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

ABUBAKAR SHARIF AUWALU

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School of Civil Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

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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.

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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 akhirinya akan musnah akibat hentaman beban mendatar yang melampau pada kitaran seterusnya. Kajian terdahalu 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 kapada 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 dinamil 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 menjaminkan 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.

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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
AC1 - 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

δ	-	Minimal error
D, d	-	Diameter
F	-	Force
v	-	Velocity
p	-	Pressure
I	-	Moment of Inersia
r	-	Radius
Re	-	Reynold Number
$\gamma(\delta)$		Pressure Load
ρ		Fluid Density
τ		Stress Tensor
$\alpha(\beta)$		Reservoir Depth Ratio
F_d		Hydrodynamic Force
f_y		Steel yield strength
f_{cu}		Concrete Compressive Strength
S_σ		Scale factor in stress
S_i		Scale Factor in length
σ		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

Eb	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

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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^2 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 with1300 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

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LIST OF PUBLICATIONS

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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