

PERFORMANCE OF STEEL BOLT CONNECTED INDUSTRIALIZED  
BUILDING SYSTEM SUBJECTED TO HYDRODYNAMIC FORCE WITH  
DEBRIS

ABUBAKAR SHARIF AUWALU

A thesis submitted in fulfilment of the  
requirements for the award of the degree of  
Doctor of Philosophy

School of Civil Engineering  
Faculty of Engineering  
Universiti Teknologi Malaysia

APRIL 2021

## **DEDICATION**

This thesis is dedicated to Ahl al-Baytil Mustapha (SAW). It is also dedicated to my father Haj Mahir Sharif Bala Gabari, my mother Hajia Safiya Mahir, and my biological brother sharif Alkali who wanted to see my success.

## ACKNOWLEDGEMENT

The author would like to thank the almighty Allah for His blessing, guiding and be with him throughout the research.

In particular, the author likes to express his most sincere appreciation to his supervisor, Professor Dr. Norhazilan Md Noor for his valuable guidance, assistance, and direction to ensure the completion of this research. All the discussions and teachings especially during the thesis write-up, the supervisor had guided the right way in completing this research, may almighty Allah reward the supervisor abundantly.

The author wishes to express his sincere appreciation to his al-marhum former supervisor Associate Prof. Dr Abdulkadir Marsono, may Allah make him among the people of paradise, ameen. Sincere thanks to all the Structure Laboratory technicians for helping him in laboratory testing of specimens. The author would like to express his gratitude to Universiti Teknologi Malaysia and School of Civil engineering for providing all the facilities throughout the research. Special thanks to the author's parents Haj Mahiru shrif Bala Gabari and Hajia Safiya Mahiru. Furthermore, special thanks to Sharif Alkali, Sharif Auwalu, Sharif Suyudi and Sharif Umar for their unconditional support throughout the research.

The author's fellow postgraduate student should also be recognised for their support. His sincere appreciation also extends to all his colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. The author is grateful to all his family members

## ABSTRACT

Several major floods have hit Malaysia within the last decades. In order to dampen the effects of the floods on communities' different types of flood mitigation projects, mostly structural mitigation measures were carried out. While some of the measures have been successful in reducing the impact of the flooding, others were not that successful, leading to the collapse of building structures. Therefore, there is a need to concentrate on a recovery framework specially tailored towards building permanent settlements using a robust and cost-effective building system. An industrialized building system (IBS) has been proposed as one of the best solutions for rapidly building permanent settlements in flood-prone zones. However, the existing IBS is not designed to sustain the horizontal impact due to the debris carried by the flood. Thus, a new permanent settlement built in the aftermath of floods using the IBS will eventually be destroyed by the extreme impact of horizontal load in the next flood cycle. Previous studies on the behaviour and performance of the IBS subjected to horizontal impact are found to be lacking. Furthermore, the joint of an IBS is likely to be the weakest point and vulnerable to failure when subjected to the horizontal load. There is, therefore, the need to develop an improved IBS that is able to withstand the horizontal impact of the flood. Thus, this study aimed to investigate the performance and behaviour of steel bolt-connected IBS structures subjected to the sudden impact of hydrodynamic force with debris as well as the horizontal impact of the pendulum. Both dam-break tests and pendulum impact tests were simulated using Autodesk computational fluid dynamic (CFD) simulation and Autodesk simulation mechanical (nonlinear finite element analysis (NLFEA)) for optimizing the laboratory experimental work, respectively. A scale of 1:5 models (one-dimension (1D), two-dimensional (2D), and three-dimensional (3D)) were designed using Eurocode 2, developed, and constructed according to the Buckingham Pi Theorem and Similitude Theory and later tested in the laboratory. The three models which include the single column-footing, 2D IBS frame and 3D IBS platform were properly tested for the dam-break test with and without debris using 1 m, 2 m, and 3 m reservoir water height. These three models were also tested for the sudden impact of the pendulum. The result shows the percentage difference between experimental results and the CFD numerical simulation for the stress of the 3D platform is 12.87%, while the displacement difference is recorded as 0.09 cm. However, the bolt-connected IBS models resisted the highest hydrodynamic forces as compared to the estimated ones from FEMA P-646 and FEMA P-55. Hence, this assured the reliability of the bolt-connected IBS structure for real practice. Furthermore, results of the pendulum impact tests were verified with the published literatures and they showed a very good agreement. The results show that bolt-connection is more effective and contributes additional robustness to the IBS method. Moreover, bolt connection has proven to be effective in restricting damages from spreading to other structural components. The findings of this study are crucial to improving the current IBS method of construction. The study has also successfully enhanced understanding on the behaviour of debris impact on building structures and contributed new knowledge on debris impact in relation to the design code of practice.

## ABSTRAK

Dalam dekad belakangan ini, Malaysia telah mengalami beberapa bencana banjir besar. Untuk mengurangkan kesan banjir terhadap masyarakat, berbagai jenis projek mitigasi bencana banjir telah dilaksanakan, terutamanya langkah-langkah mitigasi struktur. Sebilangan langkah-langkah telah berjaya mengurangkan hentaman banjir, tetapi masih ada langkah lain yang kurang berkesan dan kemudian menyebabkan keruntuhan struktur bangunan. Oleh itu, kerangka pemulihan yang khusus untuk pembinaan penempatan tetap dengan menggunakan sistem bangunan yang mantap dan menjimatkan kos adalah diperlukan. Sistem Binaan Berindustri (IBS) telah dicadangkan sebagai salah satu penyelesaian terbaik untuk membina penempatan tetap dengan pantas di zon-zon berisiko banjir. Walau bagaimanapun, IBS semasa adalah tidak direkabentuk untuk menahan hentaman mendatar oleh banjir. Oleh itu, penempatan kekal baru yang dibina menggunakan IBS selepas banjir juga akhirnya akan musnah akibat hentaman beban mendatar yang melampau pada kitaran seterusnya. Kajian terdahulu mengenai tingkah laku dan prestasi IBS yang dikenakan hentaman mendatar masih kurang. Di samping itu, bahagian sambungan IBS berkemungkinan merupakan bahagian yang paling lemah dan mudah terdedah kepada kegagalan apabila dikenakan beban mendatar. Oleh yang demikian, penyambung yang ditambahbaik yang mampu menahan hentaman mendatar banjir adalah perlu dibangunkan. Oleh itu, kajian ini bertujuan untuk mengkaji prestasi dan tingkah laku struktur IBS dengan penyambung *bolt* yang dikenakan hentaman mendadak daya hidrodinamik dan hentaman mendatar pendulum. Kedua-dua ujian empangan-pecah dan ujian hentaman pendulum disimulasikan dengan menggunakan dinamik bendalir pengkomputeran Autodesk (CFD) dan mekanik simulasi Autodesk (NLFEA) masing-masing untuk mengoptimumkan kerja-kerja ujian makmal. Model kecil yang berskala 1:5 (satu dimensi, dua dimensi, dan tiga dimensi) direkabentuk menggunakan *Eurocode 2*, dikembangkan dan dibina berdasarkan teorem *Buckingham Pi* dan teori penyerupaan, dan kemudian diuji di makmal. Ketiga-tiga model yang merangkumi tapak tiang tunggal, rangka 2D IBS dan pelantar 3D IBS telah diuji dengan ujian empangan-pecah dengan serpihan dan tanpa serpihan menggunakan ketinggian air takungan 1 m, 2 m dan 3 m. Ketiga-tiga model ini juga diuji dengan hentaman mendadak pendulum. Hasilnya, perbezaan peratusan antara hasil ujian makmal dan simulasi numerik CFD untuk tegasan pelantar 3D adalah 12.87%, dan perbezaan peratusan untuk anjakan adalah 0.09 cm. Namun, model IBS dengan penyambung *bolt* mampu menahan daya hidrodinamik tertinggi berbanding dengan anggaran nilai dari FEMA P-646 dan FEMA P-55. Oleh itu, ini telah menjamin kebolehpercayaan struktur IBS dengan penyambung *bolt* dalam amalan sebenar. Selain itu, hasil ujian hentaman pendulum juga telah disahkan dengan literatur yang diterbitkan dan menunjukkan persetujuan yang baik. Hasil menunjukkan bahawa sambungan *bolt* adalah lebih berkesan dan mampu menyumbang kekuatan tambahan kepada kaedah IBS. Di samping itu, sambungan *bolt* terbukti berkesan dalam menyekat rebakan kerosakan ke komponen struktur yang lain. Pencarian kajian ini adalah sangat penting untuk meningkatkan kaedah pembinaan IBS semasa. Kajian ini juga telah berjaya meningkatkan pemahaman yang lebih baik terhadap tingkah laku hentaman serpihan pada struktur bangunan dan menyumbang pengetahuan baru mengenai hentaman serpihan yang dikaitkan dengan kod amalan rekabentuk.

## TABLE OF CONTENTS

	<b>TITLE</b>	<b>PAGE</b>
	<b>DECLARATION</b>	<b>iii</b>
	<b>DEDICATION</b>	<b>iv</b>
	<b>ACKNOWLEDGEMENT</b>	<b>v</b>
	<b>ABSTRACT</b>	<b>vi</b>
	<b>ABSTRAK</b>	<b>vii</b>
	<b>TABLE OF CONTENTS</b>	<b>ix</b>
	<b>LIST OF TABLES</b>	<b>xv</b>
	<b>LIST OF FIGURES</b>	<b>xix</b>
	<b>LIST OF ABBREVIATIONS</b>	<b>xxvii</b>
	<b>LIST OF SYMBOLS</b>	<b>xxix</b>
	<b>LIST OF APPENDICES</b>	<b>xxxii</b>
<b>CHAPTER 1</b>	<b>INTRODUCTION</b>	<b>1</b>
1.0	Problem Background	1
1.1	Background of the Problem	1
1.2	Problem Statement	4
1.3	The Research Seeks to Address the Following Questions	4
1.4	Aim and Objectives of the Study	5
1.5	Scope of the Study	5
1.6	Importance of the Study	6
<b>CHAPTER 2</b>	<b>LITERATURE REVIEW</b>	<b>7</b>
2.0	Introduction	7
2.1	Rainfall in Malaysia	7
2.1.1	Effect of Rainfall in Malaysia	11
2.2	Flood in Malaysia	12
2.2.1	Flash Flood	12
2.2.2	Heavy or Monsoon Flooding	13

2.3	Design Codes for Flood and Tsunami Structures	16
	2.3.1 Bernoulli Equation	23
2.4	Previous Research on Dam-break Test	24
	2.4.1 Pre-conclusion of Previous Research on Dam-break Test	34
2.5	Impact of the Debris Flow	34
	2.5.1 Pre-Conclusion	48
2.6	Existing Solution to Mitigate Flood	48
	2.6.1 Methods of Reconstruction	49
	2.6.1.1 Industrialized Building System	50
	2.6.1.2 Connection and Joint in IBS (Precast Frame)	54
	2.6.1.3 Connection Problems in IBS	64
2.7	Buckingham Pi Theorem	74
2.8	Concluding Remarks	84
<b>CHAPTER 3</b>	<b>RESEARCH METHODOLOGY</b>	<b>87</b>
3.0	Introduction	87
3.1	Autodesk Simulation CFD	88
3.2	Procedure of Autodesk Simulation CFD	89
3.3	Procedure of Autodesk Simulation Mechanical	91
	3.3.1 Material Properties, Boundary Conditions, Meshing and Loads	92
3.4	Stage 1: Laboratory Materials Preparation	94
3.5	Case Study of the Research	95
3.6	Modelling and Similitude Law	97
	3.6.1 Geometric Similarity	98
	3.6.2 Kinematic Similarity	99
	3.6.3 Determination of Pi	100
3.7	Construction of Scaled 1:5 IBS Specimens	101
	3.7.1 Specifications of Reinforced Concrete Structures	102
	3.7.2 Formwork Fabrications	105
3.8	Casting Procedure	108

3.9	Dam-break	110
3.9.1	The Facilities of Dam-break Testing Tank	111
3.9.2	Instrumentation for Dam-break Data Collection	113
3.9.2.1	Pressure Meter cell	114
3.9.2.2	Accelerometer	115
3.9.2.3	High Speed Camera	116
3.9.2.4	Data Logger System	116
3.9.3	Dam-break Experimental Test	117
3.9.3.1	Model 1: Dam-break Test of Single Column-footing	117
3.9.3.2	Model 2: Dam-break Test of IBS 2D Frame	119
3.9.3.3	Model 3: Dam-break Test for 3D IBS Platform	121
3.10	Concluding Remarks	123
<b>CHAPTER 4</b>	<b>RESULTS OF MATERIALS TESTING</b>	<b>125</b>
4.0	Introduction	125
4.1	Reinforcement Details	126
4.2	Concrete Mix Design	131
4.3	Design Process of Corbel and Steel Bolts	136
4.3.1	Design of Full Scaled Corbel	136
4.3.2	Design of Steels Bolts	137
4.3.2.1	Flexural of Steel Bolts for Scaled Down Structure	139
4.3.2.2	Design of Pull Out for the Steel Bolts	140
4.3.2.3	Design of Sliding Shear	141
4.4	Conclusion	141
<b>CHAPTER 5</b>	<b>NUMERICAL SIMULATION</b>	<b>143</b>
5.0	Introduction	143
5.1	Autodesk Simulation CFD	144



5.1.1	Model 1: CFD Simulation of IBS Single Column-footing	145
5.1.2	Model 2: CFD Simulation of IBS 2D Frame	147
5.1.3	Model 3: CFD Simulation of 3D IBS Platform	149
5.1.4	Pre-conclusion of CFD Results	152
5.2	Nonlinear Finite Element using Autodesk Simulation Mechanical	153
5.2.1	Autodesk Simulation Mechanical for Single Column-footing	153
5.2.2	Autodesk Simulation Mechanical for IBS Frame	155
5.2.3	Autodesk Simulation Mechanical for 3D Platform	157
5.3	Concluding Remark of Simulations	159
<b>CHAPTER 6</b>	<b>DAM-BREAK TEST</b>	<b>163</b>
6.0	Introduction	163
6.1	Model 1: Hydraulic Pressure Test of Single Column with Footing	164
6.2	Model 2: Hydraulic Pressure Test for 2D IBS Frame Structure	168
6.2.1	Test 1 of 2D IBS Frame for 1 m Reservoir Water Height	168
6.2.2	Test 2 of 2D IBS Frame for 2 m Reservoir Water Height	170
6.2.3	Test 3 of 2D IBS Frame for 3 m Reservoir Water Height	173
6.3	Module 3: Hydraulic Pressure Test for 3D IBS Structure	175
6.3.1	Test of 3D IBS Platform for 1 m Reservoir Water Height	175
6.3.2	Test of 3D IBS Platform for 2 m Reservoir Water Height	177
6.3.3	Test of 3D IBS Platform for 3m Reservoir Water Height	179
6.4	Discussion of Dam-Break Test for 3 Different Models.	181
6.4.1	Estimation of Hydrodynamic Forces	184

6.5	Result and Discussion of Structural Vibration Test	186
6.5.1	Dynamic Properties of Single Column Test	187
6.5.2	Dynamic properties of 2D IBS Frame structure	189
6.5.3	Model 3: Dynamic Properties of 3D Platform Test Results	192
6.6	Model 4: Dynamic Properties of 3D IBS Platform Test for Debris	197
6.6.1	Debris Impact Load	199
6.7	Comparison of Dam-break Tests with CFD Simulations	205
6.8	Concluding Remarks	208
<b>CHAPTER 7</b>	<b>PENDULUM IMPACT TEST</b>	<b>209</b>
7.0	Introduction	209
7.1	Free Swinging Pendulum Test	210
7.2	Impact Test for Model 1	212
7.3	Impact Test of 2D Frame	216
7.4	Impact Test of 3D Platform	221
7.5	Discussion of Pendulum Impact Force	227
7.6	Comparison of Pendulum Impact Test with Simulation Mechanical	229
7.7	Concluding Remarks	230
<b>CHAPTER 8</b>	<b>CONCLUSION AND RECOMMENDATION</b>	<b>233</b>
8.1	Conclusion	233
8.1.1	Design and Fabrication of the Steel Bolt-Connected Precast Framing IBS	233
8.1.2	Simulation of The Dam-Break and Pendulum Impact Tests	233
8.1.3	Performance and Capacity of Bolt-Connected IBS Subject to Sudden Impact of Hydrodynamic Force	234
8.1.4	Performance and Capacity of Bolt-Connected IBS Subject to Sudden Impact of Pendulum	234
8.2	Significance of the Study	235
8.3	Recommendations for the Suture Studies	236

<b>REFERENCES</b>	<b>237</b>
<b>LIST OF PUBLICATIONS</b>	<b>287</b>

## LIST OF TABLES

TABLE NO.	TITLE	PAGE
Table 2.1	(cont.) some of the historical flood disasters in Malaysia	16
Table 2.2	Categorization of IBS Components (Azman, 2010)	52
Table 2.3	Similitude Relation for deflection of a down scaled model (S=10)	77
Table 2.4	Similitude Relation for the Mass of a Scaled Down Model (S=10)	79
Table 2.5	Similitude Relation for Deflection of a Scaled Down Model (S=10) (Murugan et al., 2013)	79
Table 2.6	Similitude Relation for Stress Induced in a scaled down Model (S=10).	80
Table 2.7	Summary of the Reviewed Literature	80
Table 3.1	Relevant variables for dimensional analysis of this research	100
Table 3.2	Scaling dimensions of the model	101
Table 4.1	5 mm Diameter Size of Steel Bars Results	130
Table 4.2	6 mm Diameter Size of Steel Bars Results	130
Table 4.3	6 mm Diameter Size of Steel bolts Results	130
Table 4.4	The proportions of concrete materials	132
Table 4.5	Compressive Strength for 7 Days of Curing	134
Table 4.6	Compressive Strength for 28 Days of Curing	134
Table 4.7	Splitting Tensile Test for 7 Days of Curing	135
Table 4.8	Splitting Tensile Test for 28 Days of Curing	135
Table 5.1	Simulation CFD Results for Model 1	147
Table 5.2	Simulation CFD Results for Model 2	149
Table 5.3	Simulation CFD Results for Model 3	151
Table 5.4	Simulation Mechanical Results for Model 1	154
Table 5.5	Simulation Mechanical Results for Model 2	156
Table 5.6	Simulation Mechanical Results for Model 3	159

Table 6.1	Maximum Forces for the 3 Tests of Model 1.	182
Table 6.2	Maximum Forces for 3 Tests of Model 2	183
Table 6.3	Maximum Forces for 3 Tests of Model 3	183
Table 6.4	Comparisons of Estimated Hydrodynamic Forces with Experimental Force	186
Table 6.5	Dynamic Properties of Single Column-Footing for Test 1	188
Table 6.6	Dynamic Properties of Single Column-Footing for Test 2	188
Table 6.7	Dynamic Properties of Single Column-Footing for Test 3	188
Table 6.8	Maximum acceleration for Single column-footing	189
Table 6.9	Dynamic Properties of Model 2 for Test 1	189
Table 6.10	Dynamic Properties of Model 2 for Test 2	189
Table 6.11	Dynamic Properties of Model 2 for Test 3	190
Table 6.12	Peak Values of Accelerations for Model 2	192
Table 6.13	Dynamic Properties of the 3D Platform for Test 1	195
Table 6.14	Dynamic Properties of the 3D Platform for Test 2	195
Table 6.15	Dynamic Properties of the 3D Platform for Test 3	196
Table 6.16	Maximum Acceleration for Model 3	197
Table 6.17	The Properties of the Debris Used	198
Table 6.18	Comparison of the hydrodynamic force of FEMA P646 and FEMA P55	200
Table 6.19	Test 1 of the 3D Platform for 3 Different Debris	202
Table 6.20	Test 2 of the 3D Platform for 3 Different Debris	202
Table 6.21	Test 3 of the 3D Platform for 3 Different Debris	202
Table 6.22	Test 4 of the 3D Platform for 2 m Water Height with 3 Different Debris	203
Table 6.23	Test 5 of the 3D Platform for 2 m Water Height with 4 Different Debris	203
Table 6.24	Test 6 of 3D Platform for 3 m Water Height with Four Different Debris	204
Table 6.25	Comparison Between Dam-break Results and CFD for Model 1	205

Table 6.26	Comparison Between Dam-break and CFD Results for Model 2	206
Table 6.27	Comparison Between Dam-break Results and CFD for Model 3	207
Table 7.1	Dynamic Properties of the Impact Test 3 for Model 1	215
Table 7.2	Calculated Values of Velocity Force and Stress of Model 1.	216
Table 7.3	Dynamic properties of the 2D frame for impact test of 2.0 m distance	219
Table 7.4	Calculated values of velocity, force and stress for 2D frame	219
Table 7.5	Dynamic properties of the middle column for the test of 1.5m distance	223
Table 7.6	Dynamic properties of the 3D platform for beam test of 0.5 m	224
Table 7.7	Dynamic properties of the 3D platform for 2 m impact distance	226
Table 7.8	Calculated values of velocity, force, and stress of the 3D platform for the last column impact tests	226
Table 7.9	The summary of sudden impact of the pendulum on IBS components	232

## LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
Figure 2.1	Annual moving average of mean daily temperature in: (a) Kota Kinabalu (1956–2018), (b) Kuchhing (1956–2018)	9
Figure 2.2	Annual moving average of mean daily temperature in: (c) Malacca (1960–2018), (d) Kuantan (1961–2018)	10
Figure 2.3	Annual moving average of mean daily temperature in: (e) Subang Jaya (1961–2018) (Ho and Tang, 2019)	11
Figure 2.4	Flash Flood of Penang in 2017 (Reuters, 2017)	13
Figure 2.5	Building model, (a) Testing channel, (b) Model of polymethylmethacrylate (PMMA), (c) Pressure-time history, (d) Top view of the model (Xiao and Li, 2013)	19
Figure 2.6	Displacement contour: (a) the first load step; (b) the final load step. (Xiao and Li, 2013)	20
Figure 2.7	Flood depth and design depth (Conrad <i>et al.</i> , 2012)	21
Figure 2.8	Illustrated ASCE tsunami terminology (Chock, 2015)	22
Figure 2.9	Damage to corner column due to debris damming. FEMA646. (Heintz and Mahoney, 2008)	23
Figure 2.10	Comparison of the impact of bores propagating on the column (a) Numerical (b) Experimental (Shibayama <i>et al.</i> , 2014).	27
Figure 2.11	Comparison of the impact of bores propagating on the column: Graph of numerical and experimental results (Shibayama <i>et al.</i> , 2014).	28
Figure 2.12	Centrifuge model tests and effective stress analyses, (a) Primary mechanism of failure, (b) Existing design procedure of a breakwater (Lai, 2015)	29
Figure 2.13	Centrifuge model tests and effective stress analyses: (a) Deformation of caisson and rubble mound, (b) Centrifuge model of building (Lai, 2015).	29
Figure 2.14	(a) Artificial earth bank after tsunami. (b) Overview of waterway and bank model (Tokida, 2015)	30
Figure 2.15	(a) Collapse of a wood frame house. (b) Total collapse of constructions (Lekkas <i>et al.</i> , 2011)	30

Figure 2.16	Sequence of images showing the evolution of the flow at various times (Silvester and Cleary, 2006)	31
Figure 2.17	Typical sequence photo of wave impact during TWB (van de Lindt <i>et al.</i> , 2009)	32
Figure 2.18	Individual columns (Left–50x50mm, Centre–150x50mm, Right–300x50mm) (b) Typical offset column layout (50x50mm leading edge columns, 150x50mm interior column/wall) (Santo and Robertson, 2010)	33
Figure 2.19	Damaged buildings by the Zhouqu debris flow: (a) a huge amount of sediment and debris transported onto the existing alluvial fan; (b) extensively damaged apartment buildings; (c) a collapsed two-storey building (Tang <i>et al.</i> , 2011).	35
Figure 2.20	Buildings with different damage degrees: (a) complete damage, (b) heavy damage, (c) moderate damage, (d) Damaged buildings with different structural types (Zhang <i>et al.</i> , 2018)	36
Figure 2.21	Debris motion until its collision with the structure. The vertical grey dashed lines indicate the debris travel positions along the flow depth (Shafiei <i>et al.</i> , 2016)	37
Figure 2.22	(a) A representative smart debris device (the disc) time history for experiment. The sharp rise in the acceleration (i.e. at 2.99 s) is for when the debris struck the structure, (b) A representative load cell time history. (Source: Shafiei <i>et al.</i> , 2016)	38
Figure 2.23	Typical water–debris–panel interaction in the simulations (Como and Mahmoud, 2013)	39
Figure 2.24	Schematic representation of the damage mechanisms: (a) Horizontal Plastic Hinge (HPH), (b) Vertical Plastic Hinge (VPH), (c) Shear Sliding (SS), (d) Shear Diagonal (SD) (Lonetti and Maletta, 2018).	41
Figure 2.25	Schematic of the debris impact model. (a) Single DOF model. The red elements represent the portions of the solution neglected due to simplifying assumptions. (b) Hertzian contact model (Stolle <i>et al.</i> , 2018).	42
Figure 2.26	(a) Shipping container in pendulum test setup, (b) Wood utility pole in pendulum test setup (Riggs <i>et al.</i> , 2014).	43
Figure 2.27	(a) Aluminum specimen for in-water tests showing guide wires, (b) Aluminum specimen for in-water tests showing column in upper portion of the figure (Riggs <i>et al.</i> , 2014)	44
Figure 2.28	Impact force time histories for wood pole test series with contact materials: (a) Pendulum test setup, (b) rubber sheet at 1.5 m/s and (c) plywood sheets at 1.2 m/s (Aghl, 2014)	46



Figure 2.29	(c) Force and strain time histories for one of the trials from CT5 (Aghl, 2014) (cont')	47
Figure 2.30	Key milestone of IBS (Azman, 2010)	51
Figure 2.31	Full scale test (a) General view of the experimental set-up. (b) 3D drawing model. (Negro <i>et al.</i> , 2013)	53
Figure 2.32	Definition of joint and connection (Hau, 2018)	54
Figure 2.33	Strut-and-tie, for the transfer of bearing forces (Elliott and Jolly, 2013)	56
Figure 2.34	Strut-and-tie, for the transfer of bearing forces Beam supported on corbel: (a) Types of connection and joint in IBS, (b) Shallow corbel beam to column connection, (c) Deep corbel beam to column connection (Mokhtar, 2017) (cont).	57
Figure 2.35	Detail view of narrow plate beam to column hiding connection (a and b) (Hau, 2018).	57
Figure 2.36	(c) Detail view of narrow plate beam to column hiding connection (d) Isometric view (Hau, 2018) (cont').	58
Figure 2.37	The configuration of the connection; sketching of the composite structure (Lacerda <i>et al.</i> , 2018).	59
Figure 2.38	Displayed the connection configuration (a) Isometric view of the connection and joint, (b) Placed wet grouting for dowel and (c) Steel dowel and corbel (Lacerda <i>et al.</i> , 2018) (cont').	60
Figure 2.39	Displayed 2D IBS frame with bolt and steel plate connection (c) FE AC yield of IBS frame at 125 kN (d) Experimental load-displacement relationship (Wong <i>et al.</i> , (2015)) (cont').	63
Figure 2.40	Cast-in-situ beam to column connection in precast (Negro <i>et al.</i> , 2012).	64
Figure 2.41	Connections using dowels (Negro <i>et al.</i> , 2012).	65
Figure 2.42	Mechanical couplers, (a) High resistance bolts and (b) Plan view of the bolts (Negro <i>et al.</i> , 2012).	66
Figure 2.43	Hybrid connections (Negro <i>et al.</i> , 2012).	67
Figure 2.44	Modes of failures in corbels (Park R, 1975)	67
Figure 2.45	Damage and collapses of industrial building in Italy after the 2012 Emilia earthquake (a) Lightly damage of precast masonry cladding wall, (b) Damage to the column fork, (c) Collapse of the beam, (d) Flexural-shear, (e) Lateral	

	rotation of beam, (e) Beam damaged due to lateral rotations on corbel (Savoia <i>et al.</i> , 2017).	69
Figure 2.46	(a) Poor connection system leads to issues of comfort and safety, (b) Concrete beam-column connection defect, (c and d) steel beam to concrete wall and column connection (Baharuddin <i>et al.</i> , 2006).	70
Figure 2.47	Proposed beam to column connection joint with shallow corbel, (a) Details of the connection joint, (b) Specimen after testing (Mokhtar, 2017).	71
Figure 2.48	Steel plate strengthening of specimen PC-S ready for the test (Al-Salloum <i>et al.</i> , 2018).	72
Figure 2.49	After testing steel plate strengthening of specimen PC-S (Al-Salloum <i>et al.</i> , 2018).	73
Figure 2.50	Summary of the identified gap	86
Figure 3.1	Flowchart of the overall research methodology	88
Figure 3.2	Displayed the testing tank with the model	89
Figure 3.3	Height of fluid initial condition	90
Figure 3.4	Meshing process.	90
Figure 3.5	The imported 2D frame from AutoCAD	92
Figure 3.6	Fixed end Support	93
Figure 3.7	Direction of the load	94
Figure 3.8	Flowchart of stage 2: Laboratory materials preparation	95
Figure 3.9	AutoCAD 1D steel bolt connected single column to footing structure	96
Figure 3.10	Tested 2D steel bolt connected IBS frame structure	97
Figure 3.11	AutoCAD 3D steel bolt connected IBS platform structure	97
Figure 3.12	IBS steel bolt connected Column-footing structures	103
Figure 3.13	IBS steel bolt connected 2D frame structures, (a) AutoCAD drawing and (b) Laboratory experiment	104
Figure 3.14	IBS 3D platform structure: (a) AutoCAD drawing and (b) Laboratory experiment	105
Figure 3.15	Preparing the column mould: (a) Metal column mould and (b) Column mould with reinforcement.	106
Figure 3.16	Prepared formwork for: (a) Beams (b) Slabs and (c) Footing (cont').	108

Figure 3.17	Fabrications of IBS components: (a) Mixing process, (b) Casted hollow core footing, (c) Beams, (d) Hollow-core slabs (e) Columns and (f) Assembling the IBS components for 3D platform (cont').	110
Figure 3.18	The details of dam break tank: (a) The typical drawing of the testing tank, (b) Side view and (c) Top plan view	111
Figure 3.19	Dam-break tank facilities: (a) Right view, (b) Flume area, (c) Left view and (d) Motorize torsional derive for rotating the reservoir.	113
Figure 3.20	Showing the locations of devices on the structure	114
Figure 3.21	Water proofing Pressure meters cells	115
Figure 3.22	USB accelerometer X6-1	115
Figure 3.23	Testing Pressure meter using data logger for calibration	116
Figure 3.24	During dam-break Test of Single Column-footing: (a) Schematic Diagram of the Test, (b) The Actual Laboratory Test, (c) Frontside of the Column and (d) Backside of the Column (cont').	119
Figure 3.25	2D IBS Frame Ready for Testing: (a) Schematic Diagram, (b) Frontside of the Experimental Test and (c) Backside of the Frame (cont').	121
Figure 3.26	3D platform assembled for dam-break test: (a) Schematic Diagram and (b) Experimental Structure	122
Figure 4.1	Flowchart of Stage 2 Part B	125
Figure 4.2	Reinforcement details: (a and b) Column details, (c) AutoCAD details and (d) Actual footing details.	126
Figure 4.3	Details of beam reinforcement: (a) AutoCAD drawing, (b) Laboratory experiment	127
Figure 4.4	Details of slabs reinforcement: (a) AutoCAD drawing, (b) Laboratory experiment	128
Figure 4.5	Splitting tensile test: (a) 5 mm steel bar, (b) 6 mm steel bar (c) 6 mm steel bolt	129
Figure 4.6	Testing of concrete cylinders, (a) Cylinder under compressive test, (b) Cylinders after compression tests (c) Cylinder under splitting test, (d) Cylinders after splitting tests	133
Figure 5.1	Stage 2: Process of Numerical Simulation Analysis	144

Figure 5.2	Illustrations of: (a) Test of single column-footing, (b) Maximum velocity from and (c) Maximum pressure from (cont').	146
Figure 5.3	CFD simulation test: (a) During the test, (b) Maximum pressure (c) Maximum velocity	150
Figure 5.4	Finite Element Simulation for Model 1 (a) Displacement from simulation and (b) Stress from simulation.	154
Figure 5.5	Illustration of Model 2: (a) The deformation (progressive failure) pattern, (b) The location of concrete cracks, crushes and maximum stress (c) Displacement of contour (cont').	156
Figure 5.6	Model 3 Simulation Test: (b) The stress contour of the model, (c) Displacement contour (cont').	158
Figure 6.1	Stage 3: Laboratory Experimental Tests	163
Figure 6.2	Model 1 Dam-break Test 1 for 1 m Reservoir Water Height: (a) During the Experimental Test, (b) Schematic Diagram of the Test and (c) Graph of 1 m Reservoir Water Height Test	165
Figure 6.3	Model 1 Dam-break Test 2 for 2 m Reservoir Water Height, (a) During the 2 <sup>nd</sup> Experimental Test and (b) Graph of 2 m Reservoir Water Height Test	166
Figure 6.4	Model 1 Dam-break Test 3 for 3 m Reservoir Water Height, (a) During the 3 <sup>rd</sup> Experimental Test and (b) Graph of 3 m Reservoir Water Height Test	167
Figure 6.5	Model 2 Dam-break Test for 1 m Reservoir Water Height: (a) Schematic Diagram of the Dam-break Test and (b) During the Test 1 of 2D Frame (cont')	169
Figure 6.6	Graph of 1 m Reservoir Water Height Test for Model 2	170
Figure 6.7	Dam-break Test 2 for 2 m Reservoir Water Height, (a) Frontside of the frame and (b) Backside of the 2D frame	171
Figure 6.8	Damages of the frame after the 2nd test.	172
Figure 6.9	Graph of 2 m Reservoir Water Height Test for Model 2.	172
Figure 6.10	Dam-break Test 3 for 3 m Reservoir Water Height:(a) Frontside of the 2D frame during the test, (b) Backside of the 2D frame during the test and (c) Damaged of the Frame After 3 <sup>rd</sup> Test (cont').	174
Figure 6.11	Graph of 3 m Reservoir Water Height Test 3 for Model 2.	174
Figure 6.12	Model 3 Dam-break Test 1 for 1 m Reservoir Water Height: (a) Schematic Diagram of the Dam-break Test and (b) During the 1 <sup>st</sup> Experimental Test (cont').	176

Figure 6.13	Model 3 Dam-break Test 1 for 1 m Reservoir Water Height: (a) The structure after testing and (b) Graph of 1 m Reservoir Water Height Test 1 for Model 3 (cont').	177
Figure 6.14	Dam-break Test 2 for 2 m Reservoir Water Height, a) The Structure During the Test and (b) The Structure After the Test	178
Figure 6.15	Graph of 2 m Reservoir Water Height Test 2 for Model 3	179
Figure 6.16	Dam-break Test 3 for 3 m Reservoir Water Height (c) Graph of 3 m Reservoir Water Height for Model 3 (cont').	181
Figure 6.17	Hydrodynamic force distribution and location of resultant (FEMA, 2012b).	184
Figure 6.18	Inland-location structure and momentum flux estimation parameters (FEMA, 2012b)	185
Figure 6.19	Single column-footing with accelerometers after the dam-break test.	187
Figure 6.20	The Frame is Illustrating the Positions of the Accelerometers	190
Figure 6.21	The Maximum Acceleration from AC3 for (a) Test 1 of 1 m water height, (b) Test 2 of 2 m water height and (c) Test 3 of 3 m water height	191
Figure 6.22	3D Platform Illustrates the Positions of Accelerometers During Test	193
Figure 6.23	Histories for 3 m Reservoir Water Depth Test 3: (a) Accelerometer number 1, (b) Accelerometer number 2, (c) Accelerometer number 3, (d) Accelerometer number 4 and (e) Accelerometer number 5 (cont').	194
Figure 6.24	Samples of the debris: (a) Three Different Cylinders and (b) Aerated Concrete (cont').	198
Figure 6.25	Test of the 3D platform for 3 different debris, a) During the test, b) After the test	201
Figure 6.26	Test of the 3D platform for 3 m reservoir water height with 4 different debris, (a) During the test and (b) After the test	204
Figure 7.1	Stage 4 Part B: Laboratory experimental tests	210
Figure 7.2	Free swinging test: (a) Showing a metal block, block rubber, and swinging ropes, (b) Free swinging block test.	211
Figure 7.3	Maximum acceleration for free swinging test	212
Figure 7.4	Sudden Impact Test of the Single Column-footing: (a) Schematic Drawing of Column-footing (b) Structural	

	Column Ready for Test and (c) Column-footing After Testing (cont’).	214
Figure 7.5	The relationship between impact force and impact velocity (Aghl, 2014)	215
Figure 7.6	Comparison of Displacement for the Impact force of Model 1	216
Figure 7.7	The 2D Steel Bolt Connected IBS Frame, (a) Schematic Drawing of the Frame and (b) Frame Before Impact Test.	217
Figure 7.8	The 2D frame after four consecutive impact tests.	218
Figure 7.9	Comparison of Displacement graph for 2D Frame Model 2	220
Figure 7.10	Pendulum impact test of the infill wall: (a) Schematic Drawing of the Test, (b) After impact test of 0.5 m distance and (c) After impact test of 1.5 m distance.	222
Figure 7.11	Test of the column with infill walls on both sides	223
Figure 7.12	Impact test of the beam-slab	224
Figure 7.13	Test of last column of the 3D platform.	225
Figure 7.14	Comparison of the Impact Force-time Histories for Four Different Methods	227

## LIST OF ABBREVIATIONS

AC	-	Accelerometer
FEMA	-	Federal Emergency Management Agency
CFD	-	Computational Fluid Dynamic
NLFEA	-	Non-Linear Finite Element Analysis
IBS	-	Industrialized Building System
P	-	Fluid Pressure
LVDT	-	Linear Variable Differential Transducer
BS	-	British Standard
ASTM	-	American Society for Testing and Materials
ASCE	-	American Society Civil Engineers
ACI	-	American Concrete Institute
1D		One-dimensional
2D		Two-dimensional
3D		Three-dimensional
PMMA		Polymethylmethacrylate
DFE		Design Flood Elevation
GS		Lowest Ground Surface Elevation
MCT		Maximum Considered Tsunami

## LIST OF SYMBOLS

$\delta$	-	Minimal error
$D, d$	-	Diameter
$F$	-	Force
$v$	-	Velocity
$p$	-	Pressure
$I$	-	Moment of Inertia
$r$	-	Radius
Re	-	Reynold Number
$\gamma(\delta)$		Pressure Load
$\rho$		Fluid Density
$\tau$		Stress Tensor
$\alpha(\beta)$		Reservoir Depth Ratio
$F_d$		Hydrodynamic Force
$f_y$		Steel yield strength
$f_{cu}$		Concrete Compressive Strength
$S_\sigma$		Scale factor in stress
$S_l$		Scale Factor in length
$\sigma$		Stress Factor
$F_i$		Impulsive forces
$Fr_p$		Froude number for prototype
$Fr_m$		Froude number for model
$Eu_m$		Euler number for model
$Eu_p$		Euler number for prototype
$Re_m$		Reynolds number for model
$Re_p$		Reynolds number for prototype
$We_p$		Weber number for prototype
$We_m$		Weber number for model
$Ma_p$		Sarrau-Mach number for prototype
$Ma_m$		Sarrau-Mach number for model



$E_b$	Bulk modulus of elasticity of water
$C_{str}$	Coefficient of the building structure
$Fr$	Froude number
$Eu$	Euler number
$Re$	Reynolds number
$We$	Weber number
$Ma$	Sarrau-Mach number
$L_{px}$	Length of Prototype From x-axis
$L_{mx}$	Length of Model From x-axis
$M_x$	Model x-axis
$M_y$	Model y-axis
$M_z$	Model z-axis
$(hu)_{max}$	Momentum flux
$u_{max}$	Flow velocity

## LIST OF APPENDICES

<b>APPENDIX</b>	<b>TITLE</b>	<b>PAGE</b>
Appendix A	Design of reinforcement	247
Appendix B	Steel and Concrete material properties	259
Appendix C	Dam-break tests	269
Appendix D	Pendulum impact test	277
Appendix E	Calibration of pressuremeters	285

# CHAPTER 1

## INTRODUCTION

### 1.0 Problem Background

Malaysia is experiencing heavy rainfall which can cause a lot of disasters due to the reason that the country lies entirely in the equatorial zone. Heavy rain has a great impact on many aspects of the Malaysian people's lives on the east coast of Peninsular. Though the rains are very vital for farming among others, especially wet rice farming, they may also be the main responsible for causing seasonal floods. Therefore, rains and floods are frequently identified as hazards and resources (Parker, 1996). There is a flash flood in the urban areas which is the most common and disruptive hydro-meteorological phenomena that they are experiencing most often. Flood in the rural area can cause more devastating effect not only to the environment or the life of people but also to whatever infrastructures available, it can also destroy permanent settlement which would generate a big disaster to the rural environmental areas. Numerous things are adding to the flooding challenges varying from the topography of the area, drainage problems, some engineering structures, and the climate. Floods are mostly caused due to the presents of storms wherein a lot of rainfall occurred in a very short time. These types of precipitation rains, resulting in a frontal storm. Other main factors that caused the presents of flood hazards are intensity and long duration of the rain.

### 1.1 Background of the Problem

Flood has been a serious problem in Malaysia, several major floods have been experienced within the last decade of December 2006; January 2007; August 2010; December 2012; December 2013; and December 2014 through January 2015. Malaysian Drainage and irrigation department categorized flooding into two types: heavy rains (monsoon) floods and flash flooding (DID, 2000). According to the

perspective views of hydrological experts, the clear difference between monsoon floods and flash flooding disasters is the period of dissipation whereby the river flow declines back to the normal water level. Flash flood usually takes only a few hours to return to the normal level of the water, while heavy rains (monsoon) flood could potentially prolong to a month. There is a total of 189 river basins in the whole of Malaysia which the main channels are directly flowing into the south china sea. Furthermore, 85 of the river basins are prone to frequent flooding (89 of them were in Peninsula Malaysia, while 78 are in Sabah and 22 are in Sarawak). The expected area which is exposed to flooding catastrophe is roughly 29,800 km<sup>2</sup> which is 9% of the total area of Malaysia. This is affecting over 4.82 million Malaysians, and this is near to 22% of Malaysia's total population (Abdullahi, 2015).

It has been recorded that Muar River Basin has been experiencing numerous flooding for over a long a period, there was a series of monsoon rain events that had caused flooding in the Muar River Basin geographical region. The floods that were recorded are shown from December 1926 to January 1927, February to April 1967, November 1967 to January 1968, December 1970 to January 1971, and November 1979, respectively. From 1980 to 2010, a total number of 29 flood incidents have been noted (Abdullahi, 2015). Among the side effects of flooding include damages to houses, shops, schools, farmland, industries, and water quality. The research had shown that flood victims faced problems of repairing cost, some with small scale businesses could not be able to reopen their business after the flooding disaster (Vinet, 2008).

Malaysian government recognizes the Drainage and Irrigation Department (DID) as the authorized department that is handling flooding disasters in the country. They DID, however, is an agency that is dominated by engineers who were professionally trained for controlling floods. The main policy and strategy of DID for flood mitigation comprises large structural measures which include dams and embankments for controlling flood flows. Despite the claims of DID in recent years, the department decided to consider non-structural processes which include the following: alerting systems for mitigating the flood impact, planning for the land use, forecasting of the flood. In order to implement the rule guidelines for mitigating the

flood, the following measures were considered first: (i) Implementing the flood mitigation structures with relevance to engineering and commercial environment; (ii) Implementing structural measures of complementary; (iii) Implementing non-engineering measures in the places where there is lacking technical solution, and (iv) Persistence on strengthening the forecasting of the flood plus warning systems. Furthermore, the authority had carried out a different number of projects for mitigating the flood which most of which were structural mitigation procedures such as channelization of rivers, increasing river embankments and constructing multi-purpose dams (Abdullahi, 2015).

Some of the strategies for flood mitigation have been successful in decreasing some of the effects of flood, although they are not completely successful in the entire flood management. Furthermore, it is predicted that the upcoming floods may become harsher because of higher populations, more intensive farming and the increasing of industries. All these can easily increase the effect of floods, exposure, and vulnerability to flooding hazards. Likewise, on the side of the crowds, it is predicted that the impact of the flood could become more dangerous and enduring with longer recovery time as the erosion of social capital becomes further and more pronounced (Abdullahi, 2015).

It is a harsh fact that flooding is happening every year whereby there is an anticipation of extreme flooding once in every 5-years due to heavy monsoon rainfall. Under this circumstance, people need shelter for living safely, and it is not easy to mitigate the frequency and intensity. Therefore, there is a need to concentrate on recovery framework, which is building a permanent settlement by producing a building system in which the structures can be built very fast and must be robust and cheap. There are many proposed solutions which include container, modular blocks and IBS frame structure that is readily available in the local market. IBS has been acknowledged as one of the best solutions, yet IBS has some problems, and the performances are not fully investigated especially the performance and the behaviour at the joint. Since floods with debris move at high speed, the sudden impact imposed by flood with debris onto the sidewall of permanent settlement may cause failure especially at the joint.

## **1.2 Problem Statement**

An industrialized building system (IBS) has been proposed as the best solution for building a permanent settlement in the flood-prone zone where they experienced an extreme flood disaster. IBS can offer speedy site assembly with high quality of construction; this makes it the best candidate for rebuilding post-disaster permanent settlements. Moreover, IBS is very strong for sustaining vertical load, but it is not designed to sustain the horizontal sudden impact load especially at the joint. Since the existing IBS system is not designed to sustain a horizontal impact due to flood with debris, the construction of newly built permanent settlements will be destroyed by flood in the next cycle. Hence, it will increase the cost of flood disaster recovery in the long term. However, studies on the behaviour and performance of IBS subjected to horizontal impact are lacking. Furthermore, the joint of an IBS is likely to be the weakest point and vulnerable to failure when subjected to horizontal load. There is, therefore, the need to develop a bolt-connected IBS able to withstand the horizontal impact of the flood. Nevertheless, the performance and the behaviour of steel bolt connections are still in the infancy stage. Therefore, this study would be investigating the details of how the bolt connection performs and behaves subject to sudden impact due to horizontal load. If bolt can be proven to be more effective, then this would contribute to the additional robustness of the IBS. Hence, it can potentially become the best solution for flood-prone zone structures in the future.

## **1.3 The Research Seeks to Address the Following Questions**

1. How to convert the conventional reinforced concrete structural system to Industrialized Building System?
2. Could the converted IBS provide a better qualitative and reliable building system to the future structures especially for flood disaster recovery purposes?
3. How to create a building system that would prevent one structural component from transferring its failure to another component subject to sudden horizontal load?

## **1.4 Aim and Objectives of the Study**

The aim of this study is to investigate the performance and behaviour of steel bolt-connected IBS structures subjected to the sudden impact of hydrodynamic force with debris and horizontal impact force of pendulum. The impact will be simulated using simulation software programs (NLFEA and CFD) and laboratory experimental work. In addition, to achieve the stated aim, the following objectives of the research are stated as follows.

- 1 To design and fabricate steel bolt-connected precast framing IBS components using current design code and construction method.
- 2 To simulate the dam-break tests and pendulum impact tests using Autodesk CFD simulation and Autodesk simulation mechanical (NLFEA) for optimizing the laboratory experimental work.
- 3 To identify the performance and the capacity of bolt-connected IBS components subjected to the sudden impact of hydrodynamic force on 1D, 2D, 3D IBS components.
- 4 To investigate the performance and the capacity of bolt-connected IBS components subjected to the sudden impact of pendulum on 1D, 2D, and 3D IBS components.

## **1.5 Scope of the Study**

This study focuses on investigating the performance and the behavior of scaled 1:5 IBS structures using steel bolt as the mode of the connections. There are two phases in this research which are: Autodesk simulation software programs and the laboratory experimental work. Two simulation software programs were used in phase one. On the other hand, Autodesk simulation CFD was used for simulating dam-break tests, the observed parameters in this simulation are velocity and pressure. While the other

software is simulation mechanical for nonlinear finite element analysis test, then, the observed parameters are force, stress, and displacement. These two simulation software programs were used to simulate the three IBS models (1D single column-footing, 2D frame and 3D platform) for optimizing the laboratory work. The second phase is designed to conduct two different laboratory tests for studying the performance and the behaviour of the proposed steel bolt-connected IBS components. The first laboratory experiment is the dam-break test, this test was simulating the sudden impact of flooding on the real structures. The second laboratory experiment is a pendulum impact test with the purpose to simulate the sudden impact of debris against three IBS models which include: 1D single column-footing, 2D frame and 3D platform. A total of 51 IBS components were designed and fabricated in the laboratory for this study, they were described as 14 precast hollow core slabs (7 slabs with 220 x 1940 x 40 mm and 7 slabs with 220 x 1500 x 40 mm), 21 precast beams (15 beams with 1300 x 100 x 60 mm and 6 beams with 340 x 100 x 60 mm), 8 hollow core footing, and 8 precast columns (100 x 100 x 700 mm) were made and assembled, and tested as a bolt connected IBS structures. Hence, the specimens were designed based on the guidelines of Eurocode 2.

## **1.6 Importance of the Study**

This research is addressing the crisis of construction mitigation and humanity during a disaster of a flood through the following points:

1. Flood-prone: some parts of Malaysia are in the flood-prone zone, and every year flooding is affecting one of those areas. This research is to find a solution to the devastation of floods by providing a reliable structure throughout the housing lifespan.
2. By replacing the conventional method of construction with a new innovative IBS system would reduce the construction time, provide better site management, reduced wastage, establish better qualitative structure, produce rapid building, and reduces the cost of construction



## REFERENCES

- Abdelwahed, B. (2019) 'A review on building progressive collapse, survey and discussion', 11.
- Abdullahi, M. G. (2015) 'Floods in Malaysia Historical Reviews , Causes , Effects and Mitigations Approach', (November 2014).
- ACICommittee444 (1982) 'Models of Concrete Structures.', *American Concrete Institute*.
- Aghl, P. P. (2014) *Determination of Demands Resulting From High Mass , Low Velocity Debris Impact on Structures*. Lehigh University.
- Al-Faesly, T., Palermo, D., Nistor, I. and Cornett, A. (2012) 'Experimental modeling of extreme hydrodynamic forces on structural models', *International Journal of Protective Structures*, 3(4), pp. 477–506.
- Al-Salloum, Y. A., Alrubaidi, M. A., Elsanadedy, H. M., Almusallam, T. H. and Iqbal, R. A. (2018) 'Strengthening of precast RC beam-column connections for progressive collapse mitigation using bolted steel plates', *Engineering Structures*. Elsevier, 161(May 2017), pp. 146–160.
- ASCE (2017) *Minimum design loads for buildings and other structures, ANSI/ASCE Standard*.
- ASTM C150-05 (2005) 'Standard Specification for Portland Cement', *ASTM International, West Conshohocken, PA*.
- ASTM C496-96 (1996) 'Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens', *ASTM International, West Conshohocken, PA*, 04(March), pp. 1–4.
- ASTMC39/C39-11a (2011) 'Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.'
- Azimi, M., Adnan, A. Bin, Rahman, A., Mohd, B., Tahir, M., Faridmehr, I. and Hodjati, R. (2014) 'Seismic Performance of RC Beam-Column Connections with Continuous Rectangular Spiral Transverse Reinforcements for Low Ductility Classes', *Hidawi Publishing Corporation. The Scientific World Journal*, 2014, p. 12.

- Azman, M. N. A., et al (2010) “‘Perspective of Malaysian Industrialized Building System on the Modern Method of Construction.’”, *11th Asia Pacific Industrial Engineering and Management Systems Conference, Melaka, Malaysia*. <http://www.apie>.
- Baharuddin, A., Rahman, A. and Omar, W. (2006) ‘Issues and Challenges in the Implementation of Industrialised Building Systems in Malaysia’, *Proceedings of the 6th Asia-Pacific Structural Engineering and Construction Conference (APSEC 2006), Kuala Lumpur, Malaysia ISSUES*, (September), pp. 5–6.
- Bhuiyan, T. R., Hasan Reza, M. I., Choy, E. A. and Pereira, J. J. (2018) ‘Direct impact of flash floods in Kuala Lumpur City: Secondary data-based analysis’, *ASM Science Journal*, 11(3), pp. 145–157.
- BS12:1991 (1991) ‘Specification for Portland cement’, *British standard institution*.
- Buckingham, E. (1914) ‘On Physically Similar Systems: Illustrations of the Use of Dimensional Equations.’, *Physical Review* 4, 4(4), pp. 345–376.
- C778-02, A. (2002) ‘Standard Specification for Standard Sand’, *ASTM International, West Conshohocken, PA*.
- Caraballo-Nadal, N., Zapata-Lopez, R. and Pagán-Trinidad, I. (2006) ‘Building damage estimation due to riverine floods, storm surges and tsunamis: A proposed methodology’, *Proceeding of the 4th LACCET, International Latin American and Caribbean Conference for Engineering and Tehcnology (LACCET 2006), Mayagüez, Puerto Rico*, (June).
- Castro-Bolinaga, C. F. and Diplas, P. (2014) ‘Hydraulic modeling of extreme hydrologic events: Case study in Southern Virginia’, *Journal of Hydraulic Engineering*, 140(12), pp. 1–12.
- Catur, N., Yuliati, E., Murni, D. S. and Ari, W. (2018) ‘Comparative study of behaviour of reinforced concrete beam-column joints with reference to monolithic and non-monolithic connection’, 02021.
- Cawley, J. G. (2014) *Review of guidelines for the design of tsunami vertical evacuation buildings*. Oregon State University.
- Chen, H. Y., Xu, W. L., Deng, J., Xue, Y. and Li, J. (2014) ‘Experimental Investigation of Pressure Load Exerted on a Downstream Dam by Dam-Break Flow’, 140(February), pp. 199–207.
- Chen, W., Hong, H., Li, S., Shahabi, H., Wang, Y., Wang, X. and Ahmad, B. Bin (2019) ‘Flood susceptibility modelling using novel hybrid approach of

- reduced-error pruning trees with bagging and random subspace ensembles’, *Journal of Hydrology*. Elsevier, 575(February), pp. 864–873.
- Chock, G. (2015) ‘The ASCE 7 Tsunami Loads and Effects Design Standard’, in *Structures Congress 2015*. American Society of Civil Engineers, pp. 1446–1456.
- Como, A. and Mahmoud, H. (2013) ‘Numerical evaluation of tsunami debris impact loading on wooden structural walls’, *Engineering Structures*. Elsevier Ltd, 56, pp. 1249–1261.
- Congress, S. (2014) ‘Three Dimensional Loading Effects of Tsunamis on Bridge Superstructures’, (2011), pp. 1348–1358.
- Conrad D, Kapur O, Mahadevia A, Maldonado D, Moline J, Overcash G, Passman S, Manuel P, Reeder A, Seitz L, S. A. (2012) ‘Determination of Hazards’, in *Engineering principles and practices for retrofitting flood-prone residential structures*. Conrad D, Kapur O, Mahadevia A, Maldonado D, Moline J, Overcash G, Passman S, Manuel P, Reeder A, Seitz L, Sheldon A. *Engineering principles and practices for retrofitting*.
- Derschum, C., Nistor, I., Stolle, J. and Goseberg, N. (2018) ‘Debris impact under extreme hydrodynamic conditions part 1: Hydrodynamics and impact geometry’, *Coastal Engineering*. Elsevier, 141(September), pp. 24–35.
- DID (2000) *Urban storm water management manual for Malaysia, Kuala Lumpur*, Department of Irrigation and Drainage Malaysia.
- Dressler, R. F. (1952) ‘Hydraulic resistance effect upon the dam-break functions’, *Journal of Research of the National Bureau of Standards*, 49(3), p. 217.
- Elias, Z., Hamin, Z. and Bahrin, M. (2013) ‘Sustainable Management of Flood Risks in Malaysia: Some lessons from the legislation in England and Wales’. Elsevier B.V., 105, pp. 491–497.
- Ellingwood (2008) ‘Modeling Beam Column\_Joints in Fragility Assessmen.pdf’, *Journal of Earthquake Engineering*, (1363–2469), p. 27.
- European, U. (2011) ‘Eurocode 2: Design of concrete structures - Part 1-1 : General rules and rules for buildings’, *Avenue Marnix 17, B-1000 Brussels*, 1(2005).
- Fadwa, I., Abbas, T., Nazih, E. and Sara, M. (2014) ‘Reinforced concrete wide and conventional beam – column connections subjected to lateral load’, *Engineering Structures*. Elsevier Ltd, 76, pp. 34–48.

- Fao, K.F., 2012. Irrigation in Southern and Eastern Asia in figures AQUASTAT survey–2011. Food and Agriculture organization of the united Nations. (no date) ‘Malaysia: Geography, Climate and Population’, *Aquastat*, (Table 1), pp. 1–12.
- FEMA (2011) ‘Coastal Construction Manual’, *FEMA P-55*, II(August), p. 400.
- FEMA, F. E. M. A. (2012a) ‘Guidelines for Design of Structures for Vertical Evacuation from Tsunamis. Second Edition (FEMA P-646)’, *FEMA P-646 Publication*, (August).
- FEMA, F. E. M. A. (2012b) ‘Guidelines for Design of Structures for Vertical Evacuation from Tsunamis’, *FEMA P-646 Publication*, (April).
- Greco, M., Landrini, M. and Faltinsen, O. . (2004) ‘Impact flows and loads on ship-deck structures’, *Journal of Fluids and Structures* 19, pp. 251–275.
- Guerrero, H., Rodriguez, V., Escobar, J. A., Alcocer, S. M., Bennetts, F. and Suarez, M. (2019) ‘Experimental tests of precast reinforced concrete beam-column connections’, *Soil Dynamics and Earthquake Engineering*. Elsevier Ltd, 125(December 2018), p. 105743.
- Haehnel, R. B. and Daly, S. F. (2004) ‘Maximum impact force of woody debris on floodplain structures’, *Journal of Hydraulic Engineering*, 130(2), pp. 112–120.
- Harris, H. G. and Sabnis, G. (1999) ‘Structural Modling and Expeimental Techniques. 2nd’, *NewYork. CRC Press*.
- Hau, K. K. (2018) *Precast concrete connections, Department of Civil and Environmental Engineering*.
- Ho, K. and Tang, D. (2019) ‘Science of the Total Environment Climate change in Malaysia : Trends , contributors , impacts , mitigation and adaptations’, *Science of the Total Environment*. Elsevier B.V., 650, pp. 1858–1871.
- Hong, H., Panahi, M., Shirzadi, A., Ma, T., Liu, J., Zhu, A. X., Chen, W., Kougias, I. and Kazakis, N. (2018) ‘Flood susceptibility assessment in Hengfeng area coupling adaptive neuro-fuzzy inference system with genetic algorithm and differential evolution’, *Science of the Total Environment*. Elsevier B.V., 621, pp. 1124–1141.
- Hunt, B. (1984) ‘Perturbation solution for dam-break floods’, *J. Hydraul. Eng.*, 110(8), p. 1058.
- Jabar, I. L. and Ismail, F. (2018) ‘Challenges in the Management of IBS Construction Projects’, *Asian Journal of Quality of Life*. e-IPH Ltd., 3(9), p. 37.

- Jabar, I. Iaili, Ismail, F. and Mustafa, A. A. (2013) 'Issues in Managing Construction Phase of IBS Projects', *Procedia - Social and Behavioral Sciences*. Elsevier B.V., 101, pp. 81–89.
- Jalayer, F., Aronica, G. T., Recupero, A., Carozza, S. and Manfredi, G. (2018) 'Debris flow damage incurred to buildings: an in situ back analysis', *Journal of Flood Risk Management*, 11(2013), pp. S646–S662.
- Kang, H. sub and Kim, Y. tae (2016) 'The physical vulnerability of different types of building structure to debris flow events', *Natural Hazards*. Springer Netherlands, 80(3), pp. 1475–1493.
- Kaushal, P. and Hk, S. (2012) 'Concept of Computational Fluid Dynamics ( CFD ) and its Applications in Food Processing Equipment Design', 3(1), pp. 1–7.
- Kibert, C. J. (2007) 'The next generation of sustainable construction.', *Building Research & Information* 35 (6):, pp. 595–601.
- Kim, B., Sanders, B. F. and Asce, A. M. (2016) 'Dam-Break Flood Model Uncertainty Assessment : Case Study of Extreme Flooding with Multiple Dam Failures in Gangneung , South Korea', 142(5), pp. 1–18.
- Lacerda, M. M. S., da Silva, T. J., Alva, G. M. S. and de Lima, M. C. V. (2018) 'Influence of the vertical grouting in the interface between corbel and beam in beam-to-column connections of precast concrete structures – An experimental analysis', *Engineering Structures*. Elsevier, 172(May), pp. 201–213.
- Lai, S. (2015) 'Combined failure mechanism of breakwaters and buildings subject to Tsunami during 2011 East Japan earthquake', *Geotechnics for Catastrophic Flooding Events*. Taylor & Francis Group, London, (1), pp. 978-1-138-02709–1.
- Larocque, L. A., Imran, J., Asce, M., Chaudhry, M. H. and Asce, F. (2013) 'Experimental and Numerical Investigations of Two-Dimensional Dam-Break Flows', 139(June), pp. 569–579.
- Lekkas, E., Andreadakis, E., Alexoudi, V., Kapourani, E. and Kostaki, I. (2011) '2011 ) Tsunami Impact on Structures and Infrastructure'.
- Leon, A. S., Asce, M., Kanashiro, E. A., González-castro, J. A. and Asce, M. (2013) 'Fast Approach for Unsteady Flow Routing in Complex River Networks Based on Performance Graphs', 139(2012), pp. 284–295.

- van de Lindt, J. W., Gupta, R., Garcia, R. A. and Wilson, J. (2009) 'Tsunami bore forces on a compliant residential building model', *Engineering Structures*. Elsevier Ltd, 31(11), pp. 2534–2539.
- Livermore, S. N. and Motley, M. (2014) *Evaluation of Tsunami Design Codes and Recommendations for Bridges Susceptible to Tsunami Inundation*, University of Washington. MSc Thesis. University of Washington.
- Lonetti, P. and Maletta, R. (2018) 'Dynamic impact analysis of masonry buildings subjected to flood actions', *Engineering Structures*. Elsevier, 167(March), pp. 445–458.
- Lu, C., Dong, B., Pan, J., Shan, Q., Hanif, A. and Yin, W. (2018) 'An investigation on the behavior of a new connection for precast structures under reverse cyclic loading', *Engineering Structures*. Elsevier, 169(September 2017), pp. 131–140.
- M.N.A. Azman, M.H. Hanafi, T.A. Majid, M. S. S. A. (2010) 'Perspective Malaysia on the modern construction method', (December), pp. 7–10.
- Malaysian Standard MS 522: (2003) 'Portland cement (ordinary and bardening', part I Spe.
- Marsono, A. K., Ying, W. J., Tap, M., Chieh, Y. C. and Haddadi, A. (2015) 'Standard Verification Test for Industrialised Building System ( IBS ) Repetitive Manufacturing', *Procedia CIRP*. Elsevier B.V., 26, pp. 252–257.
- Moana, M., Lacerda, S., José, T., Moacyr, G., Alva, S., Cristina, M. and Lima, V. De (2018) 'In fl uence of the vertical grouting in the interface between corbel and beam in beam-to-column connections of precast concrete structures – An experimental analysis', *Engineering Structures*. Elsevier, 172(May), pp. 201–213.
- Mokhtar, R. (2017) 'Behaviour of Precast Beam-To-Column Connections By Using Partly Hidden Corbel Rohani Mokhtar Department of Civil Engineering'.
- Mydin, M. A. O., Sani, N. and Taib, M. (2014) 'Industrialised Building System in Malaysia : A Review 2 Industrialised Building System History In Malaysia', 01002, pp. 1–9.
- Negro, Paolo, Dionysios A. Bournas, and F. J. M. (2013) "'Pseudodynamic tests on a full-scale 3-storey precast concrete building: global response', *Engineering Structures* 57, pp. 594–608.

- Negro, P., Editors, G. T. and Toniolo, G. (2012) *Design Guidelines for Connections of Precast Structures under Seismic Actions Third Main Title Line Third Line*.
- Nistor, I., Asce, M., Goseberg, N., Stolle, J., Mikami, T., Shibayama, T. and Asce, M. (2017) 'Experimental Investigations of Debris Dynamics over a Horizontal Plane', 143(2014), pp. 1–15.
- Nistor, I., Palermo, D., Cornett, A. and Al-Faesly, T. (2010) 'Experimental and numerical modeling of tsunami loading on structures', *Proceedings of the Coastal Engineering Conference*, (February).
- Noorazuan M.H (2006) *Urban hydrological changes in the Sankey Brook catchment. Unpublished PhD thesis. Manchester. University of Manchester*.
- Novak, P., Guinot, V., Jeffrey, A., and Reeve, D. E. (2010) 'Hydraulic Modelling- An Introduction', *Spon Press, London, UK*.
- Ozmen-Cagatay, H., Kocaman, S. and Guzel, H. (2014) 'Investigation of dam-break flood waves in a dry channel with a hump', *Journal of Hydro-Environment Research. Elsevier B.V*, 8(3), pp. 304–315.
- Paczkowski, K., Riggs, H. R., Naito, C. J. and Lehmann, A. (2012) 'A one-dimensional model for impact forces resulting from high mass, low velocity debris', *Structural Engineering and Mechanics*, 42(6), pp. 831–847.
- Park R, P. T. (1975) 'Reinforced concrete structures.', *John Wiley & Sons*, (Jul 23).
- Parker, N. W. C. and D. (1996) 'Response to dynamic flood hazard factors in peninsular Malaysia', *Geographical Journal (1996): 313-325.*, 162, pp. 313–325.
- Pimanmas, A., Joyklad, P. and Warnitchai, P. (2010) 'Structural design guideline for tsunami evacuation shelter', *Journal of Earthquake and Tsunami*, 4(4), pp. 269–284.
- Pregolato, M., Ford, A., Wilkinson, S. M. and Dawson, R. J. (2017) 'The impact of flooding on road transport: A depth-disruption function', *Transportation Research Part D. The Authors*, 55, pp. 67–81.
- Qin, R. and Duan, C. (2017) 'The principle and applications of Bernoulli equation', *Journal of Physics: Conference Series*, 916(1).
- Rajagopal, S. and Prabavathy, S. (2014) 'Exterior beam-column joint study with non-conventional reinforcement detailing using mechanical anchorage under', 39(October), pp. 1185–1200.

- Ramu, M., Raja, V. P. and Thyla, P. R. (2013) 'Establishment of Structural Similitude for Elastic Models and Validation of Scaling Laws', 17, pp. 139–144.
- Rashidi, A. and Ibrahim, R. (2017) 'Industrialized Construction Chronology: The Disputes and Success Factors for a Resilient Construction Industry in Malaysia', *The Open Construction and Building Technology Journal*, 11(1), pp. 286–300.
- Reuters (2017) 'Malaysia flash flood killed five people in penang', 6 November.
- Riggs, H. R., Cox, D. T., Naito, C. J., Kobayashi, M. H., Aghl, P. P., Ko, H. T. S. and Khowitar, E. (2014) 'Experimental and Analytical Study of Water-Driven Debris Impact Forces on Structures', *Journal of Offshore Mechanics and Arctic Engineering*, 136(4), pp. 1–8.
- Ritter, A. (1892) 'The propagation of water waves', *Ver Deutsch ingenieur zeitschr* 36, 33 part 3, pp. 947-954.
- Roosli, R. and O'Brien, G. (2011) 'Social learning in managing disasters in Malaysia', *Disaster Prevention and Management*, 20(4), pp. 386–397.
- Santo, J. and Robertson, I. N. (2010) 'Lateral loading on vertical structural elements due to a tsunami bore', *Research Report UHM/CEE/10-02*.
- Savoia, M., Buratti, N. and Vincenzi, L. (2017) 'Damage and collapses in industrial precast buildings after the 2012 Emilia earthquake', *Engineering Structures*. Elsevier Ltd, 137, pp. 162–180.
- Schmocker, L. and Hager, W. H. (2013) 'Scale Modeling of Wooden Debris Accumulation at a Debris Rack', *Journal of Hydraulic Engineering*. American Society of Civil Engineers, 139(8), pp. 827–836.
- Shafieei, S., Melville, B. W., Shamseldin, A. Y., Adams, K. N. and Beskhyroun, S. (2016) 'Experimental investigation of tsunami-borne debris impact force on structures: Factors affecting impulse-momentum formula', *Ocean Engineering*, 127(August), pp. 158–169.
- Shibayama, T., Nistor, I., St-germain, P., Townsend, R., Nistor, I., Asce, M., Townsend, R., Shibayama, T. and Asce, M. (2014) 'Smoothed-Particle Hydrodynamics Numerical Modeling of Structures Impacted by Tsunami Bores'. American Society of Civil Engineers, 1(February), pp. 66–81.
- Shiohara, H. (2001) 'New Model for Shear Failure of RC Interior Beam Column Connections', (February), pp. 152–160.



- Shufeng, L., Qingning, L., Hao, Z., Haotian, J., Lei, Y. and Weishan, J. (2018) 'Experimental study of a fabricated confined concrete beam-to-column connection with end-plates', *Construction and Building Materials*. Elsevier Ltd, 158, pp. 208–216.
- Silvester, T. B. and Cleary, and P. W. (2006) 'Wave Structure Interaction Using Smoothed Particle', (December), pp. 1–8.
- Stolle, J., Derschum, C., Goseberg, N., Nistor, I. and Petriu, E. (2018) 'Debris impact under extreme hydrodynamic conditions part 2: Impact force responses for non-rigid debris collisions', *Coastal Engineering*. Elsevier, 141(September), pp. 107–118.
- Sujatha, B. and Kumar, B. A. (2016) 'Effect Of Expansion Joints On Dynamic Analysis Of Structure', 4(2), pp. 116–124.
- Tang, K. H. D. (2019) 'Climate change in Malaysia: Trends, contributors, impacts, mitigation and adaptations', *Science of the Total Environment*. Elsevier B.V., 650, pp. 1858–1871.
- Tighnavard, A., Kadir, A., Marsono, B. and Gohari, A. (2019) 'Sustainable materials selection based on flood damage assessment for a building using LCA and LCC', *Journal of Cleaner Production*. Elsevier Ltd, 222, pp. 844–855.
- Tokida, K. (2015) 'Geotechnical lesson and application on earth bank for tsunami disaster prevention', *Geotechnics for Catastrophic Flooding Events – Iai (Ed) 2015 Taylor & Francis Group, London, ISBN 978-1-138-02709-1*, 1, pp. 191–198.
- Vinet, F. (2008) 'Geographical analysis of damage due to flash floods in southern France: The cases of 12-13 November 1999 and 8-9 September 2002', *Applied Geography*, 28(4), pp. 323–336.
- W.H. Mosley , By (author) R. Hulse, B. (author) J. . B. (2012) 'Reinforced Concrete Design : to Eurocode 2', *MacMillan Education UK*, 7, p. 464.
- Weerasuriya, A. U. (2013) 'Computational Fluid Dynamic (CFD) simulation of flow around tall buildings', *Engineer: Journal of the Institution of Engineers, Sri Lanka*, 46(3), p. 43.
- Whitham, G. B. (1955) 'The effects of hydraulic resistance in the dam-break problem.', *Proceedings of the Royal Society of London, Series A, Mathematical and Physical Sciences*, 227 (170), pp. 399–407.

- Wight, J. K., Cagley, J. R., Criswell, M. E., Durrani, A. J., Ehsani, M. R., Garcia, L. E., Hawkins, N. M., Hanson, N. W., Joglekar, M. R., Kopczynski, C. S., Kreger, M. E., Leon, R. T., Meinheit, D. F., Moehle, J. P., Park, R. and Saiidi, M. (1988) 'Recommendations for design of slab-column connections in monolithic reinforced concrete structures', *ACI Structural Journal*, 85(6), pp. 675–696.
- Xiao, S. and Li, H. (2013) 'Impact of Flood on a Simple Masonry Building', *Journal of Performance of Constructed Facilities*. American Society of Civil Engineers, 27(5), pp. 550–563.
- Yau, Y. H. and Hasbi, S. (2013) 'A review of climate change impacts on commercial buildings and their technical services in the tropics', *Renewable and Sustainable Energy Reviews*. Elsevier, 18, pp. 430–441.
- Yeh, H., Robertson, I. N. and Preuss, J. (2005) 'Development of design guidelines for structures that serve as tsunami vertical evacuation sites', *Open File Report 2005-4*, (November 2005), p. 42.
- Yu, J. and Tan, K. (2013) 'Experimental and numerical investigation on progressive collapse resistance of reinforced concrete beam column sub-assemblages', *Engineering Structures*. Elsevier Ltd, 55, pp. 90–106.
- Zhang, S., Zhang, L., Li, X. and Xu, Q. (2018) 'Physical vulnerability models for assessing building damage by debris flows', *Engineering Geology*. Elsevier, 247(April), pp. 145–158.

## LIST OF PUBLICATIONS

**Abubakar sharif Auwalu**, Abdul Kadir Marsono, Mahmood Md Tahir, Arizu Sulaiman” Behaviour of Cold-Formed Ferrocement Composite Column Under Axial Loading”

<http://www.jcreview.com/fulltext/197-1587482553.pdf?1587536827>

The Performance of Steel Bolt Connected Industrialized Building System Frame Subjected to Hydrodynamic Force

**Abubakar Sharif A**, Norhazilan Md Noor,

B. Marabi\*1, A. K. Marsono2, M. Vafaei3 and **A. S. Auwalu4** “Assessing The Efficiency Of Single Outriggered Frame System In Tall Buildings Laterally Loaded”  
Paper ID 78, IGCESH2016