIONING EFFECT IN COLUMN TO BEAMS BY BOLTS OF
INDUSTRIALIZED BUILDING SYSTEM (IBS) FOR SCHOOL BUILDINGS**

HEWA QADER MUSTAFA

UNIVERSITI TEKNOLOGI MALAYSIA

POST TENSIONING EFFECT IN COLUMN TO BEAMS BY BOLTS OF
INDUSTRIALIZED BUILDING SYSTEM (IBS) FOR SCHOOL BUILDINGS

HEWA QADER MUSTAFA

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Civil-Structure)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JUNE 2014

*Dedicated to my beloved mother,
wife and Children,
All my family members,
My course-mates and friends.*

..Thank you for every thing..

*Special thanks to my supervisor,
And every one who had involved
in this study.*

.. May God bless all of you...

Thank you

ACKNOWLEDGEMENT

Upon the completion of this master thesis, firstly, I would like to greatly thank ALLAH for allow use and providing me with patience and determination to finish this study. Secondly, I would like to express from deeps of my heart all the appreciation to my beloved supervisor, Associate Professor Dr. Abdul Kadir Bin Marsono for his continuous guidance, help, support, and encouragement throughout the work of my thesis. He supported me in every possible way to fulfill my research objectives and complete my study. Without his help it was going to be hard to achieve my objectives and complete my study in due time.

At the end I would like express appreciation to my beloved wife (Samar) and children (Salar, Sahand, and Abdullah) who spent sleepless nights with and was always my support in the moments when there was no one to answer my queries, and never give up in giving me encouragement and enthusiasm to finish my project.

ABSTRACT

Industrialized building system (IBS) is a construction term of Products, elements, or building system. In addition to capacity and behaviour of post tension system by bolts for the column to beam connection under cyclic lateral loads. A six cycle of a push over tests was carry out on a scaled model of 1:5 two-story one-bay specimen frame, four post-tensioned (PT) precast columns and two precast concrete beams components are fabricated. The main objectives of this study were to study the lateral strength of IBS assembled by using a post tensioned bars. It also examine the mechanism failure of the IBS post tension structures at various performance levels along the regime of lateral loads. The results of experimental work, at every cycle of loading are recorded the sway of IBS frame and found cracks or crushing of IBS components. The test was extended to the level of robustness of the system. During investigation, it was found that the maximum sway under cyclic lateral loading must align with the lateral stability and ductility. On the other hand the connection behavior indicated from the experimental give a merits to the post-tensioned IBS system under cyclic lateral loads. It capable to produce a more useful energy dissipation mechanism without the excess of residual displacements.

ABSTRAK

Sistem Bangunan Industri (IBS) adalah satu istilah pembinaan berdasarkan produk, pada sistem bangunan. Keupayaan dan kelakuan kejuruteraan sistem pasca tegangan di jangka meningkat dengan adanya sambungan bolt antara rasuk dan tiang pada beban sisi berulang. Enam siri tujahan berulang telah dijalankan ke atas model satu tingkat kerangka bangunan berskala 1:5. Empat tiang pratuang pasca tegangan dan dua rasuk konkrit pratuang telah bina di makmal. Objektif utama kajian ini adalah untuk mengkaji kekuatan sisi IBS dipasang dengan menggunakan bar pasca tegangan. Ia juga mengkaji mekanisma gagal pada struktur IBS pasca ketegangan pada berbagai tahap sesaran beban sisi. Keputusan ujikaji mendapati tujahan pada rangka IBS menyebabkan retak dan penghancuran pada komponen ekstrem. Ujian pada had muktamad ini juga telah dilanjutkan ke tahap ujian kemantapan sistem. Hasil ujian mendapati bahawa sesaran maksimum pada beban sisi harus selaras dengan kestabilan sisi dan kemuluran sambungan. Mekanisma gagal struktur ujian IBS menunjukkan bahawa sistem baru ini mampu menghasilkan mekanisma pelepasan tenaga tanpa sesaran yang berlebihan dan memberi kebaikan kepada sistem bangunan IBS yang baru ini.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xi
	LIST OF FIGURES	xii
	LIST OF ABBREVIATIONS	xviii
	LIST OF APPENDICES	xx
1	INTRODUCTION	1
	1.1 Background	1
	1.1.1 Reinforced Concrete Frame Structures	1
	1.1.2 Precast Concrete Structures	2
	1.1.3 Industrialized Building System (IBS)	3
	1.1.4 Post-Tensioning in Construction	4
	1.2 Problem Statement	4
	1.3 Objectives	6
	1.4 Case Study	7
2	LITERATURE REVIEW	8
	2.1 Definition of IBS	8

2.2	Backgrounds of Precast Concrete Structures	11
2.3	Researches Classification of IBS System	14
2.4	Advantages of Industrialized Building System (IBS)	17
2.5	Disadvantages of Industrialized Building System	18
2.6	CIDB Classification of IBS System	20
2.7	Post Tensioning System in Precast Concrete Structures	22
2.8	Benefits of Post-Tensioning	25
2.9	Precast Building Piers System	25
2.10	Typical column-to Beam Connections	28
2.11	Hybrid System	29
2.12	Column-to-Cap-Beam Connections	33
2.13	Segmental Precast Post-tensioned IBS Columns	34
2.13.1	Behavior of Precast Column Mechanical Under Cyclic Loading and Monolithic Loading	36
2.13.2	Self-Centering System for columns	40
2.14	Pseudo-Dynamic Testing Method	42
2.15	Push Over Analysis	44
2.16	Ductility in Precast Concrete Structures	46
2.17	Anchor Tools in Precast Building Construction	48
2.17.1	Bolted Connections	49
2.17.2	Welded Connections	50
2.17.3	Dowel/Anchor Bolt Connections	51
2.18	Robustness in Precast Concrete Structures	51
2.19	Summary of Literature Review	43
3	RESEARCH METHODOLOGY	54
3.1	Introduction	54
3.2	Laboratory Work	56
3.2.1	Specimen Design	56
3.2.2	Preparation of the Specimen	57
3.2.3	Steel Reinforcement	59
3.2.3.1	Beam Reinforcement	60

3.2.3.2	Column and Stump Reinforcement	61
3.2.4	Strain Gauges	62
3.2.5	Casting Process for the IBS Components	64
3.2.5.1	Arranging and Checking the Moulds Before Casting	64
3.2.5.2	Preparing Concrete Materials for Casting	65
3.2.5.3	Casting IBS Components	66
3.2.6	Curing Process of IBS Components	67
3.2.7	Painting of IBS Components	69
3.2.8	Compressive Strength Test Of Cylindrical Samples	70
3.2.9	Splitting Tensile Strength	71
3.2.10	Modulus of Elasticity (E-Value Test)	72
3.2.11	Assembling the Components for IBS Frames Test	73
3.2.12	Pseudo Dynamic Push Over Test	77
3.2.12.1	Materials and Instruments Used in the Test	77
3.2.12.2	Test Procedure	80
4	RESULT AND DISCUSSION	82
4.1	Introduction	82
4.2	Compressive Strength	83
4.3	Splitting Strength	84
4.4	E -value	86
4.5	Experimental Scheme for IBS Frame	87
4.5.1	Load -Displacement Relationship of LVDT Equipment	88
4.5.2	Load -Displacement Relationship by Using Laser Instruments	91
4.5.3	Rotation of Columns of Inclinometer and Demec Points.	94
4.5.4	Stress-Strain Relationship of Steel Reinforcement in Beams and Columns	97
4.6	Mechanism of Failure in IBS System	103
4.6.1	Cracking in IBS Frame	104

4.6.2	Crushing in IBS System	109
4.6.3	The Mode of Failure for IBS Frame	113
4.7	Summary of Discussions and Results	115
5	CONCLUSION	116
	REFERENCES	119
	Appendices A-E	124

LIST OF TABLES

TABLE NO	TITLE	PAGE
2.1	List of definitions of IBS	10
2.2	Comparison of industrialized construction classification	15
2.3	IBS classification	20
2.4	Classification of building system according to relative weight of Component	21
3.1	Applied load during the cyclic test	81
4.1	Values of compressive strength of concrete	83
4.2	Load failure of Splitting strength test of concrete	85
4.3	Column rotation angle due to demec points	95
4.4	Column rotation angle under cyclic loading	96

LIST OF FIGURES

FIGURE NO	TITLE	PAGE
2.1	Brickfields Secondary School (I), Kuala Lumpur During construction	14
2.2	Brickfields Secondary School (I), Kuala Lumpur after construction	14
2.3	Post tensioning system by bolts	23
2.4	Types of PT rotational column: (a) PT segmental column, (b) PT segmental column with yield devices, (c) PT rocking column, and (d) PT rocking column with yield devices	24
2.5	Elevation of Reinforced Concrete System column	26
2.6	Expected Behavior of Connection in Reinforced Concrete Frames	27
2.7	Three-dimensional reinforced concrete slotted beam super assembly and origin (Prototype structure)	28
2.8	Three-dimensional reinforced concrete slotted beam super assembly and origin (Superassembly SA1 extracted from prototype)	29
2.9	Hybrid System concepts	30
2.10	Elevation of Hybrid System Column	31

2.11	Expected Behavior of the Connection in Hybrid Frames	32
2.12	Unbonded PT concrete segmental columns under lateral load	36
2.13	Typical load deflection between the behavior of (a) bonded steel and (b) unbonded post tensioned steel systems	37
2.14	The structure under Cyclic Loading	40
2.15	The structure under Monolithic loading	40
2.16	Structure of self-centering connection of IBS Columns	41
2.17	Pseudo-dynamic test	42
2.18	Pseudo-dynamic testing method	43
2.19	Connecting test machine with computer	44
2.20	Push over curve	46
2.21	Hybrid or controlled rocking system	48
2.22	Anchor Bolt system	50
2.23	Structural response behavior	53
3.1	Methodology process	55
3.2	Column moulding	56
3.3	Beam moulding	57
3.4	Column and stump mould before and after painting	58
3.5	Beam mould before and after painting	59

3.6	Beam reinforcement	60
3.7	Column reinforcement	61
3.8	Strain gauge fixed with steel bars	63
3.9	Strain gauge fixed with concrete	63
3.10	Preparing moulds for casting	64
3.11	Concrete materials	65
3.12	The concrete mixing	66
3.13	Casting batch of IBS with two cylinder samples	66
3.14	Second batch of casting by small mixer	67
3.15	Casting second batch of IBS with two cylinder samples	67
3.16	Curing process of IBS components	68
3.17	Cylinders inside water basin	69
3.18	Painting IBS components	69
3.19	Compressive strength test	70
3.20	Splitting test	72
3.21	E-Value test	73
3.22	Assembly of IBS Components	74
3.23	Setup of Footings and Stumps	75
3.24	Setup of footings, Stumps ,Bottom beam and columns	75
3.25	Assembling IBS components and necessary accessories on steel rig for lateral cyclic test	76

3.26	Materials and equipment used in pseudo dynamic test	78
3.27	Lasers and demec points	79
3.28	Manual hydraulic jacks and load cell	79
3.29	Data logger and PC for data solution	80
4.1	Failure of cylinder sample under compression test	83
4.2	Failure of cylinder sample under splitting test	84
4.3	Stress -strain relationship for concrete under uniaxial compression	87
4.4	Load-Displacement of LVDT No.1	89
4.5	Load-displacement of LVDT No.2	90
4.6	Load- Displacement of LVDT No.3	90
4.7	Direction of laser tool instruments	91
4.8	Load- displacement relationships at the top of IBS frame	92
4.9	Load- displacement relationships at the bottom of IBS frame	93
4.10	Arrangement of demec points and Inclinator around the frame	94
4.11	Rotation curve of column in IBS frame by Demec data	96
4.12	Rotation curve of column in IBS frame by Inclinator data	97
4.13	Strain gauges for steel bars in the IBS frame	98

4.14	Tensile strength test for 6mm dia. steel bars	99
4.15	Stress-Strain relationships for steel bar at the bottom of column (SG1)	100
4.16	Stress-Strain relationships for steel bar at the top of column (SG2)	100
4.17	Stress-Strain relationships for steel bar at the top of Stump (SG3)	101
4.18	Stress-Strain relationship for steel bar at the outer edge in top of the beam (SG4)	101
4.19	Stress-Strain relationships for steel bar at the outer edge in the bottom of the beam (SG5)	102
4.20	Stress-Strain relationships for steel bar in the mid span of the beam (SG6)	102
4.21	Cracking at the connection part during the second cycle	105
4.22	Cracking at the column and connection at third cycle of loading	106
4.23	Cracking at the column and beam at fourth cycle of loading	107
4.24	Cracking at the column and connection part in fifth cycles	108
4.25	Cracking all parts of the IBS column during the last cycle	109
4.26	Crushing at the bottom of column under applying 11kN load	110
4.27	Crushing in the connections in the middle of the column under 12 kN load	111
4.28	Spalling after crushing at right side in connection	

	joint between beams to column under failure cycle	111
4.29	Crushing at left side in connection joint between beams to column under failure cycle	112
4.30	Crushing at bottom of connection joint between beams to column under failure cycle	112
4.31	Crushing at the top of column under failure cycle	113
4.32	Failure mode of IBS frame	114
4.33	Rotation and movement of of column	114

LIST OF ABBREVIATIONS

ATC	-	Applied Technology Council
BS	-	British Standard
CIDB	-	Construction Industry Development Board
D.O.F	-	Degree of Freedom
Demec	-	Demountable mechanical gauge
E	-	Elastic modulus
EC2	-	European Code 2
FEM	-	Finite Element Method
GPa	-	Gega Pascal
IBS	-	Industrialized Building System
JKR	-	Jabatan Kerja Raya
kN	-	Kilo Newton
LVDT	-	Linear Variable Displacement Transducer
MMC	-	Modern Method Construction
MPa	-	Mega Pascal
NSP	-	Nonlinear Static Procedure
OSM	-	Off-Site Manufacturing
PDT	-	Pseudo Dynamic Test
PT	-	Post Tension
PVC	-	Polyvinyl Chloride
RC	-	Reinforced Concrete
SG	-	Strain Gauge
SLS	-	Serviceability Limit State
UBPT	-	Un Bonded Post-Tensioning

- ULS - Ultimate Limit State
- UTM - Universiti Teknologi Malaysia

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	E-Value test data	124
B	LVDT data	125
C	Laser instrument data	128
D	Strain gauge data for steel reinforcement bars	129
E	Technical Paper	133

CHAPTER 1

INTRODUCTION

1.1 Background

Maintaining life safety in engineering design is the primary concern to structures. After a structure can maintain life safety, the next goal is to reduce the amount of damage in the structure following large lateral deformations. Reducing the amount of damage to the structure will allow for rapid repairs and a reduction of closure time. Damage may be in the form of spalling concrete, buckling or fracture of column longitudinal reinforcement, and permanent lateral displacement.

1.1.1 Reinforced Concrete Frame Structures

Reinforced concrete (RC) frames consist of horizontal elements (beams) and vertical elements (columns) connected from the ranges of convent ally rigid to pinned joints. These structures are cast monolithically with; beams and columns are

cast in a single operation to obtain unison act under loading. RC frames provide resistance to both gravity and lateral loads through bending in beams and columns.

Reinforced concrete is a combination of concrete, which is strong and relatively durable in compression with reinforcing and steel, which is strong and ductile in tension. In order to maintain the composite action, load transfer between the concrete and steel is essential. It is basically influenced by the bond, which is idealized as continuous stress field that develops in the vicinity of the steel reinforcing concrete interface.

1.1.2 Precast Concrete Structures

The concept of precast (also known as “prefabricated”) construction includes those buildings where the majority of structural components is standardized and produced in plants in a location away from the building, and then transported to the site for assembly. These components are manufactured by industrial methods based on mass production in order to build a large quantity of buildings in a short time at acceptable cost. The main features of this construction process are as follows:

- The Classification and specialization of the human workforce.
- The use of tools, machinery, and other equipment, usually automated, in the production of standard and interchangeable parts and products.

1.1.3 Industrialized Building System IBS

Industrialized building has been defined as the term given to building technology in which modern systematic methods of design, production planning and control as well as mechanized and automated manufacture are applied. Also The Industrialized Building Systems (IBS) which all building components such as the wall, slab, beam, column and staircase are mass-produced either in the factory or on the factory site under strict quality control and minimal wet site activities. The industrialized building system (IBS) can be generally interpreted as in which all building components are mass produced either in a factory or at site factory according to specifications with standardized shapes and dimensions, and transported to the construction project site to be rearranged with certain standard to form a building. Industrialization has demonstrated a high capacity to reduce the costs, improve the quality and get complex products available to the vast majority of people. It is the case for most products offered on the market today, including construction materials and components (roof trusses, prestressed concrete slabs, windows, curtain walls, etc.).

The development of an industrialized building system (IBS) is not new in the construction industry. The history of precast in UK housing dates from the middle 1900's, when this and other forms of industrialized (prefabricated) construction were used to address the problem of widespread destruction of housing stock during the Second World War.

Today, many private companies in Malaysia have teamed up with foreign experts from Australia, Netherlands, United States and Japan to offer precast solutions to their projects. Numerous construction projects have utilized the precast components, especially to meet the requirement of time constraint and with high accuracy and quality. The precast components are mainly used in the construction of schools, colleges, quarters, apartments, hospitals, roads, port and other infrastructures.

The advantages of using Industrialized Building Systems (IBS) are:-

- a) Reduction of unskilled workers
- b) Reduce wastage
- c) Increase in quality
- d) Safer working environment in a construction site
- e) Reduce construction period

1.1.4 Post-Tensioning in Construction

During the construction, the post tensioning which has been widely used in building superstructures, but has seen only limited applications in building substructures. There are many possible situations where post-tensioning can be used in building substructures to provide structural and economical benefits such as control of deflections, increased stiffness, improved crack control (higher cracking moment, fewer cracks smaller crack widths), reduced reinforcement congestion, continuity of reinforcement, efficient utilization of high strength steel and concrete, quick, efficient joining of precast elements, continuity between existing components and additions.

1.2 Problem Statement

Although IBS in one side have good quality for saving time in constructing buildings especially for tall buildings or normal buildings such as (schools , hospitals and industrial buildings) which is save more time during the period of construction of Projects. The effect of the post tensioned beam of columns is due to the demand

for shorter construction periods and the desire for innovative designs that yield safe, economical and efficient structures. However, there is a lack of knowledge of the behavior and performance of precast segmental columns during earthquakes, and consequently their widespread use in seismic regions is yet to be realized. Also, only limited research has previously been carried out on the seismic response of precast concrete segmental IBS columns, the behavior of a precast segmental column under seismic loading differs fundamentally from that of a conventional reinforced concrete column.

The failure of a structure can occur from many types of situation. Most of these problems are unique to the type of structure or to the various industries. However, most can be traced to one of five main causes.

The first cause is, whether due to size, shape, or the choice of material, is that the structure is not strong and tough enough to support the load. If the structure or component is not strong enough, catastrophic failure can occur when the overstressed construction reaches a critical stress level. All of these individual variations of components that have been prefabricated in the factory need to be transported to construction site for final stage of erection. The connection and joint of the separated components have become the major problem during the construction as the speed and integrity of the structure is directly affected by the design and fabrication of the connection

The second causes are instability, whether due to geometry, design or material choice, causing the structure to fail from fatigue or corrosion. These types of failure often occur at stress points, such as squared corners or from bolt holes being too close to the material's edge, causing cracks to slowly form and then progress through cyclic loading. Failure general occurs when the cracks reach a critical length, causing breakage to happen suddenly under normal loading conditions.

The third types of failure are caused by manufacturing errors. This may be due to improper selection of materials, incorrect sizing, improper heat treating, failing to adhere to the design, or shoddy workmanship. These types of failure can occur at any time, and are usually unpredictable.

The fourth cause is due to the use of defective materials. The material may have been improperly manufactured, or may have been damaged from prior use.

The fifth cause of failure is from lack of consideration of unexpected problems. Vandalism, sabotage, and natural disasters can all overstress a structure to the point of failure. Improper training of those who use and maintain the construction can also overstress it, leading to potential failures

1.3 Objectives

In this study the main objectives of effect of post tension in IBS Columns are summarized in two points:

- To experiment in discovering the failure mechanism of columns in IBS post tension structures to enhance the performance of the system.
- To study the effect of column post-tensioned cycle on ductility of structure due to lateral cyclic loads.

1.4 Case Study

The study aim is to develop precast segmental post tensioned concrete columns for moderate seismic regions. This study will give a clear understanding of the behavior and failure mechanisms of the new type of post tensioned precast concrete connection. The behavior of the connection includes load-displacement relationship, moment-rotation relationship and steel reinforcement stress-strain relationship. The proposed beam-to-column connection should withstand the lateral load in order to get the stability, strength and ductility of the frame. The result of this test will be beneficial in the development of unbounded post tensioned for building constructions. It enables frame to resist from lateral load in other words, to gain stability, and increase the rate of construction significantly. The scaled model test also saves the time and cost of the investigation.

REFERENCES

- Abdala, A. A., Dewi, S. M., and Zacoeb, A. Experimental Study of Precast Walls with Variation Type of Opening Due to Vertical and Lateral Static Load.
- Akkar, S., Sucuoğlu, H., and Yakut, A. (2005). Displacement-Based Fragility Functions for Low-and Mid-Rise Ordinary Concrete Buildings. *Earthquake Spectra*, 21(4), 901-927.
- Badir, Y. F., Kadir, M. A. and Hashim, A. H. (2002). Industrialized Building Systems Construction in Malaysia. *Journal of Architectural Engineering*, 8(1), 19-23.
- Bari, N. A. A., Abdullah, N. A., Yusuff, R., Ismail, N., and Jaapar, A. (2012). Environmental Awareness and Benefits of Industrialized Building Systems (IBS). *Procedia-Social and Behavioral Sciences*, 50, 392-404.
- Bergsten, S. (2005). Industrialised Building Systems: Vertical Extension of Existing Buildings by Use of Light Gauge Steel Framing Systems and 4D CAD Tools.
- Bing, L., Kwong, Y. W. and Hao, K. J. (2001). Seismic Behaviour of Connection Between Precast Concrete Beams. *CSE Research Bulletin*, (14).
- BS 8110-1:1985. Structural Use of Concrete Code of Practice for Design and Construction
- Çalışkan, Özlem, et al. (2013). Shear Strength of Epoxy Anchors Embedded into Low Strength Concrete. *Construction and Building Materials*. 38:723-730.
- Chopra, A. K., and Goel, R. K. (2002). A Modal Pushover Analysis Procedure for Estimating Seismic Demands for Buildings. *Earthquake Engineering and Structural Dynamics*, 31(3), 561-582.
- Chou, C. C., Chang, H. J., and Hewes, J. T. (2013). Two-Plastic-Hinge and Two Dimensional Finite Element Models for post-Tensioned Precast Concrete Segmental Bridge Columns. *Engineering Structures*, 46, 205-217.

- Daly, A. F., and Witarnawan, I. W. (2000). A Method for Increasing the Capacity of Short and Medium Span Bridges. In *10th REAAA (Road Engineering Association of Asia and Australasia) Conference* (pp. 4-9).
- Dawood, H. M. M. M. (2010). *Seismic Behavior and Design of Segmental Precast Post-Tensioned*. Doctoral Dissertation, Washington State University.
- Gioncu, V, & Mazzolani, F. M. (2002). Ductility of Seismic Resistant Engineering Structures.
- Guerra, L. P. Design, Modeling and Experimental Testing of a Seismic Resistant Bridge Column with Post-Tensioned Connection.
- Guo, J., Xin, K. G., Wu, W. P. and He, M. H. (2012). A Simplified Model and Experimental Response of Self-Centring Bridge Piers with Ductile Connections. *Advanced Materials Research*, 446, 1036-1041.
- Hamid, Z., Kamar, K. A. M., Zain, M., Ghani, K. and Rahim, A. H. A. (2008). Industrialized Building System (IBS) in Malaysia: The Current State and R&D Initiatives. *Malaysian Construction Research Journal (MCRJ)*, 2(1), 1-11.
- Hewes, J. T., & Priestley, M. N. (2002). Seismic Design and Performance of Precast Concrete Segmental Bridge Columns (No. SSRP-2001/25).
- Hieber, D. G., Wacker, J. M., Eberhard, M. O. and Stanton, J. F. (2005). *Precast Concrete Pier Systems for Rapid Construction of Bridges in Seismic Regions (No. WA-RD 611.1)*. Washington State Department of Transportation.
- Wang, Z., Song, W., Wang, Y. and Wei, H. (2011). Numerical Analytical Model for Seismic Behavior of Prestressing Concrete Bridge Column Systems. *Procedia Engineering*, 14, 2333-2340.
- Jaya, R. V. K. (2012). Behaviour of Precast Beam-Column Mechanical Connections Under Cyclic Loading. *Asian Journal of Civil Engineering (Building and Housing)*, 13(2), 233-245.
- Kamar, Kamarul Anuar Mohd, et al. (2011). Industrialized Building System (IBS): Revisiting Issues of Definition and Classification. *International Journal of Emerging Sciences* 1.2 (2011): 120.
- Kassim, U. and Walid, L. (2013). Awareness of the Industrialized Building System (IBS) Implementation in Northern Malaysia-A Case Study in Perlis. *Procedia Engineering*, 53, 58-63.

- Kim, T. H., Lee, H. M., Kim, Y. J. and Shin, H. M. (2010). Performance Assessment of Precast Concrete Segmental Bridge Columns with a Shear Resistant Connecting Structure. *Engineering Structures*, 32(5), 1292-1303.
- Lee, W. K. and Billington, S. L. (2007). Simulation And Performance-Based Earthquake Engineering Assessment of Self-Centering Post-Tensioned Concrete Bridge Systems. Vol. 68, No. 06.
- Leet K, and Bernal D (1997). *Reinforced Concrete Design*. International Ed., McGraw-Hill, Singapore.
- Ling, J. H. (2007). *Improving the Performance of Precast Concrete Beam-To-Beam Connection with Inadequate Lap Length* Doctoral Dissertation, Universiti Teknologi Malaysia.
- Marsono, A. K., Ng, S. C., and Makhtar, A. M. (2006). Simulation of Industrialised Building System Components Production.
- MCEER, University at Buffalo, State University of New York, (2009). Proceedings of the Special International Workshop on Seismic Connection Details for Segmental Bridge Construction Held in Seattle, Washington, July 22-14, 2009.
- Micro-Measurements, V. (2007). *Strain Gage Installations for Concrete Structures*. Application Note TT, 611.
- Muir, C. A., Pampanin, S. and Bull, D. K. (2012). Background, Design and Construction of a Two-Storey, Two-By-One Bay, Reinforced Concrete Slotted Beam Superassembly.
- Murtiadi, S. (2013). Hybrid Precast Concrete Column and Sandwich Concrete Beam under Static Loading. *Procedia Engineering*, 54, 286-298.
- Mwafy, A. M. and Elnashai, A. S. (2001). Static Pushover Versus Dynamic Collapse Analysis of RC Buildings. *Engineering Structures*, 23(5), 407-424.
- National Precast Concrete Association (NPCA) (2013). *Precast Concrete Architectural Repair Guide*. Blacksburg. Virginia Tech University Hurst Basketball Facility.
- Oğuz, S. (2005). *Evaluation of Pushover Analysis Procedures for Frame Structures* Doctoral dissertation, Middle East Technical University.
- Palermo, A. and Pampanin, S. (2005). Application of Hybrid Concept for an Improved Seismic Ductile Design of Bridges

- Pampanin, Stefano, MJ Nigel Priestley, and S. Sritharan. Analytical Modelling of the Seismic Behaviour of Precast Concrete Frames Designed with Ductile Connections." *Journal of Earthquake Engineering* 5.03 (2001): 329-367.
- Pampanin, S. (2005). Emerging solutions for high seismic performance of precast/prestressed concrete buildings. *Journal of Advanced Concrete Technology*, 3(2), 207-223.
- Pegon, P. (2008). *Continuous PsD Testing with Substructuring*. In *Modern Testing Techniques for Structural Systems*. Springer Vienna. 197-257.
- Rahman, A. Baharuddin, A. and Omar, W. (2006). Issues and Challenges in the Implementation of Industrialised Building Systems in Malaysia.
- Reinhorn, A. and Shao, X. (2004). Advanced dynamic testing techniques in structural engineering. CIE616, Department of Civil, Structural and Environmental Engineering, University of Buffalo.
- Richard, R. B. (2007). A Generic Classification of Industrialized Building Systems. *Open Building Manufacturing: Core Concepts and Industrial Requirements*, 35-48.
- Roh, H. and Reinhorn, A. M. (2010). Hysteretic Behavior of Precast Segmental Bridge Piers with Superelastic Shape Memory Alloy Bars. *Engineering Structures*, 32(10), 3394-3403.
- Roh, H. and Reinhorn, A. M. (2010). Hysteretic Behavior of Precast Segmental Bridge Piers with Superelastic Shape Memory Alloy Bars. *Engineering Structures*, 32(10), 3394-3403.
- Sharma, A., Reddy, G. R., Vaze, K. K., & Eligehausen, R. (2013). Pushover Experiment and Analysis of a Full Scale Non-Seismically Detailed RC Structure. *Engineering Structures*, 46, 218-233.
- Shim, C. S., Chung, C. H., & Kim, H. H. (2008). Experimental Evaluation of Seismic Performance of Precast Segmental Bridge Piers with a Circular Solid Section. *Engineering Structures*, 30(12), 3782-3792.
- Simanjuntak, J. H. (1998). U.S. Patent No. 5,809,712. Washington, DC: U.S. Patent and Trademark Office.
- Starossek, U. (2006). Progressive Collapse of Structures: Nomenclature and Procedures. *Structural Engineering International*, 16(2), 113-117.

- Starossek, U. and Haberland, M. (2010). Disproportionate Collapse: Terminology and Procedures. *Journal of Performance of Constructed Facilities*, 24(6), 519-528.
- Toranzo, L. A., Carr, A. J. and Restrepo, J. I. (2001). Improvement of traditional masonry wall construction for use in low-rise/low-wall density buildings in seismically prone regions. In Proc., 2001 Technical Conf.—Future Directions: A Vision for Earthquake Engineering in New Zealand.
- Warszawski, A. (1999). *Industrialized and Automated Building Systems: A Managerial Approach*. Routledge.
- West, J. S., Breen, J. E. and Kreger, M. E. (1999). *Interim Conclusions, Recommendations, and Design Guidelines for Durability of Post-Tensioned Bridge Substructures* (Vol. 1405, No. 5). The Center.
- Yildirim, S. G. (2012). Design Education of Industrialised Building Systems. *Procedia-Social and Behavioral Sciences*, 51, 84-89.