# Experimental Study of IBS Precast Cruciform Column Under Monotonic Pushover Loads

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**Abstract.** Industrialised Building System (IBS) was introduced since 1964 in Malaysia in order to mechanise the construction industries. There are many efforts that had been done by the Government of Malaysia encouraging the implementation of IBS. However, IBS hesitates the industries stake holders because lack of confidence to implement this new method of construction. IBS technology serve many advantage toward the industry. Therefore, the purpose of this research to conduct physical experimental to the precast concrete column that belong to IBS system of scaled 1:5. The IBS column model will be test under lateral monotonic load and bending test. The monotonic test was done twice with footing vertically and without footing horizontally. The test produce the performance graph of load against displacement. The failure mode column was made based on the column was made based on the graph and visual effect. Hence, the result was compared with the result from frame software analysis at ultimate state. The research shows that the IBS precast cruciform column possess sufficient strength that can withstand extreme lateral load with the characteristics failure of bendingy.

## Introduction

### *Background of Study*

The development of the country have led to the increase to the need of constructed facilities. The contractor have to compete between themselves to get the project completed with less profit and penalty during construction. The construction industry has been criticized for being slow in improving a better and modern techniques in construction even though they are contributing toward 6% of GDP. The construction industry also being stated that for its poor performance in time delivering and late in finishing the project as well as the cost overrun. Moreover, due to constrained work given to the industry, more foreign cheap labours are engaged to construction [7]. It is also stated that there are total number of 552,000 of foreign labours that are registered under CIDB. In order to prevent this, Industrialised Building System (IBS) are introduced. IBS is to methodologically describe the adoption of construction industrialisation, mechanisation and the uses of the prefabrication technology of component in building structural system.

### *Problem Statement*

IBS is define as a mass construction method. IBS is an industrialised building system which all the building parts and components are mass produced either offsite or onsite under strict quality control or minimal on sites activities. The production and handling of IBS required expert labours thus increasing the cost the hire or trained workers for highly skilled jobs. Moreover, the cost for overall construction cost are more expensive due to high capital investment, lack of IBS volume, ad high cost of logistic. The term IBS is always misinterpreted with negative perception due to its relationship between industrialised building that were built in 1960's. They are refer as cheap and low quality buildings with bad aesthetic. Besides, some of the general purpose contraction are already familiar with the conventional system in construction are more comfortable and have confidence in using it. Moreover, the contractor do not have sufficient knowledge about the quality of IBS that better than the conventional method.

### *Objectives*
The objectives of the study is to obtain the failure characteristic of 1:5 scaled of homogenously cruciform column tested in laboratory verify using frame analysis and to obtain the ultimate bending capacities of IBS homogenous cruciform.

### *Scope of Study*
The scope of this study will obtain the failure characteristics of IBS conventional column that will be use for 5 storey building. The column are tested laterally using a monotonic pushover loads.

## Literature Reviews

### *Industrialised Building System*
Industrialised Building System (IBS) is a method of construction which involve prefabricated components and on-site installation of manufactured construction products using a specialized technique to create a components or a building systems [2]. According to CIDB, IBS consists of 5 categories which are precast concrete system, steel framing system, steel formwork system, prefabricated timber framed system and blockwork system.

IBS usage could assure reliable advantages such as less wastage, reduction of unskilled workers, increase environmental and construction site cleanliness and better quality control [2]. IBS is a prefabricated components that produced under controlled and consistent condition and resulting in high quality of work [10]. IBS able to accelerate the construction work since it is normally prefabricated in the factory and transported to the site and lower the cost by less wasted material are produced. IBS is able to provide cleaner, neater and safer construction sites because less hazardous to the workers due to less usage of formworks are used on sites [10]. IBS can reduce foreign workers on site compare to the convention method which is labours dependent.

### *Cross Shaped Column*
Special shaped column are consist of cross-shaped, L-shaped, or T shape column. This type of column are usually related to the bearing capacity and seismic performance. Special shaped column are widely used in many countries in high rise building shear walls due to its benefits such as high strength and stiffness, excellent ductility and the convenience of the structure [5]. Moreover, it is also said that special-shaped column are suitable for saving architectural space and aesthetic purpose.

## Methodology

The objectives of this research is obtain the failure characteristic IBS precast column element using laboratory test and software analysis. Besides, it is also to investigate the ultimate lateral load capacities of IBS conventional column with design reinforcement. The design are built in 1:5 small scale model with reinforcements which will be test with push over method. In order to achieve the objective of the research study, the research of the methodology is divided into three main stage as shown in Figure 1. Those three stage are preliminary stage, laboratory work and posting stage which include result and data analysis, software analysis, recommendation and conclusion.

### *Laboratory Work*
The research is a comparison to the research at full IBS blockworks system and act as a conventional column with a similar dimension of cruciform shaped column. The column is 780mm in height. The research will be only focus in testing the column. The research involved the laboratory processes of IBS precast concrete casting, assembly and test. The detail process of laboratory works includes concrete mix design, plywood formwork design, preparation of reinforcement, concrete casting and curing and lastly structural testing which are lateral monotonic load test and bending capacity test. The structural laboratory of Faculty of Civil Engineering (FKA) have provide every equipment and material that was required for the research.

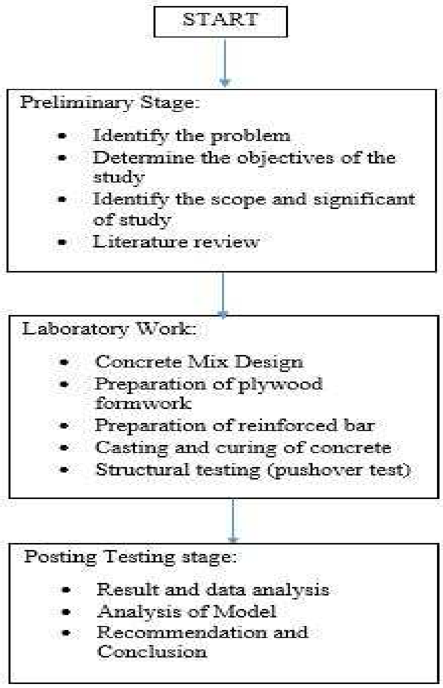


Figure 1: Research Methodology

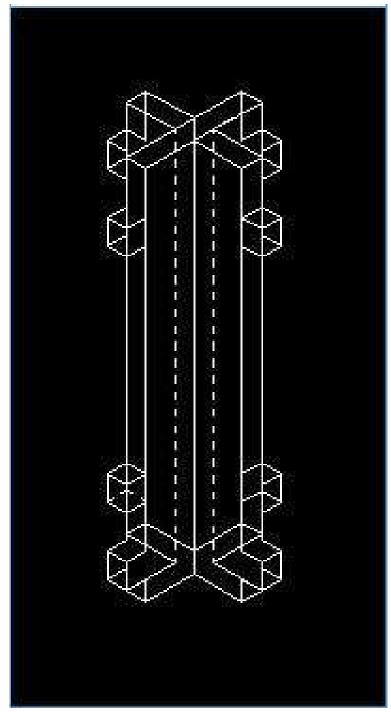

Figure 2: The Design View of Column

***Monotonic Lateral Load Test***

The tests was conducted at the Structural and Material Laboratory Faculty of Civil Engineering, UTM. The model will be place vertically at the testing rig and the model was tested under monotonic lateral load test. The instruments that was used in the experiment were:

- Testing Rig
- Data logger
- Load cell
- 6 LDVT
- G clamp
- Hydraulic Jack

Monotonic load test is a test in which the IBS precast column is subjected to repeating lateral loading until desired displacement are achieved. The purpose of this testing is to acquire the performance of a structures and to investigate the failure mode of the model.


Figure 3: Monotonic Test Set Up

Figure 4: Bending Test Set Up

The measurement instrumentation consisted of 6 Linear Displacement Transducer (LDVT) with a schematic illustration as in Figure 3. The measurement that can be gain from the experiment is are the displacement of the structure as load are applied in interval and the amount of load applied. The measurements devices were connected to the data logger which transmitting the output to a personal computer in digital format. The structure was fixed at the base of the testing rig using G clamp and the top of the structure was loaded with weight and the load will be measured through the load cell.

***Bending Test***

The test was conducted at Structural and Material Laboratory Faculty of Civil Engineering, UTM. The column are place in the testing frame. The instruments that being used for the experiment are as below.

- Testing Rig
- Data logger
- Load cell
- 2 LVDT
- G clamp

Bending test is a test for determining the flexural strength of the model by applying force on top of the model. The load was applied at a height of L/3 of the column. The parameters that was measured is the displacement or deflection of the model. The measurement are measure by the LDVT and will be recorded to the data logger. In addition, the load applied was measured by the load cell.

**Result and Data Analysis**

This chapter show the result of the monotonic load test experiment on the small scaled model monolithic column. It is a representation of similar shapes of IBS blockwork column. Monotonic test is conduct as column rock capacity to know the behaviour and ultimate capacity of the model. Monotonic test is carry out twice where the column are tested with and without its footing. In addition, bending capacity test also performed in this experiment. Data was recorded and graphs was plotted for load against displacement of LDVT for each testing. Therefore, the result will be compare with analysis result sing Multiframe4d. The failure mechanism such as cracking and displacements also will be discussed in this chapter.

***Load and Displacement Relationship***

The concrete column were test at 28 days after it obtain the concrete target strength. The column was fixed at its base and clamped to the testing frame to avoid base movement to occur. Three tests were conducted to achieve the load against displacement relationship. Monotonic test were conducted twice which are with footing and without footing. The test was conducted by using horizontal push of hydraulic jack apply continuous increment of lateral displacement at the rooftop location. The pushing process was done in interval displacement from the origin until the structure failed. The displacement that occur were recorded using LDVT instrument and the value of load applied to the specimen by the load cell.

For the first monotonic test which is vertical column with footing. The column were horizontally jacked until 50 mm of rooftop displacement. The test show that the column is very strong and the failure occur was at the interface between the column and the footing. The pushover test damages the footing while the column is displaced horizontally with less crack. This is due to the anchorage between column-footing that was supress.

The second test of monotonic test is perform reusing the undamaged specimen by removing the footing from the column. The removal of column does not affect the structure of column as there is no reinforcement are being attached between footing and column. The second test is similar to the first test but that instead the column base is clamped to the plat of the testing frame without footing.

Bending test capacity are conducted as the ultimate strength capacity of the column are not fully achieved. The test assembly are differ that monotonic load test. The load are applied to the structure at the height of L/3 between the upper and the lower corbel. This is to satisfy the condition between monotonic and bending capacity test where the restraining characteristic would be similar. The first maximum load was at 54 kN before the structure have started to fail and the final load was at 48.7 kN. The test ended when the structure are 10 mm displaced vertically when the structure have been considered failed.

***Monotonic Test Result of Column with Footing***

Based on the graph in Figure 5, the applied load on the rooftop of the model are steadily increase until it become constant under 2.5 kN of load at 10 to 14 mm of displacement. Besides, reduction of load occur after reaching 16 mm of displacement which is 2.5 kN to 2.3 kN. This point was the first crack began to appear in the footing near the bottom of the last block corbel. Then, the load gradually reduced as the displacement are increase.

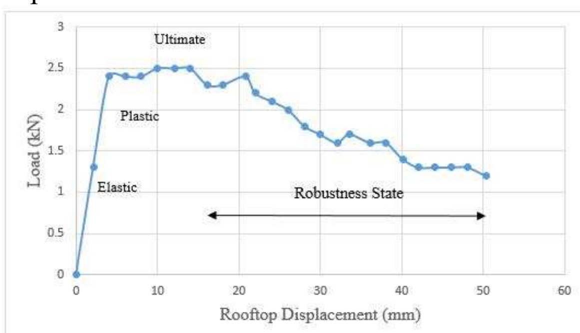


Figure 5: Load (kN) versus Rooftop Displacement (mm) for Column with Footing

Below figures shows some of the cracking and spalling that occur during the testing.The cracking begin to appear at 16 mm of displacement at load 2.3 kN and become obvious when reach 18 mm of displacement (Figure 6). The crack extended to the lower part of the corbel when reach 28 mm of displacement at 1.8 kN (Figure 7). Cracking appear at the top side of the footing at 30 mm of displacement at 1.7 kN (Figure 8). The column have lifted where the column and footing had separated. Cracking at footing also occur at 42 mm of displacement at 1.3 kN (Figure 9). Cracking and Spalling occur at 44 mm of displacement at 1.4 kN (Figure 10). The footing crush after reaching 46 mm of displacement as shown in Figure 11 and the testing was stopped at 50 mm of displacement.


Figure 6: Cracking at Footing and L1


Figure 7: Crack Extended to Lower Part of Corbel

Figure 8: Crack at Top Side of Footing

Figure 9: Crack at 42 mm of Displacement

Figure 10: Crack at 44 mm of Displacement and Spalling

Figure 11: Spalling and Crushing at Footing

Figure 12: Front View of Model after Testing Complete

***Monotonic Test Result of Column without Footing***

This test is to carry out to determine the behaviour of column without footing and as well to gain the ultimate flexural strength of column that was not acquired during the first test. Similar to the first test, the structure are loaded form zero with increasing of 2 mm displacement interval. The load drop from 1.7 kN to 1.6 kN when it reach 12 mm of displacement. Then it became constant at 13 mm and 16 mm of displacement of displacement and raise backward. This is due to the column are skidding on the supports as the load are applied to it.

The column show do not show any sign of failure even though the displacement have reach above 20 mm. The first defect that emerge is at 32 mm of displacement where the corbel undergo crushing at L1. The testing are stopped when reach 50 mm of displacement and there are no sign of other defect on the column structure. During this test, at 40 mm of displacement, one of the G clamp broke because not strong enough to withstand the force as the load applied. Below Figure 14 shows the only defect from the testing.

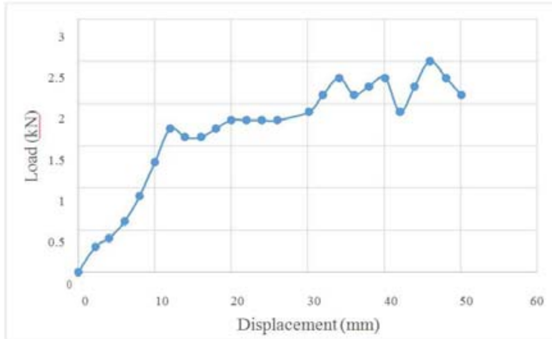


Figure 13: Load (kN) versus Rooftop Displacement (mm) for Column without Footing

Figure 14: Crushing of Corbel at 32 mm of Displacement

***Bending Test Capacity Analysis***

Based on the graph in Figure 15, the load are steadily increase as the displacement are increase. When the displacement reach 1.48 mm of displacement, the first cracking occur at the back of column at LV5. When the displacement reach 2.2 mm the load 52.9 kN dropped to 46.1 kN when it reach 3.03 mm. The drop of load is due to the column have undergo crushing at the area where load is applied. The load tend to increase back as the displacement increase. Then, a massive drop have occur from 3.9 mm to 3.7 mm of displacement. The loading also have a massive drop which from 48.7 kN to 23 kN. An explosive crushing occur at the top surface and front column. The test are stopped when the displacement have reach 10.4 mm of displacement. The column had totally failed and crushed. Therefore, the ultimate strength of the column is at 54 kN as it is the most highest load that the column can withstand. Figures 16 to Figure 24 shows the damages that occur during the test are conducted.

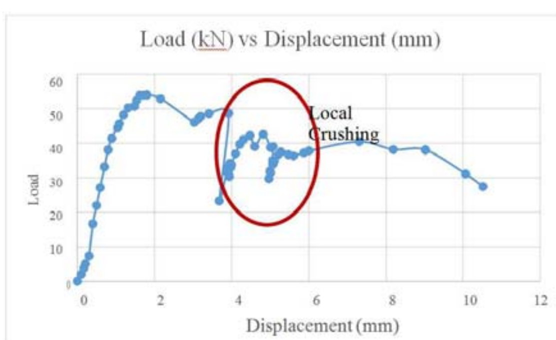


Figure 15: Load (kN) versus Displacement (mm) for Bending Test Capacity

Figure 16: First Crack at 1.48 of Displacement

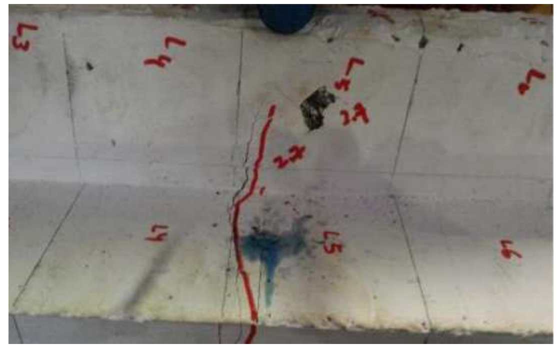

Figure 17: Top Front Cracking and Crushing at L5

Figure 18: Back Bottom Cracking and Spalling at L4

Figure 19: Top Surface Crushing

Figure 20: Crack Extended and Spalling

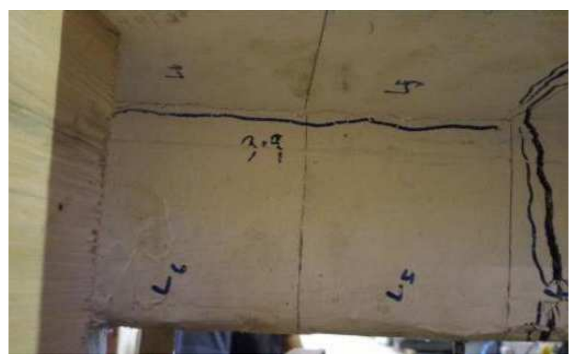

Figure 21: Crack at Bottom at 3.9 mm of Displacement

The first crack begin to appear at 1.48 of displacement at load 50.7 kN (Figure 16). As the displacement reach 2.7 mm, cracking and crushing occur at the top front of L5 of the column (Figure 17). The top surface also occur cracking and nearly crush. Cracking and spalling also occur at the back bottom at L4 (Figure 18). Moreover, the crack also extended from top to bottom at 2.7 mm of displacement. When the displacement reach to 3.7 mm, top surface undergo crushing at 23.3 kN (Figure 19). As the displacement reach 3.9 mm at load 33 kN, crack extended and spalling occur at L4 (Figure 20). The displacement increase and cracking occur at bottom of L6 at 3.9 mm of displacement (Figure 21).

As the displacement increase to 4.5 mm, minor surface crack at front exist (Figure 22). After this point, the loading tend to drop from 42 kN until 39 kN. Then, the loading increase back and graduallu increase until 10.4 mm of displacement. The top surface part undergo crushing at 10.2

mm of displacement (Figure 23). The column had totally failed when reach 10.4 mm of displacement and the testing are stopped.

Figure 22: Minor Cracking

Figure 23: Crushing at 10.2 mm of Displacement

Figure 24: Front View of Model after Testing Complete

**Analysis of Model and Discussion**

In this chapter, the test model are analyse using computer software, Multiframe4d. The analysis include the three test that been done laboratory. The graph of the three test that are compared at load-rooftop displacement location. Below figures shows the view of three model after rendering.

***Results***

In this section, the graph of the three test are compared at load-rooftop displacement location.

(a) (b) (c)

Figure 25: (a) Column without Footing, (b) Column with Footing, and (c) Column for Bending Test Capacity

*Comparison of Monotonic Analysis of Column with Footing between Experimental and Frame Analysis*. At load 2.5 kN, the rooftop displacement from frame analysis is 0.231 mm while for graph at Figure 5, the rooftop displacements is 14.04 mm. The differences between these values are due to the contact joint between column and footing are not sufficient to hold the column. This is due to no reinforcement connection between column and footing as the only reinforcement are exist inside the structural elements with coupling to other structural elements. Therefore, the failure obtain is based on the joint failure between column and the footing.

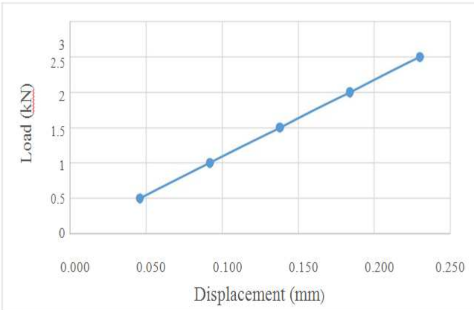


Figure 26: Load versus Displacement

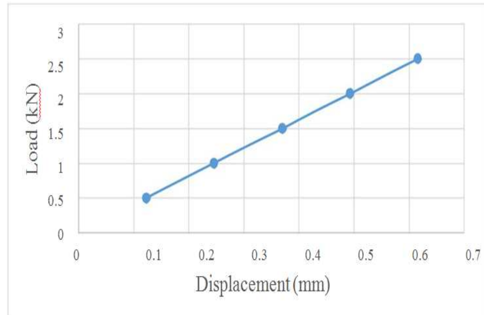


Figure 27: Load versus Rooftop Displacement

*Comparison of Monotonic Analysis of Column without Footing between Experimental and Frame Analysis*. At load 2.5 kN, the rooftop displacement from the graph in Figure 27 is 0.617 mm while for Figure 13, the rooftop displacement is 46 mm. The cause of this difference are due to insufficient strength of the G clamp as the load applied. Every increment of load causes the column to skid away from G clamp. In addition, as the load are applied, some of the G clamp have broken during the testing. Hence, the failure obtain are due to insufficient restraining of the model that result in high rooftop displacement.

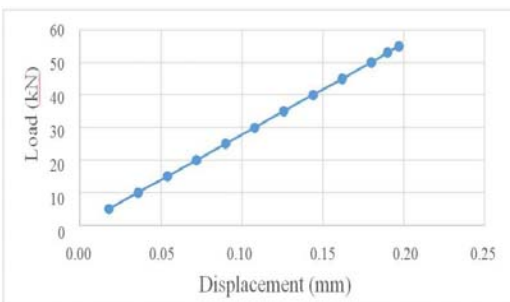


Figure 28: Load versus Displacement Based on Software Analysis

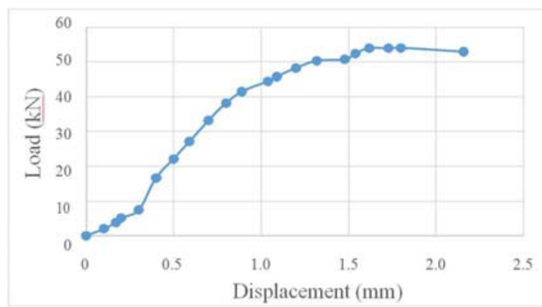


Figure 29: Load (kN) Versus Displacement Based on Experimental

*Comparison of Bending Test of Capacity of Column between Experimental and Frame Analysis.* The result from software analysis shows the elastic phase of the model. Based on the Figure 28 and Figure 29, at maximum load at 54 kN, the displacement are 0.19 mm and 1.8 mm respectively. The deflection value in software analysis are smaller compare to the experimental result.

**Conclusion and Recommendation**

The result and analysis for monotonic lateral load test and bending test carried out in this research can be summarise as follows:

1. The comparison of monotonic analysis of column with footing between experimental and frame analysis are shows the joint failure between column and footing.
2. The comparison of monotonic analysis of column without footing between experimental and frame analysis are shows due to insufficient restraining of model.
3. The comparison of bending test of capacity of column between experimental and frame analysis are shows the displacement from software analysis is smaller compare to the experimental
4. The IBS homogenous cruciform possess very strong bending capacities.

The research can be improve by including the tie bolt between column and footing to create strong bond between them for a more efficient and accurate monotonic result. Besides, the uses of bolt should be apply to the model to be attached to the base of the testing rig to make sure the model are completely fix. It is important to consider this matter in monotonic lateral load experiment where not only the behaviour of column can be obtained; the ultimate strength of the column also can be gained.

## References


[1] Abdul Kadir Marsono (2014). Monograph of Analysis and Design of Tall Building. Universiti Teknologi Malaysia.

[2] Construction Industry Development Board (CIDB) Malaysia (2003a), "Survey on the Usage of Industrialised Building Systems (IBS) in Malaysian Construction Industry", Construction Industry Development Board Malaysia (CIDB), Malaysia, Kuala Lumpur, 2003

[3] Construction Industry Development Board (CIDB) Malaysia (2003b), "IBS Roadmap 2003-2010", Construction Industry Development Board Malaysia (CIDB), Malaysia, Kuala Lumpur, 2003

[4] Kamarul Anuar Mohd Kamar, Z. A. (2011). Industrialized Building System (IBS): Revisiting. *International Journal of Emerging. Sciences, 1(2)*, 120-132.

[5] Lin Fang, B. Z.-F.-W.-L. (2015). Seismic behavior of concrete-encased steel cross-shaped columns. *Journal of Constructional Steel Research Vol 109*, 24-33.

[6] Nahavandi, H. (2015). Pushover Analysis of Retrofitted Reinforced Concrete Buildings. Master Thesis, Portland State University.

[7] Ng Ban Kiong, Z. A. (2012). Analysis Building Maintenance Factors For IBS Precast ConcreteSystem: A Review. *International Journal of Application or Innovation in Engineering & Management (IJAIEM) Vol. 2, Issue 6*, 878-883.

[8] Readon, C. (2013). Precast Concrete. *Your Home Techniical Manual Fourth Edition*, 270-277.

[9] Shamsuddin, S. M. (2012, October 2-4). *Drivers and Challenges of Industrialised BuildingSystem (IBS) in Sustainable Construction.* Retrieved from Drivers and challenges of IBS in sustainable construction: http://www.academia.edu/2318833/Drivers_and_challenges_of_IBS_in_sustainable_construc tion

[10] Sing Sing Wong, L. K. (2015). Advantages and Setbacks of Industrialized Building System (IBS) Implementation: A Case Study in Sarawak. *International Journal of Sustainable Construction Engineering & Technology (ISSN: 2180-3242)*, 52-59.

[11] Themelis, S. (2008). Pushover Analysis for Seismic Assesment and Design of Structures. Ph.D Thesis, Heriot-Watt University.

[12] wiseGeek. (2016). *What is Bending Test*. Retrieved from www.wisegeek.com/what-is-a-bending-test.htm view on April 2016.