

**HIGH PERFORMANCE INDUSTRIALISED BUILDING SYSTEM
MULTI-LAYERS SLIM BEAMS**

SHERZAD QADIR MAJID

A dissertation submitted in partial fulfillment
of the requirements for the award of the degree
of Master of Engineering (Civil-Structure)

**Faculty of Civil Engineering
Universiti Teknologi Malaysia**

February 2012

*To my beloved parents, my brothers and sisters, my
wife, my beloved kids ***Zhinaz, Zhinyar and Zhiya***
Thanks for your prayers, supports & encouragement*

ACKNOWLEDGEMENT

First and foremost, I would like to thank my supervisor of this research, Associate Professor Dr. Abdul Kadir Marsono for the valuable guidance and advice. He inspired me greatly to work for this research. His willingness to motivate me contributed tremendously to my master degree.

Besides, I would like to thank all staff of civil engineering faculty for providing me with a good environment and facilities in the structural laboratory to complete this research. In addition, I would also like to thank our librarian for letting me borrow some books, for the computer labs for letting me use computers and internet.

Finally, an honourable mention goes to my family, father, mother, sisters, brothers, my wife and my kids; and friends, especially my best friend Navid Ranjbar; for their helps, understandings and supports on me in completing this academic degree. Without their support I would face many difficulties while doing this research.

And it would not be successful without God who guides us in our everyday life and activities; I thank Him for the good health he has given to me, and for the success of my study. For all the people who helped me a lot, thank you very much and may God bless you all. Last but not least, I would like to express my earnest gratitude to whom that always believing in me.

ABSTRACT

The qualities and the quantities of materials are not controlled in proper way when a lot of concrete and many steel reinforcements are being wasted. Variation of the sizes of beams and columns are not simplified and generalized, which leads to the increase of cost of construction and unnecessary need. Nowadays, Industrialised Building system (IBS) has become an alternative to speed up the construction completion and to increase the flexibility. The IBS multi-layers slim beam with new type of connection is a new innovation. It is based on the concept of mobility and deployable to speed up the construction process, unification and adaptability. For this purpose, an experimental investigation into the behaviour of six IBS multi-layers slim beams made of high strength concrete and rectangular spiral shear reinforcement with new type of connection has been carried out in three different testing assemblies. These tests were carried out to determine the laboratory ultimate strength capacity of these multi-layers IBS slim beams and to assess the performance and the behaviour of connections. All specimens were connected to a column frame steel-section channel supported on a 3.4 m span. The models were subjected to two point loads. Deflections at various points, crack patterns, crack widths, strain in steel, strains on concrete surface and rotation of connection were recorded during the test. The concrete properties i.e. compressive strength and tensile strength were also recorded. It was found that the capacity of SET 2 (2 slim beams) increased by 87% with comparison to SET 1 (1 slim beam) and the capacity of SET 3 (3 slim beams) increased by 28% with comparison to SET 2 (2 slim beams). The crack patterns of all specimens were similar and the mode of ultimate failure was flexural behaviour. It was associated with crushing and spalling of the concrete at supports. The initial stiffness of connection increased with the increase of the number of slim beams in the set beam. The rotational capacity (ductility) behaved differently as the size of the combined beams increases, and the connections lose their ductility with the increasing number of slim beams. The experimental results were comparable with simulation results carried out by finite element software.

ABSTRAK

Kualiti dan kuantiti bahan yang tidak dikawal dengan baik akan mengakibatkan pembaziran konkrit dan tetulang keluli. Perbezaan saiz rasuk dan tiang yang tidak dipermudahkan akan meningkatkan kos pembinaan yang tidak diinginkan. Pada masa kini, Sistem Bangunan Perindustrian (Industrialised Building System, IBS) telah menjadi satu alternatif untuk mempercepatkan penyiapan pembinaan dan meningkatkan keupayaan serta fleksibiliti. Set rasuk nipis IBS adalah satu inovasi baru yang mengetengahkan penyambungan yang baru. Ianya adalah berdasarkan konsep mudah alih dan membolehkan proses pembinaan di singkatkan dengan penggunaan struktur yang mudah. Bagi tujuan ini, penyiasatan makmal ke atas kelakunan enam IBS dengan rasuk nipis yang diperbuat daripada konkrit kekuatan tinggi dan tetulang ricih lingkaran segi empat tepat dan sambungan jenis baru telah dijalankan dalam tiga kumpulan ujian. Ia adalah untuk menentukan kapasiti kekuatan muktamad pelbagai set rasuk IBS langsing. Ia juga menilai prestasi dan kelakunan sambungan. Semua spesimen disambungkan kepada tiang keluli dan disokong pada rentangan 3.4 meter. Model diuji dengan dua beban titik. Pesongan di pelbagai tempat, corak retak, lebar retak, terikan keluli, terikan permukaan konkrit dan putaran sambungan dicatatkan semasa ujian. Sifat-sifat konkrit iaitu kekuatan mampatan dan kekuatan tegangan jage direkodkan. Didapati bahawa kapasiti SET 2 (2 rasuk nipis) meningkat sebanyak 87% berbanding SET 1 (1 rasuk nipis) dan kapasiti SET 3 (3 rasuk nipis) meningkat sebanyak 28% berbanding SET 2 (2 rasuk nipis). Corak retak semua spesimen adalah serupa dan mod kegagalan adalah lenturan, dengan hancuran dan kopekan konkrit pada sokongan. Kekukuhan awal sambungan meningkat dengan peningkatan bilangan rasuk tipis dalam set. Kapasiti (kemuluran) berbeza apabila bilangan rasuk nipis berubah dan sambungan kehilangan kemuluran dengan bertambahnya bilangan rasuk nipis. Keputusan eksperimen adalah sepadan dengan keputusan simulasi yang dijalankan dengan perisian unsur terhingga.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	TITLE	i
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xi
	LIST OF FIGURES	xii
	LIST OF SYMBOLS	xvi
1	INTRODUCTION	1
	1.1 Background	1
	1.2 Statement of Problem	3
	1.3 Aim of the Study	4
	1.4 Objectives of the Study	4
	1.5 Scope of the Work	5
	1.6 Arrangement of the Thesis	5
2	LITERATURE REVIEW	7
	2.1 Industrialised Building System	7
	2.2 Definition of IBS	9
	2.3 Performance and Advantages of IBS	10
	2.4 High Strength Concrete (HSC)	12

2.4.1	Flexure Capacity of HSC Beam	13
2.4.2	Ultimate Bending Moment Capacity of HSC Beams	17
2.4.3	Ductility of Beam	21
2.4.4	Deflection of HSC Beams	23
2.4.4.1	Short-term Deformation	24
2.4.5	Shear Capacity of HSC Beams	25
2.5	Beam-to-Column Steel Connection	29
2.5.1	Introduction	29
2.5.2	Beam-to-Column Connections	30
2.5.3	General Design Considerations	33
2.5.3.1	Strength and Stiffness	34
2.5.3.2	Stability	35
2.5.3.3	Serviceability	35
2.5.3.4	Cyclic Behaviour	35
2.5.4	Some Usable Steel Connections	36
2.5.4.1	Cast-in-column Steel Insert (UB Section)	36
2.5.4.2	Cleat Connector	38
2.5.4.3	Welded Plate Connector	40
2.5.4.4	Billet connection	42
2.5.4.5	Sliding Plate	42
2.5.4.6	Shallow corbel beam to column	44
2.5.4.7	H-Steel Connection	45
3	HIGH STRENGTH CONCRETE DESIGN	47
3.1	Mix Design of High Strength Concrete	47
3.2	Design of High Strength Concrete Beam using Eurocode 2	55
4	EXPERIMENTAL WORKS	56
4.1	Introduction	56
4.2	Terminology	57

4.3	Conceptual Design of New IBS System	58
4.4	Modelling and Geometry of Beam	60
4.4.1	Main Beam	60
4.4.2	Side Beam	61
4.4.3	Steel Sections	63
4.4.4	Bolts and Nuts	64
4.4.5	Shear Reinforcement	65
4.5	Engineered Mould System	66
4.6	High strength concrete trial mix	67
4.7	Strain Measurement	68
4.8	Casting and Test Procedure	69
5	DATA ANALYSIS	75
5.1	Basic Introduction	75
5.2	Properties of Concrete Used in the Study	76
5.2.1	Splitting Tensile Strength	78
5.3	Properties of Steel Reinforcement used	80
5.4	Behaviour of SB-1M	81
5.4.1	Mid-Span Deflection	84
5.4.2	Lateral and rear-face displacement of SB-1M	85
5.4.3	Other Deflections Measurement of SB-1M	87
5.4.4	Mode of Failure of SB-1M	89
5.4.5	Rotation of Connection of SB-1M	95
5.4.6	Load-Strain curve of Reinforcement steel bar	98
5.5	Behaviour of SB-2M-1S	99
5.5.1	Deflection and Displacement of SB-2M-1S	99
5.5.2	Mode of Failure and Cracks Patterns of SB-2M-1S	103
5.5.3	Moment-Rotation curve of SB-2M-1S	110
5.5.4	Tensile Strain on steel reinforcement of SB-2M-1S	111
5.6	Behaviour of SB-3M-2S	113
5.6.1	Deflection and Displacement of SB-3M-2S	113

5.6.2	Cracks Pattern and Mode of Failure of SB-3M-2S	118
5.6.3	Connection Behaviour of SB-3M-2S	123
5.6.4	Tensile strains of longitudinal steel-bars of	124
6	COMPARISONS OF TEST RESULTS	126
6.1	Comparisons of Experimental Results	126
6.2	Comparisons between Experimental and Finite Element Results	141
7	CONCLUSIONS AND RECOMMENDATIONS	152
7.1	Conclusion	152
7.2	Recommendations for Further Researches	154
	REFERENCES	155
	APPENDICES	165

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Rectangular stress block by Ibrahim and MacGregor (1997)	14
2.2	Comparison of stress block by Eurocode2 and ACI 318-08	17
4.1	Terminology Descriptions	58
4.2	Trial mixes and their properties	67
5.1	Experimental and theoretical data of concrete used in the study	77
5.2	Deflection and Displacement data of SB-1M	82
5.3	Data obtained to measure the connection rotation of SB-1M	96
5.4	Deflection Data collected from test of SB-2M-1S	100
5.5	Deflection and displacements of SB-3M-2S	114
6.1	Summarize data collected from experimental	128
6.2	Crack width and average distance between cracks for tested	132
6.3	Moment and Stiffness of steel connection for all tested beams	137

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Example of Precast building under construction	8
2.2	Strain and Stress block proposed by Hognestad (1955)	14
2.3	Strain and Stress block proposed by Oztekin et al (2003)	15
2.4	Rectangular stress distribution Eurocode 2	16
2.5	Actual and equivalent rectangular stress distributions at ultimate load	16
2.6	Details of tested beams proposed by Keun el at (2010)	18
2.7	Geometry and detailing of test beams Bernardo & Lopes (2004)	19
2.8	Beam cross-section and loading arrangement Pam et al (2001)	20
2.9	Beams details proposed by Ashour (2000)	20
2.10	Testing arrangement of beams Sarkar et al (1997)	21
2.11	Test setup and specimen details Rahal et al (2004)	28
2.12	bending moment diagram for a beam in a semi-continuous braced beam	30
2.13	Typical deformation and rotation of a partial strength joint	31
2.14	Recommended classification boundaries for beam-to-column connections according to Eurocode 3	32
2.15	Classification system by Bjorhvide et al (1990)	33
2.16	Section view and detail of UB Section	37
2.17	3-dimensional view of UB Section	38
2.18	Beam-to-column connection with cleat connector	39
2.19	Beam-to-column connection with cleat connector	39
2.20	Beam-to-column connection using solid section with welded plate connector	41

2.21	Beam-to-column connection using solid section with welded plate connector	41
2.22	Billet as Beam-Column Connector. Typical reinforcement bars are not shown for clarity	42
2.23	Beam-to-connection with sliding plat	43
2.24	Beam-to-connection with sliding plat	44
2.25	Proposed hybrid beam-to-column connection in precast concrete frame	45
2.26	Proposed H-steel connection used in hybrid concrete frame	46
3.1	Flow chart of the proposed mix design method	48
3.2	Proposed W/B Vs compressive strength relationship	50
3.3	Determination of the minimum water dosage	50
3.4	Coarse aggregate content	52
3.5	Mix design sheet prepped by Microsoft Excel Software	54
4.1	Terminology	57
4.2	New Design for IBS	59
4.3	Main beam	60
4.4	Side Beam	61
4.5	All Component of whole System	62
4.6	Steel Sections used as connection	63
4.7	Bolts used in this study	64
4.8	Spiral reinforcement	65
4.9	Steel Formwork used in this research	66
4.10	Strain Gauge installation	68
4.11	Test set up of SB-1M	70
4.12	Test set up of SB-2M-1S	71
4.13	Test set up of SB-3M-2S	72
4.14	Position of LVDTs for all Beam Specimens	74
5.1	Experimental STS vs. Compressive Strength	79
5.2	Tensile Strength due to EC2 vs. Compressive Strength	80
5.3	Stress-Strain Curve of Steel Reinforcement used in this investigation	81

5.4	Deflections-Load Curves in different locations of SB-1M	83
5.5	Mid-Span Deflection of SB-1M	84
5.6	Deflected shape of SB-1M	85
5.7	Lateral displacement of SB-1M	86
5.8	Side-Face displacement of SB-1M	86
5.9	Deflection curve under two points load of SB-1M	87
5.10	Deflection curve under steel-section of SB-1M	88
5.11	Deflection-load curve of steel-section	88
5.11a-i	Crack patterns at different loads during test of SB-1M	94
5.12	Inclinometers used to measure the connection rotation of SB-1M	95
5.13	Moment- θ curve of SB-1M	96
5.14	Non-deformed steel sections after testing SB-1M	97
5.15	Load-Strain relationship of steel bar used in SB-1M	99
5.16	Deflections and Displacement Vs Load curves of SB-2M-1S	102
5.17	Crack Pattern of Main Beam in SB-2M-1S	104
5.18	Crack Pattern of Side Beam no.4 in SB-2M-1S	105
5.19	Failure of SB-2M-1S	106
5.20	Failure of SB-2M-1S	107
5.21	Failure of SB-2M-1S	108
5.22	Failure of SB-2M-1S	109
5.23	Inclinometer used to measure the connection angle of SB-2M-1S	110
5.24	Moment-rotation of SB-2M-1S	111
5.25	Load-strain curve of longitudinal bar of main beams in SB-2M-1S	112
5.26	Load-strain curve of longitudinal bar of main beams in SB-2M-1S	112
5.27	Deflected shape of SB-3M-2S	116
5.28	Various deflections and displacement of SB-3M-2S	117
5.28a-b	Crack Pattern of Main beam within SB-3M-2S	119
5.29	Crack Pattern of Side beam 6 within SB-3M-2S	120
5.30	Crack Pattern of Side beam 5 within SB-3M-2S	121
5.31	Crushing and spalling of SB-3M-2S upon the failure	122
5.32	Moment- θ relationship of SB-3M-2S	123

5.33	Load-strain relationship of longitudinal bar of beams in SB-3M-2S	125
6.1	Load Vs Mid-span Deflection of all specimens	129
6.2	Primary Crack Pattern of SB-1M	130
6.3	Primary Crack Pattern of SB-2M-1S	131
6.4	Primary Crack Pattern of SB-3M-2S	131
6.5	Cracks patterns of SB-1M upon failure	133
6.6	Cracks patterns of SB-2M-1S upon failure	133
6.7	Cracks patterns of SB-3M-2S upon failure	133
6.8	Moment-Rotation curves of SB-1M	135
6.9	Moment-Rotation curves of SB-2M-1S	135
6.10	Moment-Rotation curves of SB-3M-2S	136
6.11	Moment-Rotation curves of steel connections in all specimens	138
6.12	Load-Strain curves of longitudinal steel bars in all specimens	140
6.13	SB-1M model in ABAQUS	142
6.14	SB-2M-1S model in ABAQUS	143
6.15	SB-3M-2S model in ABAQUS	144
6.16	Load-Midspan deflection obtained by both Experimental and FEM	145
6.17	Curvature of all Specimens obtained by both Experimental and FEM	147
5.18	Cracks Pattern and Mode of Failure of SB-1M	149
6.19	Cracks Pattern and Mode of Failure of SB-2M-1S	150
6.20	Cracks Pattern and Mode of Failure of SB-3M-2S	151
A1	Vertical strut inclination approach proposed by EC2	169

LIST OF SYMBOLS

G_c	specific gravity of the cement or cementitious material
G_{ssd}	aggregate specific gravity in saturated surface dry condition
W_{abs}	absorbed water in the aggregate in per cent
W_{tot}	total water content of the aggregate in per cent
W_h	moisture content of the aggregate in per cent
G_s	specific gravity of the liquid superplasticizer
s	total solid content of the superplasticizer in per cent
M_{sol}	mass of solids in the superplasticizer
d	superplasticizer dosage as a percentage of the mass of solids in comparison to the total mass of cementitious materials
V_{liq}	volume of liquid superplasticizer
V_w	volume of water in the liquid superplasticizer
V_{sol}	volume of solids in the superplasticizer
W	mass of water in kg per cubic metre of concrete
B	mass of binder in kg per cubic metre
C	Binder Mass
A_s	Cross sectional area of reinforcement
$A_{s,min}$	minimum cross sectional area of reinforcement
A_{sw}	Cross sectional area of shear reinforcement
E_c	Tangent modulus of elasticity of normal weight concrete

s	Height of the compression zone in equivalent stress block
E_s	Design value of modulus of elasticity of reinforcing steel
SLS	Serviceability limit state
ULS	Ultimate limit state
V	Shear force
V_{Ed}	Design value of the applied shear force
b	Overall width of a cross-section of beam
d	Effective depth of a cross-section
f_{cd}	Design value of concrete compressive strength
f_{ck}	Characteristic compressive cylinder strength of concrete at 28 days
f_c	Compressive cylinder strength of concrete at 28 days
f_{cm}	Mean value of concrete cylinder compressive strength
f_{ctm}	Mean value of axial tensile strength of concrete
h	Overall depth of a cross-section
α	Angle ; ratio
β	Angle ; ratio; coefficient
γ_c	Partial factor for concrete
γ_s	Partial factor for reinforcing steel
λ	height of the compression zone in equivalent stress block
w	Width of the compression zone in equivalent stress block
η	Effective strength

CHAPTER 1

INTRODUCTION

1.1 Background

Structural engineers, regardless of locality, have as a part of their responsibility, the safety of lives that is a prime consideration than any other profession. It is this responsibility that accounts for their conservatism. In the field of engineering materials and methods of construction, great advances have been accomplished within the past few decades through precast and prestressed concrete, high strength steel, high performance concrete. Materials improvements have also been driven along design procedures and process of materializing the structures as evidenced by the gaining popularity of ultimate strength design, plastic design and limit state design.

Industrialised Building System (IBS) is a coordinated dimensioning of components for construction where all parts of the structure such as column, beam, and slab is prefabricated or precast in the factory or site factory and assemble it on site. IBS has emerged as a potential solution for modular coordinated constructions. IBS concrete structures, where the superstructure is erected from the individual elements of prefabricated components, manufactured in factory in a favourable environment and strict production and quality control, will produces units of high

quality in term of performance and appearance. The designer can select from a range of finishes, be able to inspect and accept the units before they leave the factory. Public buildings such as schools, universities, hospitals, offices, car parks, residential housing and hotels can be built using IBS concrete components.

Malaysia have utilises precast concrete system but the use of IBS is still low compared to developed countries such as United States, Europe and Japan [1]. IBS shall be able to merge with any scheme of other constructions such as steel or other precast component producer. One of the early definitions of industrialised building system has been given by Esa et al [2], in which IBS is a continuum beginning from utilising craft-men for every aspect of construction to a system that use manufacturing production in order to minimise resource wastage and enhance value for end users.

In the 1970s, when the compressive strength of the concrete used in the columns of some high-rise buildings was higher than that of the usual concretes used in construction, there is no doubt that it was legitimate to call these new concretes 'high-strength concretes HSC'. They were used only because their strength was higher than that of the usual concretes. However, when superplasticizers began to be used to decrease the water/cement (W/C) ratio, it was found that concretes with a very low w/c ratio also had other improved characteristics, such as higher flowability, higher elastic modulus, higher flexural strength, lower permeability, improved abrasion resistance and better durability. Thus the expression 'high-strength concrete' no longer adequately described the overall improvement in the properties of this new family of concretes. Therefore the expression 'high-performance concrete HPC' became more and more widely used. High performance concrete leads to achieve high performance structure.

The use of HPC in the IBS can offer several benefits such as reduce times of casting, lifting less weight and more slim members and less mobilization effort.

In this study, an experimental investigations will carried out on new IBS concrete slim (the ratio of height to width is more or equal to 1:3) beams using new type of steel-connection which is able to erect more than one slim beam as multi-layers unit to form a frame for whole structural system as one of its high performance characteristics, this study checks the behaviour of IBS slim beam during the loading until the ultimate failure.

1.2 Statement of Problem

The IBS multi-layers slim beam is a new innovation. It is based on the concept of mobility and deployable to speed up the construction process, unification and adaptability. New innovation design has to be checked and verified experimentally. The beam components beside simulation under applied loads to be check for its real behaviour and rare availability of supporting content in code of practices for design, especially beams with spiral shear reinforcement and new type of structural connection.

Relating to these purposes, an experimental investigation into the behaviour of six IBS slim beams made of high strength concrete and rectangular spiral shear reinforcement at sizes of 100 x 300mm of concrete has been designed and put into study.

1.3 Aim of the Study

The aims of this study are to develop a high performance concrete (HPC) slim beam and the effect of its assembly for an IBS from standardised cross section.

1.4 Objectives of the Study

The prime objective of this research is to investigate the behaviour of HPC multi- layers smart IBS slim beam under two points load test to the failure.

In order to achieve the aim and the prime objective of this study, the following specific objectives are proposed:

1. To determine the experimental ultimate strength capacity of these beam structures sets of multi-layers IBS slim beams.
2. To evaluate the ultimate flexural behaviour of IBS slim beam structures sets and to check the attribute of strength of the assembly.
3. To assess the performance and behaviour of connections for load transfer mechanism formation to column.
4. To study the experimental results with finite element methods.

1.5 Scope of the Work

The scope of the work study of item (a), (b) and (c) is to fabricate to precision a series of six slim beams in laboratory with size of 100 x 300 x 3400 mm long to form 3 combination of beam structure. These beams are to be tested in laboratory condition to ultimate failure. The formation of beam structure comprising:

- a) Set 1: Single slim beam;
- b) Set 2: Double slim beam; and
- c) Set 3: Triple slim beam.

1.6 Arrangement of the Thesis

This thesis is divided into seven chapters in addition to the present one as an introduction to this thesis. In Chapter 2, a literature review is presented to give more understanding to the need of industrialised building system. It reviews theoretical and experimental studies of previous work in similar fields. Moreover, different conceptual models of steel connections are also reviewed.

In Chapter 3, the design of high strength concrete mix was illustrated and an Excel spread sheet has been developed for this purpose. Moreover, a design of high strength concrete beam in flexure as well as to shear design with spiral links has been stepwise according to Eurocode 2.

In order to better understand the formation of structures experimental work of IBS slim beams, the components and test setups of six IBS slim beams are explained

in Chapter 4. The details of beam specimens, material properties, instrumentation and the testing procedure used are described.

The results obtained from the experimental work carried out at the Structural and Material Laboratory of the Universiti Teknologi Malaysia (UTM) are presented and discussed in Chapter 5. The influence of each design parameter is studied separately, and test results are compared with Eurocode 2 [3], Eurocode 3 [4-5] and Eurocode 4 [6].

The comparisons of all specimen results have been represented in Chapter 6.

Chapter 7 presents general and specific conclusions, together with recommendations for future research. A list of references cited in the thesis and appendices are also presented.

References

- [1] L. P. CHUNG, "IMPLEMENTATION STRATEGY FOR INDUSTRIALISED BUILDING SYSTEM," Faculty of Civil Engineering, Universiti Teknologi Malaysia; Thesis, 2006.
- [2] H. Esa, and Nuruddin, M.M (1998) Policy on industrialised building system. Report on Colloquim on Industrialised Construction System, Kuala Lumpur.
- [3] Eurocode-2, "Design of concrete structures," in *part 1-1: General rules and rules for buildings*, ed, 1992-1-1:2004.
- [4] Eurocode3, "BS EN 1993-1-1:2005; Design of steel structure- Part 1-1: General rules and rules for building."
- [5] Eurocode3, "BS EN 1993-1-8:2005 : Design of steel structure- Part 1-8: Design of joints."
- [6] Eurocode4, "BS EN 1994-1-1:2004: Design of composite steel and concrete structures ".
- [7] Abdul Kadir M.R. , M. S. Jaafar, S. M. Sapuan and A.A. Ali, "Performance Comparison between Structural Element of Building Systems in Malaysia," *American Journal of Applied Sciences*, vol. 2 (5), 2005.
- [8] Mohd Rofdzi Abdullah1 , Mohd Nasrun Mohd Nawawi, Ahmad Tarmizi Haron, Mohammed Arif, "INDUSTRIALISED BUILDING SYSTEM: A DEFINITION AND CONCEPT," in *ARCOM Conference*, Nottingham, United Kingdom, 2009.
- [9] Rahman ABA and Omar. W., " Issues and challenges in the implementation of IBS in Malaysia," in *6th Asia-Pacific Structural Engineering and Construction Conference (ASPEC 2006)*, Kuala Lumpur, Malaysia, 2006.

- [10] K. K. Hamid. ZA, Zain. MZM, Ghani. MK and Rahim. AHA. Industrialized Building System (IBS) in Malaysia: the current state and R&D initiatives. *Malaysian Construction Research Journal (MCRJ)*. 2(1): 1-11, 2008.
- [11] CIB report.. CIB Publication 329, "New perspective in industrialization in construction – a state of the art report," Zurich2010.
- [12] CIDB, "Industrialised Building System (IBS) Roadmap 2003-2010," Construction Industry Development Board (CIDB), Kuala Lumpur (2003).
- [13] Kamarul Anuar Mohd Kamar, Mohamed Nor Azhari Azman and Mohd Sanusi S. Ahamad, "Industrialized Building System (IBS): Revisiting Issues of Definition and Classification," *Int. J. Emerg. Sci*, pp. PP. 120-132, 2011.
- [14] E. Hognestad, and Hanson, N. W. and McHenry, D., "Concrete stress distribution in ultimate strength design," *ACI Journal*, vol. V. 52, No.6, pp. pp. 455-480, 1955.
- [15] Ibrahim M.H. and MacGregor, J. G., "Modification of the ACI Rectangular Stress Block for High-Strength Concrete," *ACI Structural Journal*, vol. Vol. 94, No. 1, pp. pp. 40-48, 1997.
- [16] Attard, M. M. and Stewart, M. G., "A Two Parameter Stress Block for High Strength Concrete," *ACI Structural Journal*, vol. Vol. 95, No. 3, pp. pp. 305-317, 1998.
- [17] D. Marinucci, and Patnaikuni, I., "Stress Blocks for High Strength High Performance Concrete Columns and Beams," in *Proc. Sixth International Conference on Structural Failure, Durability and Retrofitting*, Singapore, 14-15 September 2000, pp. pp. 106-115.
- [18] E. Oztekin, Pul, S., and Husem, M., "Determination of rectangular stress block parameters for high performance concrete," *Engineering Structures*, vol. Vol. 25, pp. pp. 371-376, 2003.

- [19] Ozbakkaloglu M. S., "Rectangular stress block for high strength concrete," *ACI Structural Journal*, vol. Vol. 101, No.4, pp. pp. 475-483, 2004.
- [20] Bae S. and Bayrak O., "Stress Block Parameters for High-Strength Concrete Members," *ACI Structural Journal*, vol. Vol. 100, No. 5, pp. pp 626-636, Sept-Oct 2003.
- [21] P. A. Mendis, and Pendayala, R. S., "Structural design with high-strength/high-performance concrete – beams and columns," *Concrete in Australia*, vol. Vol. 23, No. 2, pp. pp. 26-28, 1997.
- [22] T. H. Wee, Chin, N. S. and Mansur, M. A., "Stress-strain relationship of high strength concrete in compression," *Journal of Materials in Civil Engineering*, vol. Vol. 8, No. 2, pp. pp. 70-76, 1996.
- [23] K. Azizinamini A, S. S. B., Brungardt P, Hatfield E., "Seismic Behavior of Square High-Strength Concrete Columns," *ACI Structural Journal*, vol. Vol. 91, No.3, pp. pp 336-345, 1994.
- [24] S. E. Swartz, Narayan Babu, H. D., Periyakarupan, N. and Refai, T. M. E., "Structural bending properties of higher strength concrete," *High Strength Concrete. ACI SP-87*, pp. pp.147-178, 1985.
- [25] P. H. Kaar, Hanson, N. W and Capell, H. T., "Stress-strain characteristics of high strength concrete," *Farmington Hills, Detroit. American Concrete Institute*, vol. SP-55, pp. pp.161-186, 1978.
- [26] ACI, "Building Code Requirements for Structural Concrete (ACI 318M-08) and Commentary," vol. First printing, June 2008, ed: American Concrete Institute, 318M-08.
- [27] D. D. Arthur H. Nilson, Charles W. Dolan, *Design of Concrete Structure*, Fourteenth ed.: Mc Graw Hill, 2010.

- [28] K. E. Leslie, Rajagopalan, K. S. and Everard, N. J. "Flexural behavior of high-strength concrete beams." *ACI Journal*. Vol. 73, No. 9, 1976, pp. 571-521.
- [29] G. U. Tognon, P.; and Coppetti, G., "Design and Properties of Concretes with Strength over 1500 kgf/cm²," *ACI JOURNAL*, Proceedings V. 77, No. 3, May-June 1980, pp. 171-178.
- [30] Okada, K. and Azimi M. A., "Memoirs of the Faculty of Engineering, Kyoto University, Japan. Vol.43, No2. pp. 304-318.
- [31] J. A. Pastor, Nilson, A. H. and Slate, F. O. "Behaviour of High-strength Concrete Beams," Research Report 84-3. Department of Structural Engineering, Cornell University, Ithaca, New York, 1984, 311pp.
- [32] Swamy, R. N., "High Strength Concrete", *ACI SP-87*, Detroit, 1985, pp. 119-146.
- [33] S. M. Uzumeri, and Basset, R. "Behaviors of High Strength Concrete Members," International Symposium on Utilization of High Strength Concrete, Stavanger, June 1987, Norway, pp. 237-248.
- [34] S. W. Shin, Ghosh, S. K., and Moreno, J. "Flexural ductility of ultra-high-strength concrete members." *ACI Journal Proceedings*, Vol. 86, No.4, 1989, pp.394-400.
- [35] H. Lambotte, and Taerwe, L. R., "Deflection and cracking of high-strength concrete beams and slabs." *SP127-7, Proceedings, High-Strength Concrete, 2nd Int. Symp. Berkeley, Calif., W.T. Hester, ed., ACI Farmington Hills, Mich., 1990, pp. 108-128.*
- [36] C.-H. Lin, Ling, F. -S., and Hwang, C. -L. " Flexural Behaviour of High Strength Fly Ash Concrete Beams," *Journal of the Chinese Institute of Engineers, Taiwan*, Vol. 15, No. 1, 1992, pp. 85-92.

- [37] Shehata, I. A. E. M. and L. C. D. Shehata, "Proceedings, 4th Int. Symp. on Utilization of High-Strength/High-Performance Concrete. Paris. 1996, pp. 945-953.
- [38] R. Pendyala, Mendis, P.A. and Patnaikuni, I., "Full-range Behaviour of High-Strength Flexural Members: Comparison of Ductility Parameters of High and Normal Strength Concrete Members," ACI Structural Journal, Vol. 93, No. 1, January - February 1996, pp 30-35.
- [39] S. Sarkar, Adwan, O., Munday, J. G. L., "High strength concrete: an investigation of the flexural behavior of high strength RC beams," The Structural Engineer, Vol. 75, No.7, April, 1997, pp 115-121.
- [40] M. A. Mansur, Chin, M. S. and Wee, T. H. "Flexural behavior of high-strength concrete beams," ACI Structural Journal, Vol.94, No. 6, November 1997, pp. 663-674.
- [41] S. A. Ashour, "Effect of compressive strength and tensile reinforcement ratio on flexural behavior of high-strength concrete beams," Engineering Structures, Vol. 22, 2000, pp. 413- 423.
- [42] L. F. A. Bernardo, Lopes, S. M. R., "Neutral Axis Depth versus Flexural Ductility in High-Strength Concrete Beams," ASCE Journal of Structural Engineering, Vol. 130, No.3, March, 2004, pp 425-459.
- [43] M. A. a. M. A. M. Rashid, M. A. "Reinforced High-Strength Concrete Beams in Flexure," ACI Structural Journal, Vol. 102, No. 3, May 2005, pp. 462-471.
- [44] S. Ashour, Khalid Mahmood, and Faisal W. Wafa., "Influence of Steel Fibers and Compression Reinforcement on Deflection of High-Strength Concrete Beams," ACI Structural Journal. Vol. 94, No. 6, Nov-Dec 1997. pp. 611-624.

- [45] M.-H. K. Keun-Hyeok Yang, Ho-Chan Lee and Myoung-Ho Oh, "Flexural behavior of hybrid precast concrete beams with H-steel beams at both ends," *Engineering Structures*, vol. 32, pp. 2940-2949, 2010.
- [46] H. J. Pam, Kwan, A. K. H and Islam, M. S., "Flexural strength and ductility of reinforced normal- and high-strength concrete beams." *Structures & Buildings*. Vol. 146, No. 4, 2001, 381-389.
- [47] D. D. a. M. Starnes, "Strength and Ductility of Concrete Beams Reinforced with Carbon FRP and Steel," *NISTIR 6830*, 2001.
- [48] Hsu; Mo, "UNIFIED THEORY OF CONCRETE STRUCTURES", Second Edition 2010: 2010 John Wiley & Sons, Ltd, 2010.
- [49] A. Ghali, "Deflection of Reinforced Concrete Members," *ACI Structural Journal*, Vol. 90, No. 4, July-August 1993, pp.368-373.
- [50] D. Galeota, and Giammatteo, M. M., "High-Strength Concrete Beams Subjected to Shear," *High Strength Concrete*. First International Conference held in Kona, Hawaii, Sponsored by the United Engineering Foundation, ASCE, 0-7844-0419- 4, 1997, 670 pp.
- [51] R. S. Pendyala, "The Behaviour of High-Strength Concrete Beams," PhD thesis, The University of Melbourne, 1997.
- [52] A. H. N. Elzanaty, A. H.; and Slate, F. O., "Shear Capacity of Reinforced Concrete Beams Using High-Strength Concrete," *ACI JOURNAL*, Proceedings V. 83, No. 2, Mar.-Apr. 1986, pp. 290-296.
- [53] G. G. Konig, R.; and Rimmel, G., "Shear Behaviour of Longitudinally Reinforced Concrete Members of HSC," *Darmstadt Concrete*, V. 8, 1993, pp. 27-42.

- [54] R. S. Mendis, "Experimental Study on Shear Strength of High-Strength Concrete Beams," *ACI STRUCTURAL JOURNAL*, vol. 97, pp. 554-571, 2000.
- [55] M. M. Attard, "Ductility of High-Strength Concrete Columns," *Australian Civil Engineering Transactions*, V. 35, No. 4, 1993, pp. 295-306.
- [56] M. K. Johnson, and. Ramirez, J. A., "Minimum Shear Reinforcement in Beams with Higher Strength Concrete," *ACI Structural Journal*, V. 86, No.4, 1989, pp. 376-382.
- [57] S.W. Shin, "Flexural Behaviour including Ductility of Ultra-high-strength Concrete Members", PhD thesis, University of Illinois, Chicago, 1986, 232pp.
- [58] Cladera A. R., "Experimental study on high-strength concrete beams failing in shear," *Engineering Structures*, Vol. 27 No.10, 2005, pp1519-1527.
- [59] Rahal K.S. "Minimum Transverse Reinforcement in 65 MPa Concrete Beams," *ACI Structural Journal*. Vol. 101, No.6, November 2004, pp.872-878.
- [60] C. Faella, Piluso, V., Rizzano, G, *Structural Steel Semirigid Connections: Theory, Design and Software*, United States:CRL Press LLC. 2000.
- [61] Ryan.J.C., "Evaluation of Extended End-Plate Moment Connections Under Seismic Loading," Master Thesis, Virginia Polytechnic Institute and State University, 1999.
- [62] R. Bjorhovde, Brazetti, J., Colson, A. (1990), " A Classification System for Beam-to-Column Connection", *Journal of Structural Engineering*, ASCE: Vol. 1116, No. ST11, pg 059-3076.
- [63] W. F. Chen, Goto, Y., Liew, J.Y.R (1996), "Stability Design of Semi-rigid Frame", New York:Wiley-IEEE, pg 18-19.

- [64] K. S. Elliot, G. Davies, H. Gorgun and M.R. Adlparvar, 1998. The stability of precast concrete skeletal structure. *PCI Journal.*, pg 42-57.
- [65] K. S. Elliott, *Precast Concrete Structures*: Butterworth-Heinemann, 2002.
- [66] Ahmad Baharuddin Abd. Rahman, A. Aziz Saim and Mohd. Hanim Osman, "HYBRID BEAM-TO-COLUMN CONNECTIONS FOR PRECAST CONCRETE FRAMES " in *6th Asia-Pacific Structural Engineering and Construction Conference*, Kuala Lumpur, Malaysia, 2006.
- [67] AISC, *Manual of steel construction-load and resistance factor design*, Second ed.: American Institute of Steel Construction, 1994.
- [68] P.-C.Aïtcin, *High Performance Concrete*. London and New York: Taylor & Francis e-Library, 2004.
- [69] A. M. Neville, *Properties of concrete*, Fourth and Final ed. England: Pearson Education, Reprinted 2004.
- [70] ACI211.1-91, "*Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete*", ed, 2002.
- [71] British Standard 1995, "Testing Aggregates," in *Part 2. Methods of determination of density*, ed: BSI, 1999.
- [72] R. 1100, "High range, water-reducing, superplasticising admixture for the production of Rheoplastic concrete," ed: BASF, The chemical Company, 1999.
- [73] J. A. Purkiss, *Concrete Design to EN 1992*, Second ed.: Butterworth-Heinemann, An imprint of Elsevier, 2006.
- [74] Eurocode1990, "BS EN1990:2002+A1:2005-Basis of structural design," ed: BSI, p. 120.

- [75] Eurocode-2, "Design of concrete structures," in *Part 2: Concrete bridges — Design and detailing rules*, ed, 1992-2:2005.
- [76] ACI363R-10, "Report on High-Strength Concrete," ed: Reported by ACI Committee 363, 2010.
- [77] BS1881-102:1983, "Testing concrete: Part 102: Method for determination of slump ", ed: Cement, Gypsum, Aggregates and Quarry Products Standards Committee.
- [78] BS1881-110:1983, "Testing concrete: Part 110: Method for making test cylinders from fresh concrete," ed: Cement, Gypsum, Aggregates and Quarry Products Standards Committee.
- [79] BS1881-116:1983, "Testing concrete: Part 116: Method for determination of compressive strength of concrete cubes," ed: Cement, Gypsum, Aggregates and Quarry Products Standards Committee.
- [80] BS1881-117:1983, "Testing concrete: Part 117: Method for determination of tensile splitting strength," ed: Cement, Gypsum, Aggregates and Quarry Products Standards Committee.
- [81] BS1881-125:1983, "Testing concrete: Part 125: Methods for mixing and sampling fresh concrete in the laboratory," ed: Cement, Gypsum, Aggregates and Quarry Products Standards Committee.
- [82] BS1881-108:1983, "Testing concrete: Part 108: Method for making test cubes from fresh concrete," ed: Cement, Gypsum, Aggregates and Quarry Products Standards Committee.
- [83] BS1881-111:1993, "Testing concrete: Part 111: Method of normal curing of test specimens (20 °C method)," ed: Cement, Gypsum, Aggregates and Quarry Products Standards Committee.

- [84] BS812-102:1995, "Testing aggregates: Part 2: Methods of determination of density," ed: BSi.
- [85] C. H. Marzouk, Fracture energy and tension properties of high-strength concrete, *J. Mater. Civ. Eng., ASCE* 7 (2) (1995) 108-116 (May).
- [86] M. K. Wiegrink, S.P. Shah, "Shrinkage cracking of high- strength concrete", *ACI Mater. J.* 93 (5) (1996) 409– 415 (September– October).
- [87] James M. Gere, *Mechanics of Materials*, Seventh ed. Toronto , Canada: Cengage Learning, 2009.
- [88] A. W. S. Beeby, R. H. 2006. Mechanisms of long-term decay of tension stiffening, *Magazine of Concrete Research* 58(5): 255–266.
- [89] A. P. F. Fantilli, D.; Rosati, G. 2005. Effect of bar diameter on the behavior of lightly reinforced concrete beams, *ASCE Journal of Materials in Civil Engineering* 17(1): 10–18.
- [90] D. K. Salys, G.; Gribniak, V. 2009. Modelling deformation behaviour of RC beams attributing tension-stiffening to tensile reinforcement, *Engineering Structures and Technologies*, in press (in Lithuanian). ISSN 2029-2317 (print), ISSN 2029-2325 (online).
- [91] H. Q. G. Wu, R. I. 2008. "An Experimental Study of Tension Stiffening in Reinforced Concrete Members under Short-Term and Long-Term Loads", UNICIV Report No. R-449. Sydney: The University of South Wales. 32 p.
- [92] M. Md.Tahir, Sulaiman,A., Mohammad,S., Saggaff,A,. Standardisation of Partial Strength Connections of Flush End-Plate Connection for Trapezoid Web Profiled Steel Sections. *Journal-The Institution of Engineers, Malaysia*. Vol. 67, No. 2, June 2006.