AN EXPERIMENTAL STUDY OF THE STRUCTURAL CAPACITY OF RECTANGULAR CONCRETE BEAM WITH RICE HUSK CONCRETE (RHC) UNDER FLEXURAL TEST- 5% AND 15% RICE HUSK REPLACEMENT

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ABSTRAK

Objektif kajian ini adalah bertujuan untuk mengkaji dan menganalisa tentang kapasiti maksimum bebanan, kapasiti momen maksimum dan tindak balas lanturan yang boleh ditampung oleh konkrit bertetulang dengan penggantian peratusan pasir halus dan sekam padi. Peratusan penggantian antara sekam padi dan pasir di dalam kajian ini ialah 5% dan 15% dengan gred konkrit C25/30. Jumlah sampel rasuk konkrit bertetulang yang telah disediakan adalah sebanyak 9 sampel yang berukuran 1500 mm x 150 mm x 300 mm bagi ujian lenturan dan 9 sampel kiub berukuran 150 mm x 150 mm x 150 mm bagi ujian kekuatan kompresif. Diantara 9 sampel tersebut, 3 daripadanya disediakan sebagai sampel contoh bagi tujuan rujukan dan 6 sampel selebihnya masing-masing dengan 5% dan 15% penggantian sekam padi. Hasil keputusan daripada kajian ini, nilai kapisiti maksimum bebanan bagi 5% penggantian sekam padi di dalam rasuk dan sampel rasuk rujukan menunjukkan tiada perbezaan yang ketara. Walau bagaimanapun, nilai kapasiti maksimum bebanan berkurang apabila penggantian sekam padi di dalam rasuk meningkat sebanyak 15%. Tambahan pula, lenturan rasuk bagi 5% penggantian sekam padi dan rasuk rujukan menunjukkan hasil yang positif dimana nilai lenturan kedua-dua sampel tiada perbezaan yang ketara. Bagi 15% peggantian sekam padi, graf lenturan menunjukkan lenturan terjadi lebih awal berbanding kedua-dua sampel yang lain. Nilai momen maksimum juga semakin berkurangan apabila sekam padi digantikan sebanyak 15% berbanding dengan 5% dan rasuk rujukan. Tujuan kajian ini dilakukan adalah bagi menyumbang alternatif dalam industri pembinaan dengan tujuan menghasilkan bangunan yang lebih murah tetapi mempunyai kekuatan dan kualiti yang sama, membantu menyelamatkan sumber alam semula jadi dan membantu negara dalam masalah kekurangan tempat pelupusan sampah. Kesemua ujian dan kajian telah dilakukan oleh staf yang mahir dan data telah dikumpul dan dianalisa.

ABSTRACT

The purpose of this study is to investigate the ultimate loading capacity, maximum moment capacity and deflection that can withstand by a reinforced concrete with the replacement of certain percentage of fine aggregate or sand with raw rice husk. The percentage replacements of the raw rice husks involve in this study are 5% and 15% mixed with concrete grade C25/30. The total of sample that had been prepared is 9 reinforced concrete beams with dimensions of 1500mm x 150mm x 300mm for flexural test and 9 cube samples which dimension size is 150mm x 150mm x 150mm for compressive strength test. Within the 9 beam samples, 3 of it is for controlled sample as references and another 6 beam samples is for 5% and 15% of rice husk replacement respectively. The results from this study indicates that, the ultimate loading capacity between 5% raw rice husk replacement beam and controlled beam show no huge differences. However, the ultimate loading capacity decrease when the rice husk replacement increase up to 15%. In addition, the deflection of 5% testing sample and controlled beam sample shows positive outcome where both deflection value is quite same. For the 15% sample, the curve of deflection shows that the deflection occurs faster than other two samples. The maximum moment also keep decreasing when the 15% replacement of rice husk in the beam while no big gap between the controlled beam and 5% beam samples. The aim of this experimental study is to contribute the idea to construction industry in order to produce economical buildings with same quality of strength, help in saving the natural sources and also help the government on the issues of constraint landfill area. All the testing is conducted in laboratory by the competent technical staff and the result is gathered and analyse precisely.

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LIST OF SYMBOLS

%	Percentage
Kg	Kilogram
mm	Millimetre
N	Newton
kN	Kilo Newton
Mpa	Mega Pascal
εy	Steel Strain
εc	Concrete Strain
RHC	Rice Husk Concrete

LIST OF ABBREVIATIONS

%	Percentage
Kg	Kilogram
mm	Millimetre
N	Newton
kN	Kilo Newton
Mpa	Mega Pascal
εy	Steel Strain
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RHC	Rice Husk Concrete

CHAPTER 1

INTRODUCTION

1.1 Background Of Study

Shelter is reffered to any architectural structure or building that provides cover to the mankind or living organisms. World population currently 7.3 billion is expected to reach 8.5 billion by 2030 and 9.7 billion in 2050 according to new UN DESA report, "World Population Prospects: 2015 Revision". Increasing the population will also lead to the increasing of buildings such as shelter, workplace and infrastructural. Generally know that, every structural building is bulit using concrete. The environmental impact of concrete whether it application or production become serious issues nowadays. Many researches all around the world struggle in their study to overcome this issue and come out with several solutions. The biggest problem from this issue is, concrete will only produce by mixing of several natural resources which are cement, aggregate and water. As the time goes by, production of concrete cannot only depend on these resources all the time because sooner or later, the natural resources decreasing by time. Nowadays, there are so many researcher and scientist come out with innovative ways to enhance the production of concrete using alternative resources.

This research is focuses on how a structure react when the fine aggregate is partially replace with some percentage of raw rice husk in concrete mixing. Some must be asked why fine aggregate and why rice husk. The main reason for replacement of fine aggregate or commonly called sand is due to intensively used of this raw material not only in construction industries to make cement, mortar, ceramics and glass but also being used in other industries such as in water filtration, in chemicals and metals processing and in plastic industry. The United Nations Environment Programme stipulates that" the use of sand greatly exceed their natural renewal rates". One can imagine that the problem will solve easily due to desert covered almost 20% of Earth with sand. The truth is not all type of sand is suitable for the market demand. The facts is several countries from Middle East that surrounded by desert imported large quantities of sand. As an example, Qatar imported sand and gravel around $6.5B in 2012 (Schoof, J, 2016). Meanwhile in Malaysia now, about 0.48 million tonne of rice husk (UNDP,2002) still not fully utilized. Rice husk or rice hulls are the coatings of seeds, or grains of rice. It function is to protects the seed during growing season since it formed from hard materials which are opaline silica and lignin. General knows, Malaysian staple food is rice. Therefore, Malaysia's agriculture department is targeting to expand the output of paddy sector to 9 to 10 tons per hectare in 2020 (NCER,2007). Increasing of paddy residue will lead to the waste management problem if cannot be manage in good condition. The burning of it will cause serious air pollution (Singh,2015). Besides the excess amount of rice husk in Malaysia, it is chosen as byproduct due to the price also far cheaper than sand that surely can give positive impact of the concrete price in the future.

The concrete containing agriculture product such as rice husk is categorized as light weight concrete. The advantages of the lightweight concrete are larger strength-to-weight ratio, greater strain capacity, lower changes of the size of object with a change in temperature and better heat and sound insulation (Chen 2008). However, lightweight concrete also has its correlated disadvantages such as lower indirect tensile strength and lower workability.

1.2 Problem Statement

The conventional reinforced concrete design method seem to lead several issue in term of environmental and cost whether it production or application. It is time to confidently consider the other alternative of making it such as partial replacement of main material with by-product or unutilized agriculture material in order to minimize the negative impacts. The main problem that led to this alternative is limited of natural resources which are used in production of concrete structure. One of the raw materials for concrete mixing is fine aggregate or also known as sand. This study try to find solution by replacing some percentage of find aggregate with raw rice husk obtain from paddy factory.

Second is environmental issue. The fine aggregate will only get by sand mining from terrestrial deposits like river channel, flood plain alluvial and marine deposits such as at the shore and offshores deposits (Gelabert, 1997) . River sand mining can causes the destruction of aquatic habitats by bed degradation, lower water levels and channel degradation. The physical disturbance of sediment while dredging the sand affects the suspended solids and the turbidity of water increasing. The turbidity will degraded water quality and reduce light penetration within river affect the photosynthesis rates and fish population in the river. The most dangerous effect of sand mining is the water quality will drop drastically according to Water Quality Index (WQI). If the WQI shows the quality of river in Class 3, it will need extensive treatment before it can be used by people.

Third issue is cost of sand as raw material in concrete production. We are living in era that cost of building are too expansive that people cannot afford to buy their own houses especially in Malaysia. Any alternative of concrete production that can reduce the cost of building surely welcoming in this industry for the benefit of all people as long as it can promise that the new method ensure the structure safety.

Last but not least, constraint of landfill area is one of the problems that need to take into account (Shafie, 2015). Uses of unutilized rice husk may give a bit positive solution to the problem. Landfill area in Malaysia also limited to domestic waste. The addition of agriculture waste may lead to the lack of landfill area. Moreover, if these unutilized agriculture dispose by burning them, surely it will cause serious haze pollution not only in Malaysia but may be dispersed to our neighbour surround us like Indonesia, Thailand and Singapore. One way as what is proposed in this research paper is to use the rice husk as by-product or partial replacement of fine aggregate. This may help a lot to reduce the few problems that related to concrete environmental issue, cost of structure and maintaining environmental health.

1.3 Objective

The main objective of this research is to determine any potential of rice husk in its natural state that can be utilize as partial replacement of fine aggregate in concrete mixing. The following is three specific objectives in order to achieve the main target:

i. To evaluate the ultimate loading capacity that can resist by rice husk reinforced concrete at difference percentage of replacement in fine aggregate.
ii. To determine the maximum moment capacity that capable to accept by rice husk reinforced concrete.
iii. To acknowledge the behaviour of deflection of rice husk reinforced concrete beam structure.

CHAPTER 2

LITERITURE REVIEW

2.1 General

Before a concrete can be modify, it is importance to know everything about concrete in term of its type, classification or behaviour. This sub chapter will give further explanation and information that has been gathered from other research all around the world. This sub chapter is divided into 3 parts which are concrete grade, behavior of concrete and the effect of concrete modification to environment.

2.1.1 Beam Structure

Historically squared timber, metal or stone were used widely in structure such as houses and factory before the invention of concrete beam. In building construction, a beam is a horizontal member spanning an opening and carrying a load. These loads may come from the floor slab, brick wall and roof. The beam member will receive all the loads and transfer it to column and direct to the foundation. It is also a structural element that can withstand load primarily by resisting against bending. The force from external loads and its own weight tend to bend the structure and it is called a bending moment.

There are several type of beams used in construction to satisfy the design or aesthetic value of the buildings. The type of beams can be classified based on it support such as simply supported beam, fixed beam, over hanging beam, continuous beam and cantilever beam. All these beams have different support at the both end. In construction, continuous beams are commonly found due to it have more than two support along the span. Internally, beams experience compressive, tensile and shear stresses as a result of loads applied to them.

An increasing interest is currently shown worldwide for good quality lightweight concrete structure. Because of it proven advantage, LWC structure are now used in the construction of lo-rise and high-rise building, bridges, industrial facilities, sea vessels and coastal systems. (Ivan Tomicic, 2012) in his study clearly stated that the effect of strengthening and ductility of lightweight concrete beam and normal weight concrete beam have shown similar result which mean that, the lightweight concrete beam can achieve the standard just like the normal concrete beam.

2.1.2 Concrete Grade

There are various type of concrete shall be used in construction depends on the type of structure itself. They can be divided between light grade concrete, standard grade concrete and high strength concrete. The different of these concrete are the uses of it. As examples, concrete grade C10 is plain concrete and used for patio slabs, pathways or non-structural work. Meanwhile, grade C25 is categorized under standard grade concrete that usually used for normal construction in all areas. Differ from grade C50, it is classed under concrete with pre tendons according to BS 8110, 1997. This type of concrete class widely used for creating foundations and beams for structural support and roads. It is the most durable grade and can withstand chemical corrosion.

Standard concrete grade used in normal concrete considered as the perfection of concrete mixing commonly found in structure (Meyer,2009). It 4 basic materials which are cement, fine aggregate, coarse aggregate and water strong enough to be used in structure without any supplementary ingredient in it. Although it is commonly used in construction, the normal concrete seems to face constraint due to decreasing of the main resources in the world.

Introducing of lightweight concrete, more or less open the eyes of the world. Lightweight concrete has many favourable engineering properties such as its light weight, high strength, low expansibility, good heat insulation, sound dampening qualities, water and fire resistance, durability, stable volume and surely low cost (H.Y. Wang, 2015). Lightweight aggregate also have lower water absorption, and electrical resistance compare to standard aggregate (A.Elsharief, 2005). A concrete can be categorized as lightweight aggregate concrete is when the aggregate have dry unit weight below than 1200 kg/m^3 (Mohammed, 2013). Lightweight aggregates concrete not only perfume well in structure but also have many advantages, including high strength, good tensile strain and low thermal conductivity coefficient. This is the main reasons this research paper focus on the structure behaviour of lightweight aggregate concrete that use rice husk as partial replacement.

2.1.3 Behaviour Of Concrete

The concrete containing rice husk as partial replacement of aggregate has proved it very light in weight but low strength achieved (Salas J and Veras J, 1986). According to (J-C Benezet, 2014), the standard requirement for lightweight concrete categories is the density of light structural need to achieve below 2000 kg/m^3 and compressive strength above 15 MPa. The result of his research conclude that the average density of lightweight concrete of rice husk aggregate about 800 kg/m^3 which below the requirement for lightweight concrete. Meanwhile, result from (Salas J and Veras J) shows that, the maximum of compressive strength achieved by natural husk is 17 MPa which is higher the requirement when 20% of aggregate replaced by rice husk. However, this researcher mentioned that the strength will be increasing if only replace the sand instead of sand and gravel.

In another study, it stated that the compressive strength of rice husk concrete aggregate can achieved up to 15.05 MPa and 12.24 Mpa when about 10% and 15% mix proportion respectively (Isma Farhan, 2017). According to his result, the best and workability percent of replacing rice husk is 15%. Several testing had been done to approve this statement which is slump test, compressive test and flexural test. The result of slump test shows that, the height of concrete slump containing 15% rice husk is 53 mm. The compressive strength at 28 days curing show that 12.24 MPa achieved. This result can be accepted as lightweight concrete according to BS 8110, 1997. The result of flexural test from his study shows that 15% of replacement rice husk is 4.8 Mpa at 28 days.

According to previous study from (Obilade, I.O, 2014), the rice husk concrete aggregate can achieved 14.47 MPa but the density of the concrete nearly achieved below 2000kg/m^3 which is 2167kg/m^3. In this study, the concrete mix proportion was 1:2:4 by both weight and volume. The results of compressive strength show it almost the same among this research which is between 10 Mpa to 15 Mpa. The method of the test also almost the same where uses of raw rice husk as partial replacement of fine aggregate.

Based on many previous researches, most of them likely to compare the replacement of aggregate between rice husk and hemp hurd. (J-C Benezet, 2014) in his study used to compare the result of lime hump concrete (LHC) and lime rice husk concrete (LRC). The approach of the paper is quite original since cereal husks are used in a lightweight insulating concrete designed with an identical way as for LHC. One of the finding in this study is rice husk are characterized by very thin about 80 µm compared to hemp hurd about 1 mm. It is known that the greater the amount of pores of smaller size, the lower the thermal conductivity. A study by (B.Federic, 2017) show that the unconfined compressive strength of LRC is lower than that of LHC even though a same mix proportioning is used for both plant-based concretes. It mentioned that the packing of rice husk could be enhanced by increasing the rice husk content on the concrete while reducing the binder content in order to keep the bulk density below 730 kg/m^3.

2.1.4 Effect Of Modification Concrete On Environment

The construction relies heavily on conventional materials such as cement, granite and sand for production of concrete. Concrete is the world’s most consumed man made material (Naik, 2008). The use of agriculture and industrial waste to complement other traditional materials in construction provides both practical and economical advantages. The uses of waste materials in construction contribute to conservation of natural resources and protection of the environment (Ramezanianpour, Mahidikhani and Ahmadibeni, 2009). According to (Obilade, I.O, 2014), rice husk in Nigeria produced from Ile Ife usually dumped in open thereby impacting the environment negatively without any benefit.

As the building sector presents major impacts on the natural environment, the development of eco-friendly concrete materials using plant aggregates has emerged as a high priority (M. Chabannes, 2014). This type of concrete allows moving towards a low carbon material with good thermos-physical properties. According to the research paper, rice husk can be consumed for electricity generation because of their calorific value. However, the incineration process is dangerous to human health and environment. Most of the study done by several researcher, they successfully proved that rice husk can be used as by-product either as cement partial replacement or sand partial replacement. For the cement replacement, the rice husks need to be burn into ash. Theoretically, the burning process is not really environment approach. The uses of raw rice husks in concrete material without any burning have rarely been investigated as the sand partial replacement. However, the process is really environmental way since it not uses any additional energy into it. Moreover, the uses of sand can be reduces drastically in concrete mixing process.

2.2 Materials

In modification of concrete mixing, it need 5 basic raw material which are cement, coarse aggregate, fine aggregate, raw rice husks and water. In this study, the concept from previous researcher had been used. This sub-topic will explain details on the material that will be used in producing simply supported beam using rice husk concrete.

2.2.1 Rice Husk Aggregate Concrete

Replacement of partial aggregate by rice husk is to produce lightweight concrete structure. This study is the extension of previous study on testing compressive strength of rice husk aggregate concrete by several researcher such as (Salas.J, 1986), (Obilade I.O, 2014), (B. Federic, 2017) and (Isma Farhan, 2017). The rice husk aggregate concrete will be used in beam structure to analyze the reaction or behavior of the structure that using rice husk aggregate concrete.

The rice husk used by (Obilade I.O, 2014) was obtained from Ile Ife, Nigeria. Since sand is denser than rice husk, replacement by an equal mass of rice husk leads to a larger increase in volume than replacement by an equal volume of sand. Increase in quantity of rice husk increase the specific surface area, thereby more water would be required.

According to (B. Federic, 2017), the raw rice husk used it the study was coming from Biousud (Arles, France). The bulk density of rice husk in the study is 90 kg/m^3 while the true density in solid phase is 1480 kg./m^3. The study indicates that 90% of rice husks have an equivalent area diameter between 3.40 mm to 5.75 mm used as aggregate. It is contradicted with (Salas.J, 1986) that mentioned in his study the density of loose and compacted husk is 121.5 kg/m^3 and 145.3 kg/m^3 respectively. The most important result from their testing was the result of compressive strength. (Obilade I.O, 2014), (Salas J, 1986) and (Isma Farhan, 2017) have proved that the compressive strength of rice husk concrete can achieve up to 15 MPa by certain percentage of replacement.

Table 2.1: Compressive strength at 28 days (Salas J, 1986)

Percentage Rice Husk (%)	0	20	40	60	80	90	100
Compressive Strength (MPa)	22.16	14.96	7.73	6.30	3.30	3.05	1.65

Table 2.2: Compressive strength at 28 days (Obilade I.O, 2014)

Percentage Rice Husk (%)	0	5	10	15	20	25
Compressive Strength (MPa)	22.15	17.62	15.31	14.76	13.98	12.62

Table 2.3: Compressive strength at 28 days (Isma Farhan, 2017)

Percentage Rice Husk (%)	0	5	10	15
Compressive Strength (MPa)	33.18	23.56	15.05	12.24

2.2.2 Steel Reinforced Concrete

General knows that any reinforce concrete having low tensile strength and ductility meanwhile they very good in compressive strength. Due to this concrete behaviour, it always counteracted with inclusion of reinforcement steel that having higher tensile strength and ductility. In simply words, concrete is sufficiently strong to compression forces by nature, but tension force can crack it. Deformed rebar on reinforcing steel have been standard requirement since 1968. According to Eurocode 1992-1-1:2004 clause 3.2.2 (3), the application rules for structure design and detailing are specific to yield strength range from 400 Mpa to 600 Mpa.

(Tariq AlJaafreh, 2016) in his study strengthening of lightweight reinforced concrete beams using carbon fibre reinforced polymers (CFRP) used the reinforcement that had a yield strength of 413 MPa (60,000 psi). However, this research study on rice husk aggregates concrete will state the yield strength of rebar as constant which is 500 MPa (72.5 psi) referred to the Eurocode standard and the type of material is high-yield steel.

2.3 Method From Previous Study

There was several studies before this succeed to make beam structure that based on lightweight concrete. Among of them used to partially replaced aggregate with fibre reinforced polymer, steel fibre and coconut shell. All the application of this study will be the references paper in the process of making lightweight simply supported beam structure with rice husk mix concrete. There are several criteria that can be learn from other researcher such as in term of the amount of sample, the type of testing on the structure and the design of the beam.

2.3.1 *Research 1 : Strengthening Of Lightweight Reinforced Concrete Beams Using Carbon Fiber Reinforced Polymer (Tariq ALJaafreh, University Of Texas At Arlington, 2016)*

This research purposed to investigate the effect of utilizing “Fiber Reinforced Polymer” (FRP) on the lightweight concrete beams. The main hypothesis is that such utilization of the FRP will lead to strengthened lightweight beams.

2.3.1.1 Method And Results

In his study, 8 samples of lightweight reinforced concrete that designed to strengthen beams by using CFRP sheet. The beams in this experiment were 152.4 mm wide x 203.2 mm deep x 1575 mm long (6 inch wide x 8 inch deep by 62 inch long). The flexural reinforcement steel consisted of 2#3 bars on the bottom side. The top reinforcement steel consisted of 2#3 bars. The shear link consisted stirrups size #3 and spaced 6 inch centre-centre in the middle 304.8 mm (12 inch) portion of the beams and 76 mm (3 inch) centre to centre on the rest of the beams. The cover on the bottom side was 1.5 inch, but the cover top and side were 25.4 mm (1 inch). Two pure beams were considered as control beams as the standard references whereas 6 other beams were strengthen by CFRP.

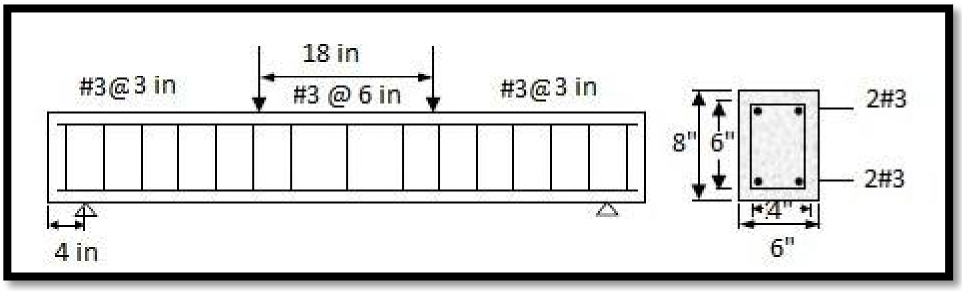


Figure 2.1: Reinforcement Arrangement

The entire specimens were casted with lightweight concrete which have average compressive strength of 28.9 MPa and the yield strength of 413 MPa. The beam then was tested using four point loading testing to determine the load deflection relationship. Two supports were used at each side of beams. The support used from thick steel to prevent any deflection at the support. A loading of 1780 kN was setting and adjusted at the center of the beam. The end result of the testing as follow:

Table 2.4: Comparison strength of beams

Beam	Theoretical Failure Load, kN	Experimental Failure Load, kN	Max Deflection, mm	Percentage strength increase compared with exp.
B1	51.9	53.6	29.7	NA
B2	66.7	51.4	12.7	-4.1%
B3	66.7	54.14	11.94	+1.00%
B4	66.7	60.1	12.19	+12.11%

2.3.2 *Research 2 : Study On Reinforced Lightweight Coconut Shell Concrete Beam Behavior Under Torsion (K.Gunasekaran, Department Of Civil Engineering, SRM University, Kattankulathur, India, 2014)*

The aimed of this study paper is to investigate and evaluates the results of coconut shell concrete beams subjected to torsion and compared with conventional concrete beams. This research is quiet closely to rice husk concrete beam due to the aggregate replacement was from plant residue.

2.3.2.1 Method And Results

Eight beams, four with coconut shell concrete and four with conventional concrete were fabricated and tested in this study. The study includes general cracking characteristics, pre cracking behavior and analysis, post cracking behavior and analysis, minimum torsional reinforcement, torsional reinforcement, ductility, crack width and stiffness. Both for coconut shell concrete (CSC) and conventional concrete (CC) have minimum compressive strength of 25 MPa at 28 days. It was fixed as target strength with minimum workability consideration.

The cross-sectional dimension of beam was taken as 200 mm x 275 mm and the length of the beam was taken as 1200 mm center to center for both CSC and CC. In both cases, the concrete grade has been considered as M25. Tables below show clearly the material used by K. Gunasekaran in his testing.

Table 2.5: Properties of Concrete Used (K.Gunasekaran)

Parameters	CSC	CC
Min targeted strength (Mpa)	20-25	20-25
Cement content (kg/m^3)	510	320
Sand (kg/m^3)	750	710
Coconut shell (CS), (kg/m^3)	332	-
Crushed granite stone (kg/m^3)	-	1171
Water-cement ratio (w/c)	0.42	0.55
Mis ratio	1:1.47:0.65:0.42	1:2.22:3.66:0.55
Slump (mm)	06	10
28 day hardened density, (kg/m^3)	1970	2385
28 day compressive strength, MPa	26.40	27.00

Table 2.6: Details reinforcements for both CC and CSC beams

Beams	Area of longitudinal reinforcement, (mm$^{2)}$	Spacing of transverse reinforcements, (mm)
CC1 and CSC1	312.15	120
CC2 and CSC2	452.38	90
CC3 and CSC3	383.08	100
CC4 and CSC4	257.48	150

Table 2.7: Diameter and numbers of bars used in beams

Beams	Longitudinal reinforcement	Transverse reinforcement 2-legged
CC1 and CSC1	2H8 mm Ø at top 2H10 mm Ø at bottom	8 mm at 150 mm c/c
CC2 and CSC2	2H10 mm Ø at top 2H10 mm Ø at bottom	8 mm at 120 mm c/c
CC3 and CSC3	2H10 mm Ø at top 2H12 mm Ø at bottom	8 mm at 100 mm c/c
CC4 and CSC4	2H12 mm Ø at top 2H12 mm Ø at bottom	8 mm at 90 mm c/c

The testing for beams was done in a loading frame of capacity 40 tones. Load was applied by means of a hydraulic jack of capacity 25 tones. Twist of the beam was measured by using dial gauges which are fixed at both sides of twist meter with at least count of 0.01 mm. Due to the study purposed to investigate the torque, K. Gunasekaran shows only torque result in his paper. The result clearly states that there was almost similar behavior in torsion between CC and CSC.

Table 2.8: Result of torsional strength

Beams	Torque (kN.M)	Twist, θ (rad/m) x 10^{-3}	Torque (kN.M)	Twist, θ (rad/m) x 10^{-3}
CC1	8.09	19.40	11.77	58.90
CC2	10.30	28.25	15.01	58.25
CC3	11.04	26.25	18.03	57.50
CC4	12.51	27.00	19.50	56.80
CSC1	7.36	20.10	13.54	64.70
CSC2	9.56	25.20	17.66	64.10
CSC3	9.86	24.20	19.50	63.30
CSC4	11.77	36.20	20.25	60.10

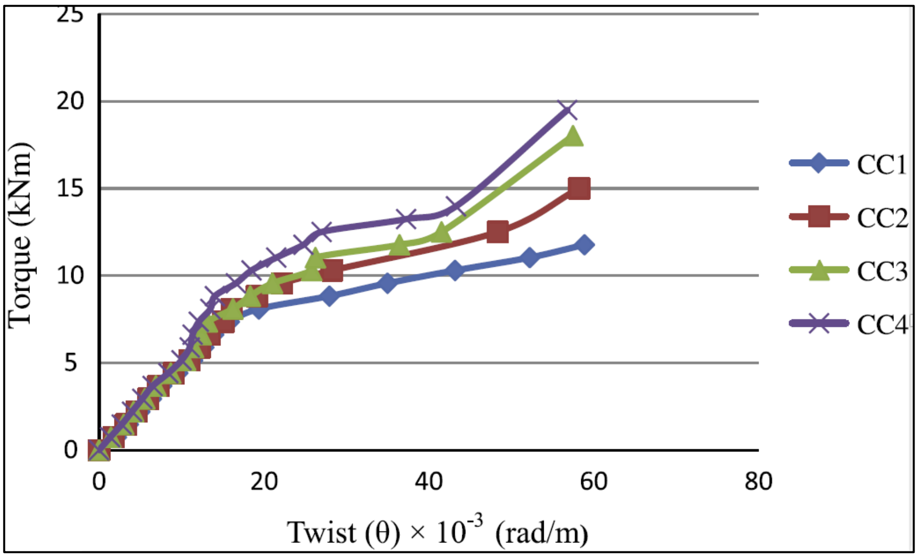


Figure 2.2: Torque Versus Twist For CC1 to CC4 beams

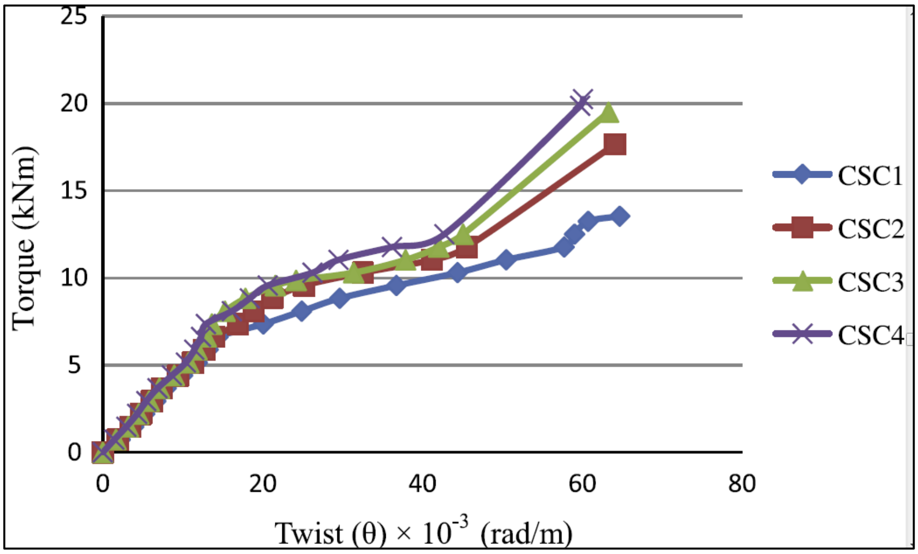


Figure 2.3 : Torque versus twist for CSC1 to CSC4

CHAPTER 3

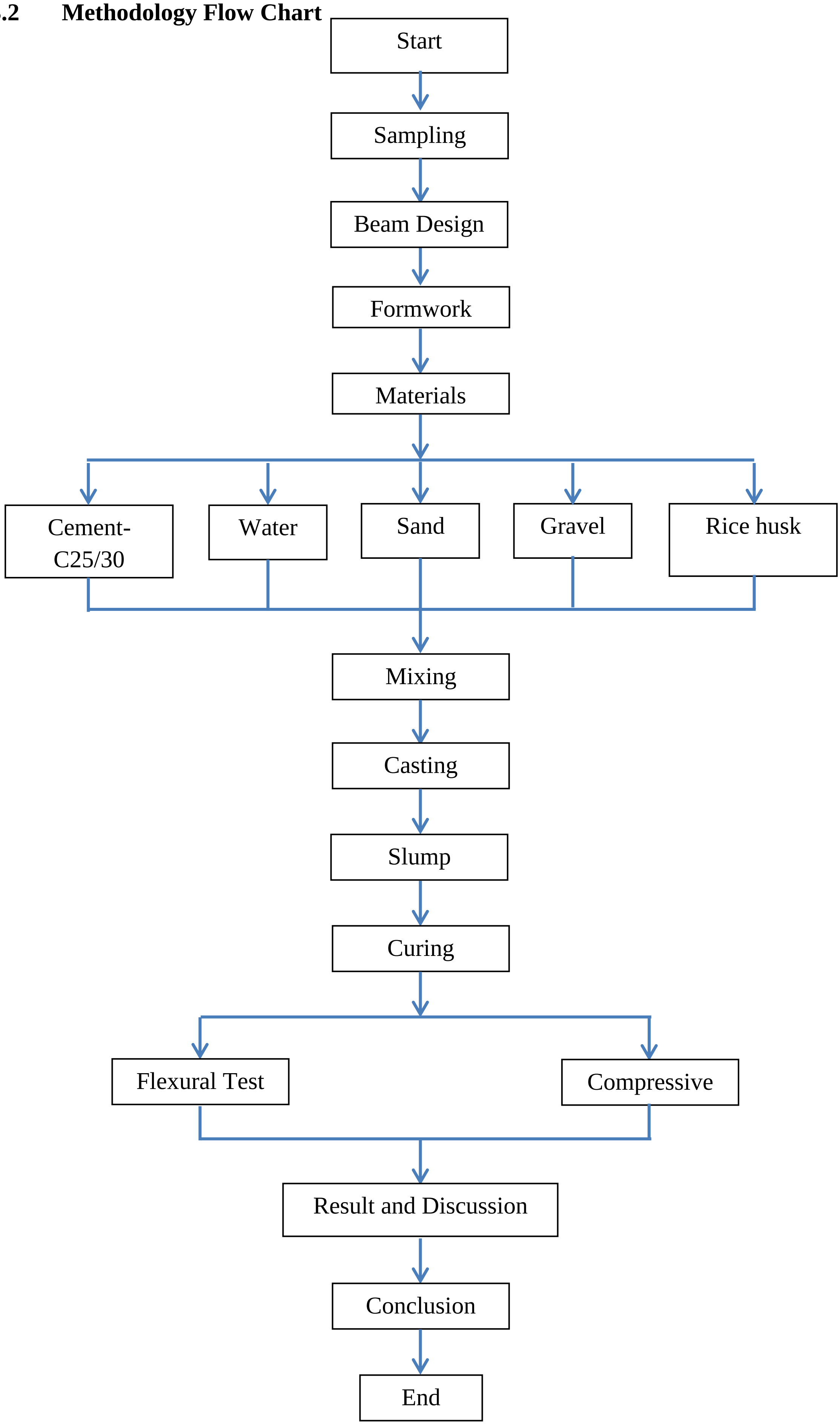
METHODOLOGY

3.1 Introduction

In this chapter, all method and procedure explained clearly to run this research. In order to achieve the purpose of this project, it needs to be done carefully and correctly by referring American Society for Testing Material (ASTM) and British Standard (BS). The testing and method in this study used the research from (K.Gunasekaran, 2014) of “Study On Reinforced Lightweight Coconut Shell Concrete Beam Behavior Under Torsion” as side references.

There are several testing that carried out in this research study as to prove that rice husk concrete is effective to use in beam structure. In order to recognize the effectiveness, flexural testing had been done first to acknowledge the behaviour of deflection and to determine ultimate load before beam failure. Before that, the rice husk concrete specification is met first as the study done by (Isma Farhan, 2017). Therefore, two standard testing for concrete before it can be cast had been done first which are slump test and compressive test. The correct method of conducting the tests led to logical discussion and conclusion at the end of this research which can help to decide whether the objective is achieved or not.

3.2 Methodology Flow Chart



The previous flow chart shows exactly the complete planning process of this research starting form preparing the sample until come out with conclusion at the end of this study. The process begin with preparing 9 sample of beam which are 3 normal aggregate concrete beams and 6 rice husk aggregate concrete beams. The 3 beams are used as the reference for comparison between standard and modify structure beams. The flexural testing only done after 28 days of curing meanwhile slump and compressive test are straight away done during casting process. The result obtain will be analyse before come out with conclusion.

3.3 Material Used

This research produce lightweight beam structure by using concrete with rice husk mixing by certain percentage. This is because, lightweight structure may cost lower than the normal weight structure. The concrete grade used is the normal concrete grade which is C25/30. All material used to prepare sample will be discuss in this sub-topic.

3.3.1 Cement

As a bonding factor, ordinary Portland cement is used in the mixing of concrete. In this study, the type of cement used is Orang Kuat Ordinary Portland Cement which the specification follow the outlined in BS 12:1958.

3.3.2 Water

Water may look as a simple material but the importance of water in concrete mixing cannot be denied. It need to be ensured that the water was free from chemical effect and should clear impurities. Water act as an activation of chemical process that will help to bind all the material during concrete mixed. Common practice in Malaysia, tap water is enough to be used in the concrete mixing. However, its quantity needs to be controlled because excess or lack of water may affect the compressive strength of concrete or its workability.

3.3.3 Coarse Aggregate

Coarse aggregate used in preparing this sample is crushed aggregate obtained from civil lab. The size of these aggregate is bigger than 4.75 mm comply with the ASTM standard for coarse aggregate. Coarse aggregate have angular physical shape that will act as interlocking to restrain the movement. These materials also affect the strength of concrete. In order to make well graded aggregate, it is really encourage to using several size of aggregate.

The function of mixing several sizes is to ensure the void between coarse aggregate is small. It means that the bigger size of aggregate will give the strength to the structure while the smaller size of it will fulfil the gap between bigger aggregate.

3.3.4 Fine Aggregate

According to ASTM, the specific size for fine aggregate is smaller than 4.75 mm. The function of fine aggregate is to fill the void that cannot be reach by coarse aggregate due to the size is smaller. This will make the concrete denser and stronger compared to concrete that only contain course aggregate. In this sample preparation, fine aggregate used is river sand provided in Civil lab that have been sieved to remove the particle that have size bigger than 4.75 mm.

3.3.5 Rice Husk

As the manipulated variable in this research, rice husk is used in order to replace the fine aggregate by certain percentage until it gets the ideal ratio. The rice husk sample was collected from local rice mill located in Rompin, Pahang. The rice husks need to be sieved first to remove unwanted particle and it will be dried in oven for 24 hours to reduce the moisture content.

3.4 Concrete Mix Design

The concrete mix design used in this study was taken the data in previous research by (Isma Farhan, 2017). There are three percentage of replacement in the concrete as follows:

Table 3.1 Concrete Mix Design

Percentage Replacement (%)	Water, Kg	Cement, Kg	Aggregate		Raw Rice Husk, Kg
			Fine, Kg	Course, Kg	
0	46	78	242	214	0
5	46	78	230	214	3.04
15	46	78	206	214	9.12

Based on the weight classes in the table above, it can conclude that the ratio used in mixing concrete is 1: 3.1: 2.7 and the water to cement ratio is 0.57.

3.5 Reinforcement Design

In this research, the reinforcement design is according to the Eurocode 2. The beam is design as simply supported beam with span of 1.5 m length. Based on the Eurocode 2, the design for simply supported beam is refer as design for rectangular section. In order to propose the size, the formula of diameter bar used is get from section 6.1: MS EN 1992-1-1:2010 under design for flexural. In this study, the reinforcement design is calculated only for the normal concrete beam. This means that, the concrete density used in the calculation is 25 kg/m^3 and the loading consider is only the self-weight of the beam. All the calculation design is based on the dimension of the beam which is 150 mm of width, 300 mm of height and the length is 1500 mm.

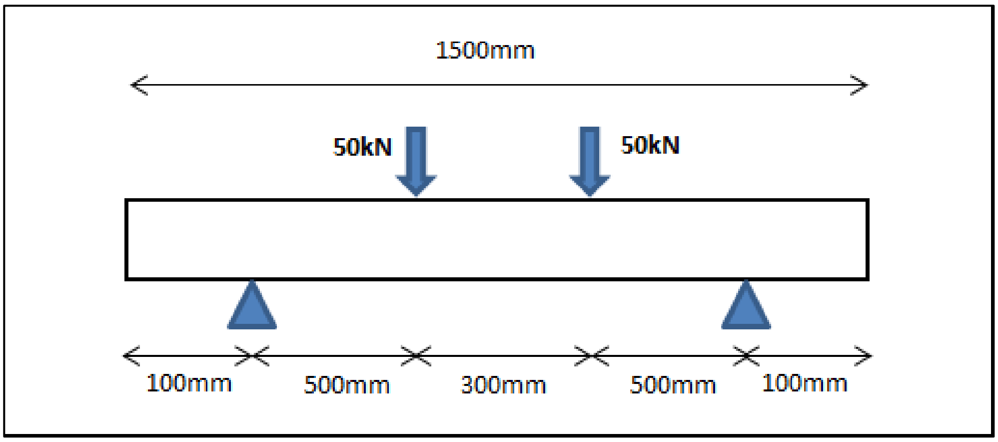


Figure 3.1: Simply Supported Beam

$\epsilon M_A = 0(cw + ve)$

$0.5(50) + 0.8(50) - 1.3(R_B) = 0$

$R_B = 50\ kN$

$\in F_y = 0 \uparrow +ve$

$R_A - 50 - 50 + 50 = 0$

$R_A = 50\ kN$

For Loading

Shear Force Diagram

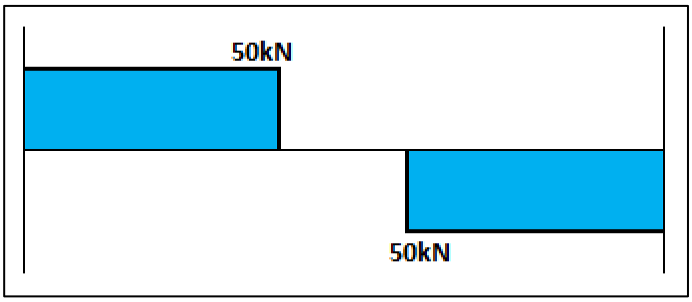


Figure 3.2: Shear Force Diagram

Bending Moment Diagram

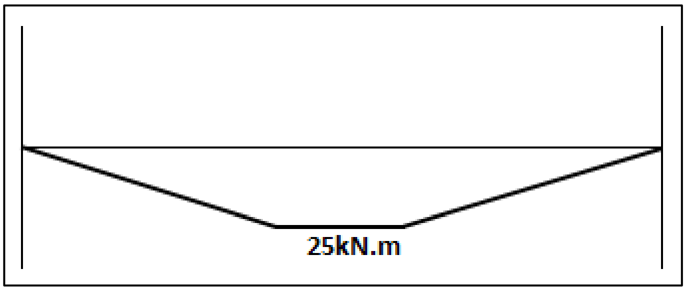


Figure 3.3: Bending Moment Diagram

For Selfweight

$$Beam\ Selfweight = (0.15 \times 0.3) \times 25 = 1.125\ kN/m$$

$$1.125\ \frac{kN}{m} \times 1.5\ m = 1.688\ kN$$

$$W_d = 1.35(1.688) + 1.5(0) = 2.278kN$$

$$M = \frac{(2.278 \times 1.5^2)}{8} = 0.481\ kN.m$$

$$M_{ED} = 25\ kN.m + 0.481\ kN.m = 25.481\ kN.m$$

- Concrete strength, fck = 25 N/mm^2
- Steel strength, fyk = 500 N/mm^2
- Ø $bar_{,t}$ = 12 mm
- Ø link = 6 mm

Durability, fire resistance and bond.

- $C_{nom,bond}$ = 12 mm + 10 = 22 mm
- $C_{nom,\ durability}$ = 25 mm + 10 = 35 mm

R60; b_{min} = 120 ; a = 40

- $C_{nom,fire}$ = 40 – 6 – 6 = 28 mm **Use: Cnom = 35 mm**

Effective depth, d

$$d = h - C_{nom} - \emptyset link - \frac{\emptyset bar}{2}$$

$$d = 300 - 35 - 6 - \frac{12}{2} = 253\, mm$$ **Use d = 253 mm**

Maximum moment design, Med = 25.481 kN.m

$$k = \frac{25.481 \times 10^6}{25 \times 150 \times 253^2} = 0.106 < 0.167 \ \ (compression\ not\ required)$$

$$z = d\left[0.5 + \sqrt{0.25 - \frac{0.106}{1.134}}\right] = 0.90d$$

$$As, req = \frac{25.481 \times 10^6}{0.87 \times 500 \times 0.90 \times 253} = 257.26\, mm^2$$

Proposed 3H12 (339 mm^2)

$$As, min = 0.26(\frac{2.6}{500})(150 \times 253) \leq 0.0013(150 \times 253)$$

$$As, min = 51.53 \geq 49.34$$ **As,min = 51.53 mm^2**

$$As, max = 0.04bh = 0.04 \times 150 \times 300 = 1800\, mm^2$$ **As,max = 1800 mm^2**

Shear reinforcement design

$$V_{Rd,max} = \frac{0.36(150)(253)(25)(1 - \frac{25}{250})}{(25 + \tan 22)} = 105.851\, kN$$

- Ved = 50 kN < Vrd,max = 105.851 kN ; **Use θ = 22^o**

$$\frac{Asw}{S} = \frac{50 \times 10^3}{0.78(500)(253)(25)} = 0.203$$

Try H6 = 56.6 mm^2

$$spacing, S = \frac{56.6}{0.203} = 278.8$$

Maximum spacing, Smax = 0.75(253) = 189.8 mm

Minimum link

$$\frac{Asw}{S} = \frac{0.08 \times \sqrt{25} \times 150}{500} = 0.12$$

Try H6 = 56.6 mm^2

$$spacing, S = \frac{56.6}{0.12} = 472\ mm$$

Use shear & minimum link ; H6-175

$$V_{min} = (\frac{56.6}{175}) \times (0.78 \times 500 \times 253 \times 2.5)$$

$$Vmin = 79.78\ kN > Ved = 50\ kN$$

Use Vminimun = 50 kN

Deflection

$$\rho_0 = \sqrt{25} \times 10^{-3} = 0.005 \quad < \quad \rho = \frac{265.39}{150 \times 253} = 0.007$$

$$l/_d = 1.0\left[11 + 1.5\sqrt{25}\left(\frac{0.005}{0.007 - 0}\right) + \frac{1}{12}\sqrt{25}(\frac{0}{0.007}) = 16.36\right]$$

- Modification factor 2 = 1.0
- Modification factor 3 = (339/257.26) = 1.32

$$(l/_d)_{allowable} = 16.36 \times 1.0 \times 1.32 = 21.60$$

$$(l/_d)_{actual} = \frac{1500}{253} = 5.93\ <\ (l/_d)_{allowable}$$

Deflection Pass !

Cracking

$$fs = \frac{500}{1.15} \times \frac{1}{1.35}\left[\frac{100 + 1.125(1.5)}{1.35(101.685)}\right]\frac{1}{1} = 238.56 \sim 240$$

Wk = 0.3 mm; fs = 240 N/mm^2; max bar spacing = 200 mm

$$S_{actual} = \frac{150 - (2 \times 35) - (2 \times 6) - 12}{3 - 1} = 28\,mm\ < Smax = 200\,mm$$

Cracking Pass !

Detailing

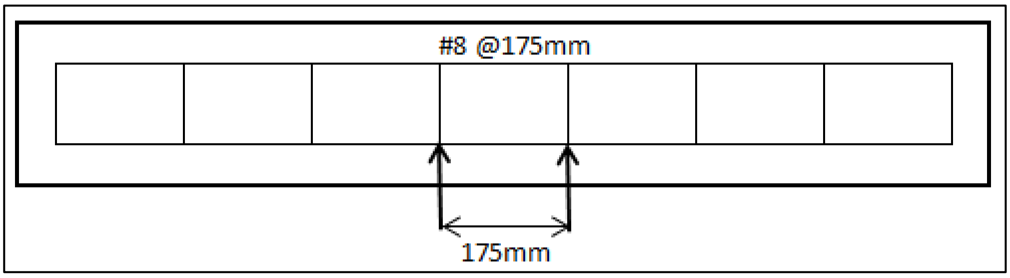


Figure 3.4: Spacing Detailing Of Beam

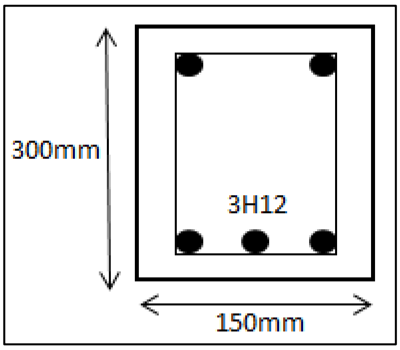


Figure 3.5: Proposed Bar Arrangement

3.6 Parameter Testing

For this research study, there are few parameters considered to ensure the quality of the structure member achieve standard to be used in daily construction. The parameters that are involved as follows:

I. Flexural Strength

Flexural strength is from the result of Magnus Frame Four Point Test. It is defined as value of stress in samples just before it yield or until fracture. Manually, the stress can be calculated by formula of $\sigma = \frac{3FL}{2bd^2}$.

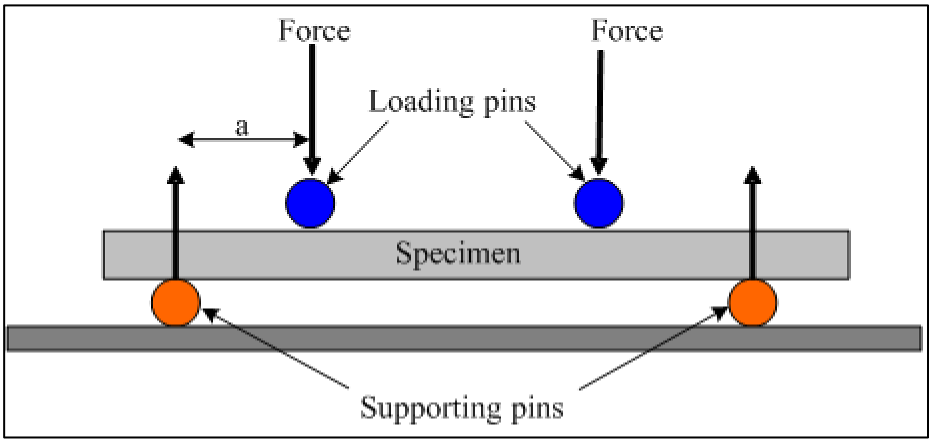


Figure 3.6: Four Point Loading

II. Strain Steel

Steel is used as the reinforcing material in concrete so that it good in tension. All ductile material such as structural steel can be analysed by its ability to yield in normal temperature. The liner portion of the curve in figure below is elastic region and the slope is Young modulus.

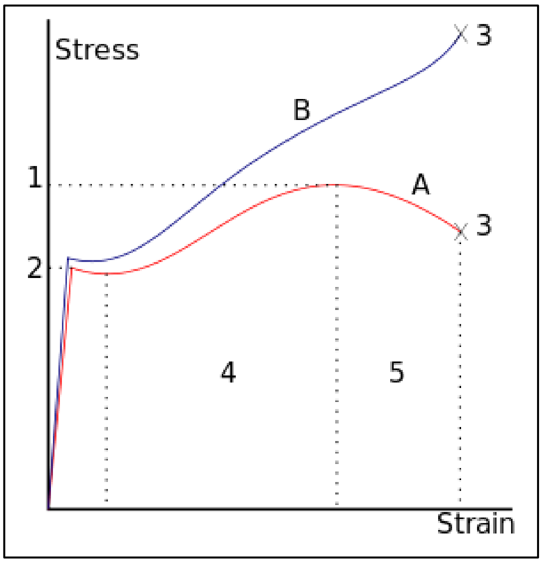


Figure 3.7: Steel Stress-Strain Curve

III. Strain Concrete

Concrete is considered as brittle material due to the ultimate strength and breaking strength are the same. The typical stress-strain curve for brittle is liner. This brittle type of material does not have yield point and necking not happen before failure. In concrete strain, the tensile strength usually negligible compared to the compressive strength.

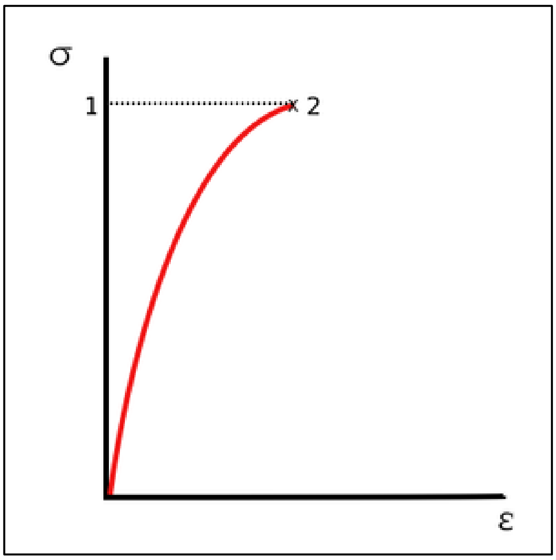


Figure 3.8: Concrete Stress-Strain Curve

IV. Deflection

The deflection behaviour is important in the parameter testing of beam structure. This is because, the ultimate load before achieving maximum deflection will show the result of the capability of rice husk concrete beam.

3.7 Sample Preparation

There are two type of sample prepared in this study which is beam member and cube. The beam member is needed to test the flexural strength and the cube is to test the compressive strength. The mould used in this preparation is plastic mould for cube and timber formwork for beam structure. The dimension of cube samples is 150 mm (W) x 150 mm (L) x 150 mm (H) while the sample of beam have dimension of 150 mm (W) x 300 mm (H) x 1500 mm (L).

For cube test, the total numbers of sample are 3 unit samples taken from same concrete that use to cast the beam. Meanwhile, there are 9 samples of beam casted which are 3 standard beams that contains 0% of rice husk aggregate and 6 rice husk concrete beam with difference percentage of rice husk replacement. The 3 standard beams used as reference for normal concrete beam structure to compare with the rice husk concrete beam structure at the end of the study.

For the standard beam that contains 0% of rice husk, the mixing of concrete contain of 46 kg of water, 78 kg of cement, 242 kg of fine aggregate and 214 kg of course aggregate with the concrete mix design ratio is 1: 3.1: 2.7 and the water to cement ratio is 0.57 according to study done by (Isma Farhan, 2017).

3.8 Slump Test

The concrete slump test is used for the measurement of a property of fresh concrete. It is done comply with ASTM C143/C 143M-05. The concrete slump test is used to determine of concrete’s workability or fluidity, also indirectly to determine of concrete consistency or stiffness. The test is popular due to the simplicity of apparatus used and simple procedure. It indicates the behaviour of compacted concrete cone under the action of gravitational force. This testing is useful to controlling the quality of concrete used in structure due to it can indicate the changes value of slump in term of it materials, water content or proportion of mixing.

The apparatus used in slump test is mould, temping rod, scale for measurement, scoop, base plate and brush. The slump mould should made of metal with thickness is not less than 1.5 mm and in cone shape. The height of slump cone is 300 mm with 200 mm of the base diameter and 100 mm for the top diameter. The steel temping rod have 600 mm of its length and 16 mm of the diameter.

The first step in slump test is ensured the internal surface of the mould is thoroughly cleaned and freed from superfluous moisture before commencing the test. If the cone is in completely dry in condition, it needs to be dampening using a damp cloth. The mould then placed on a smooth, horizontally levelled rigid and non-absorbent surface such as rigid plate. It is held firmly in place during filling by standing on two foot pieces provided in the slump cone. The mould is filled with concrete in three layers with each approximately one-quarter of height of the mould. Each layer need to be tamped down with 25 strokes using tamping rod. After tamping the top layer, the concrete is struck off level with a trowel and any mortar leaked out between mould and base plate is cleaned away. This is the most important part where the mould is then removed from concrete immediately by raising it slowly and carefully in vertical direction and read the slump. The test is completed in 90 seconds.

3.9 Compressive Test

Compressive strength test or also known as cube test is one of the common testing that had been done in all construction in the world. It is importance because by this single test it can be judge whether the concreting has been done properly or not by analysed the compressive strength result. For general construction, compressive strength varies from 15 MPa to 30 MPa and higher in commercial and industrial structure.

There are several factors considered in compressive strength testing such as water – cement ratio, cement strength itself, quality of concrete material and quality control during the production of concrete. Test for compressive strength is carried out either in cube or cylinder. This test is one of the damage concrete test based on specification of British Standard Institution 2009 (BS EN 12390-3:2009).

For cube test 3 numbers of specimens with dimension of 150 mm x 150 mm x 150 mm cubical moulds is prepared. This concrete is poured in the mould and tempered properly to reduce the void in the concrete. After 24 hours, these moulds removed and the test samples are put in water for curing process. The surface of these samples was made even and smooth. In order to get it, cement paste was put and spread smoothly on the whole area of specimen. On the 28th days of curing process, the sample tested by compression testing machine. The load applied gradually at the rate of 1 N/mm^2 per second till the specimen fails. Then, load at the failure divided by area of specimen gives the compressive strength of concrete.

The type of compressive strength testing machine used is MATEST S.p.A. TREVIOLO 2408 ITALY that has 2,000 kN capacity.

3.10 Flexural Test

Generally, flexural test is important to determine the flexural modulus or flexural strength of a material. When then sample placed under flexural loading all three fundamental stresses present which are tensile, compressive and shear. Flexural strength is defined as maximum stress at the outermost fibre either compression or tension side of samples. Meanwhile, flexural modulus is calculated from slope of the stress vs strain deflection curve. These two values used to evaluate the ability of beam to withstand flexure or bending forces.

In this study, the type of flexural test used is four points loading. During the test conducted, ASTM C 78 – 2 used as the reference. The loading was gradually increment until the samples failure. The result showed in graphical format for flexural strength and yield strength. In this research study, apparatus used for flexural test is Magnus Frame Four Point Test.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Slump Test

The method of slump test used to acknowledge the fluidity of the concrete shown by the stiffness of the concrete after removing the slump mould. In other words, this test purposed to see how much water effect the concrete mixing. If water is too much, the slump concrete will be totally collapse. Table 4.1 below shows the result of slump test for 3 type of sample. Only a true slump is of any use in the test. A collapse slump will generally mean that the mix is too wet or that it is a high workability mix, for which the slump test is not appropriate. Very dry mixes having slump 0 – 25 mm are typically used in road making, low workability mixes having slump 10 – 40 mm are typically used for foundations with light reinforcement, medium workability mixes with slump 50 – 90 mm, are typically used for normal reinforced concrete placed with vibration, high workability concrete with slump > 100 mm is typically used where reinforcing has tight spacing, and/or the concrete has to flow a great distance.

Table 4.1: Slump Test Result

Percentage Replacement, %	Slump Height, (mm)
0	61
5	58
15	52

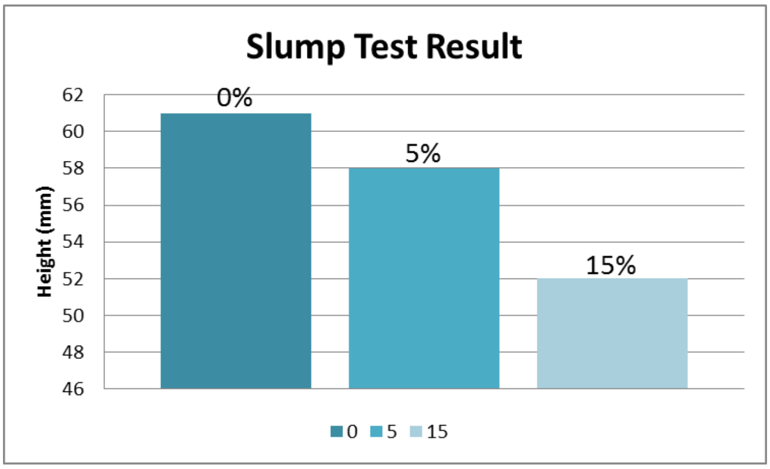


Figure 4.1: Slump Height Comparison

Based on this result, the minimum of slump height is 52 mm and maximum is 61 mm. It shows that the concrete has medium workability mixes suitable for normal reinforced concrete placed with vibration. The decreasing of slump height value might be because of the rice husk is a good absorbing materials. Comparing the beam with 0% of rice husk and 15% of rice husk, the water was absorbed more for the beam sample with high percentage of rice husk replacement. Moreover, the workability also effect a little bit. Compared both 0% and 15%, the concrete with 15% of rice husk is quite difficult to handle during the process of vibration because the fluidity of the concrete is less.

4.2 Compressive Strength Test

Compressive test or cube test using 150 mm x 150 mm x 150 mm cube test. The sample taken is the same batch of concrete mixing for the beam. In this study, 3 samples for every percentage of rice husks mixing is taken for cube test. The samples were then cured for 28 days. The result of compressive strength for all percentage of rice husk replacement is tabulated below.

Table 4.2: Compressive Test Result

Percentage Replacement (%)	Load (kN)	Compressive Strength (MPa)
0	716.4	31.84
5	510.1	22.67
15	265.03	11.78

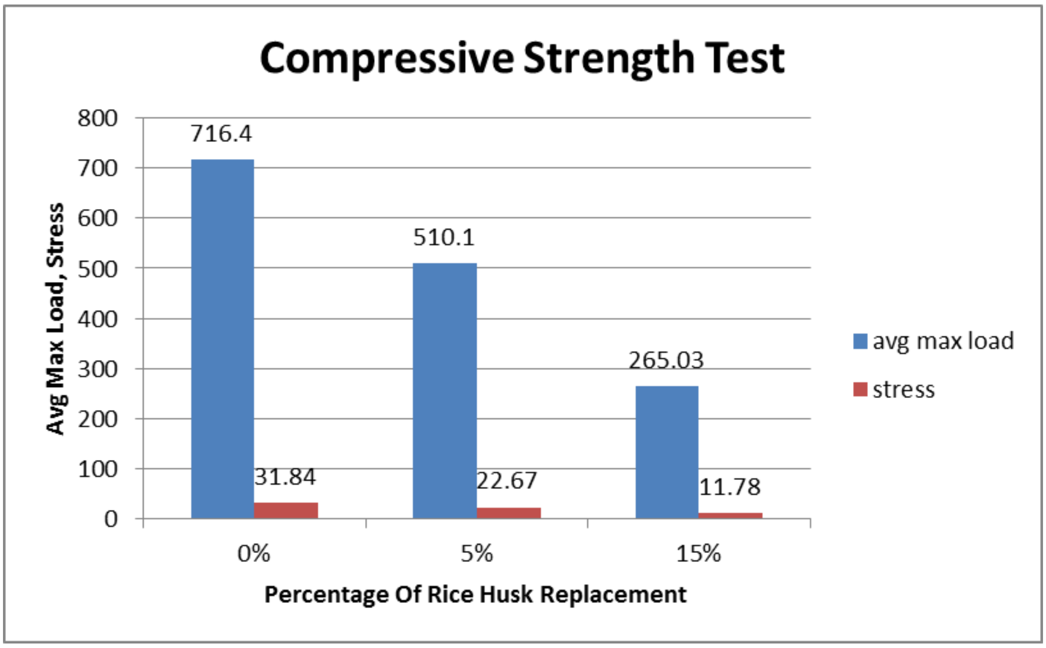


Figure 4.2: Compressive Strength Comparison

Based on the data and the chart, it clearly show that the replacement of rice husk have given influence to the strength of the beam in term of maximum load that can accept by the cube sample. For the controlled sample, it has the highest value of stress which is 31.84 MPa, follow by the 5% replacement sample which is 22. 67 MPa and

15% sample which is 11.78 MPa. A hypothesis can be made is the increase amount of rice husk as the fine aggregate replacement, the decrease value of stress obtained. This may be happened due to the properties of the rice husk itself. Rice husk is a good water absorption material. When it mixed with the same amount of water and cement for the different percentage, rice husk will absorb the water in a quick time. When the water content in the concrete mixing is decrease, the bonding strength between others material also decreases.

4.3 Flexural Strength Test

The beam sample tested on the 28 days of curing. The method of curing beams sample is by covering it with wet gunny and spray with water every day. The testing involved for this test is four point loading test according to ASTM C78. All the data collected is given in the table below.

4.3.1 Ultimate Loading Capacity

Table 4.3 Maximum Loading Capacity

Sample	Controlled	5%	15%
1	121.206	145.710	137.582
2	137.565	121.206	87.375
3	121.928	121.928	136.453
Average	126.900	127.130	120.470

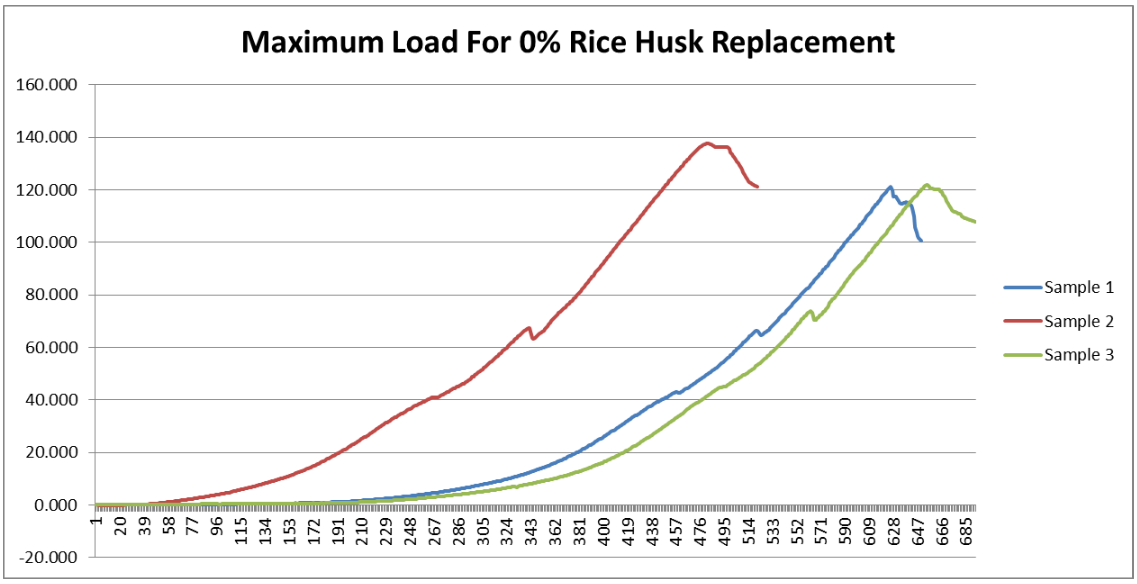


Figure 4.3 Maximum Load Comparisons For Controlled Beam

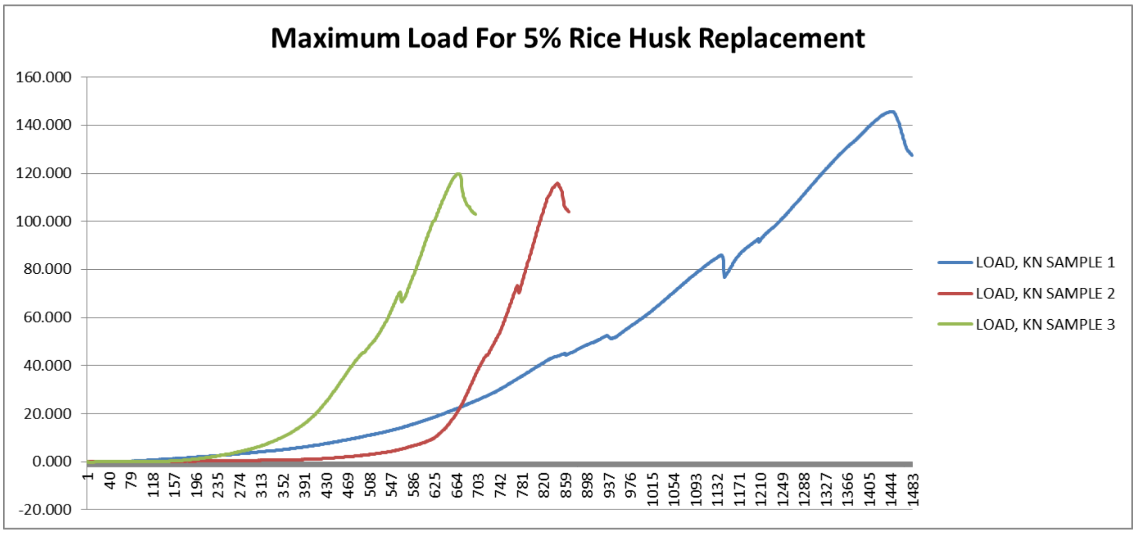


Figure 4.4 Maximum Load Comparisons For 5% Beam

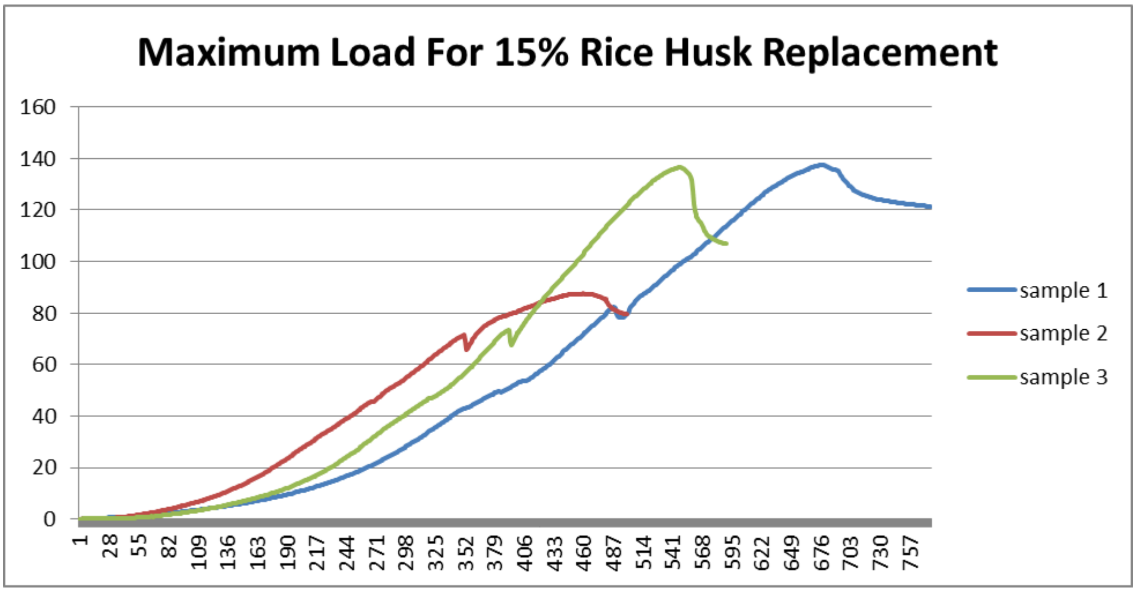


Figure 4.5 Maximum Load Comparisons For 15% Beam

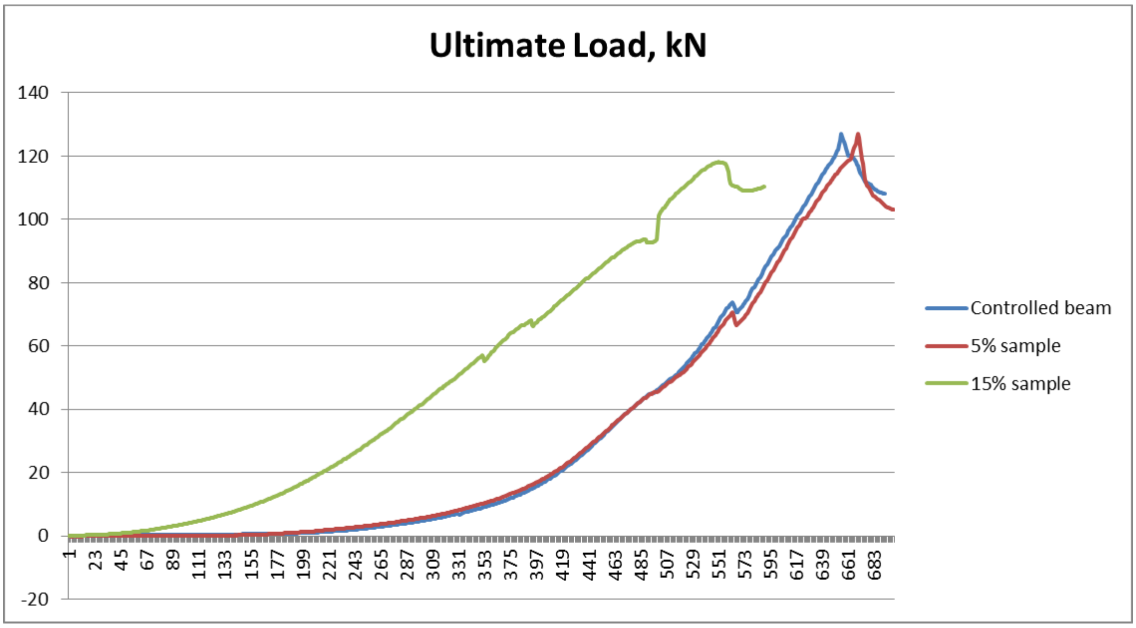


Figure 4.6 Average Maximum Loads For All Percentage

The average load of 2 samples for controlled beam and 5% rice husk replacement beam shows no drastically impact to the maximum loading capacity. Both sample show no difference in ultimate loading curves where the load increasing linearly until reach at the failure point and drastically dropped. Based on the result and the graphical curves, there are no big effect of 5% rice husk replacement on the beam due to it still can achieve the same maximum load as the controlled beam. However, for the 15% of rice husk replacement in concrete beam, the result and the curve show it the maximum load of the beam can achieve is quite lesser than other two samples which is 120.47 kN. This may happen due to the properties of the rice husk itself compared to the fine aggregate. Rice husks had a good reaction with water content where it will absorb the water quickly. When the water content lesser, the bonding between others material will become loosen and will affect the strength of concrete. Furthermore, the size of raw rice husk is bigger than fine aggregate. Even though the rice husk is sieve with 4.75 mm which is the size of fine aggregate, but the actual size of sand is tinier than raw rice husk. In other words, sand will filled more gaps in the concrete particle while rice husk will left small gaps between the bonding.

4.3.2 Deflection

The result of deflection get from the transducer reading put below the beam. When the load apply to the beam, the transducer start to give value of deflection of the beam in millimetre. The reading of deflection is collected and tabulated below.

Table 4.4: Deflection Of Beam

Sample	Controlled (mm)	5% (mm)	15% (mm)
1	7.207	8.775	11.617
2	7.893	7.194	10.674
3	7.519	7.929	10.398
Average	7.540	7.966	10.896

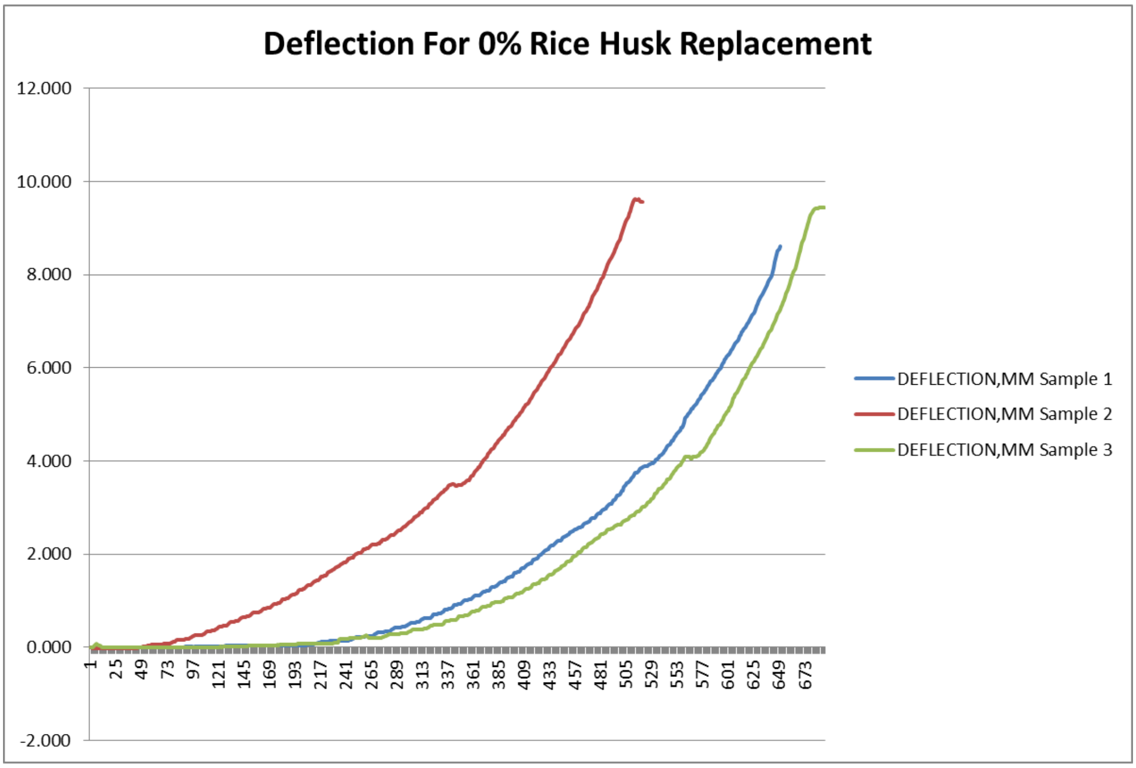


Figure 4.7: Deflection Comparison Curve For Controlled Beam

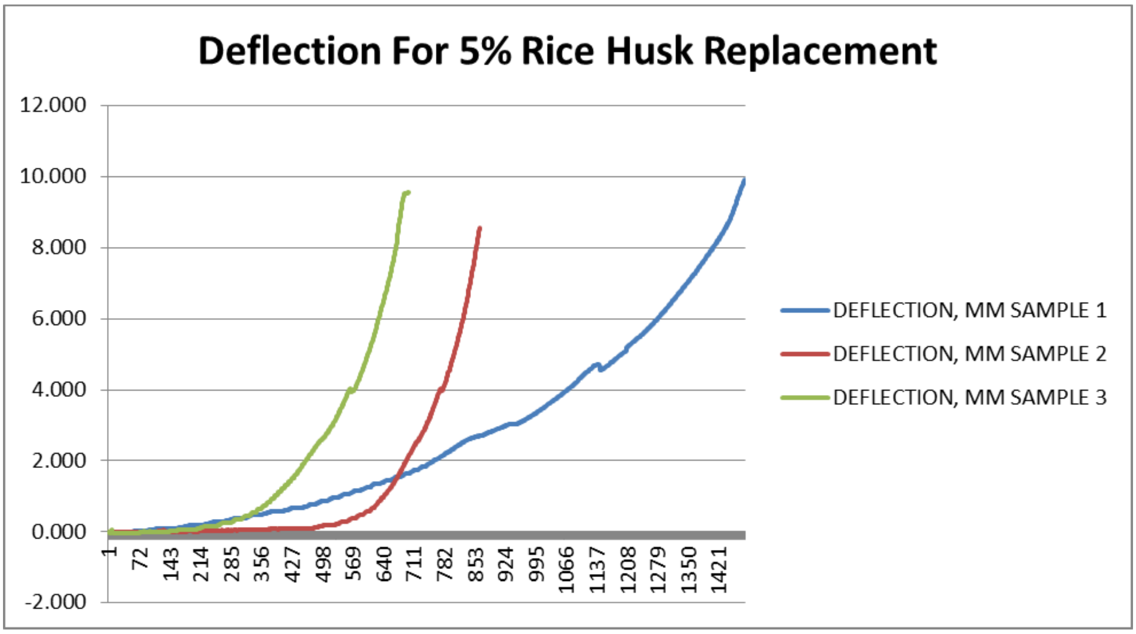


Figure 4.8: Deflection Comparison For 5% Beam

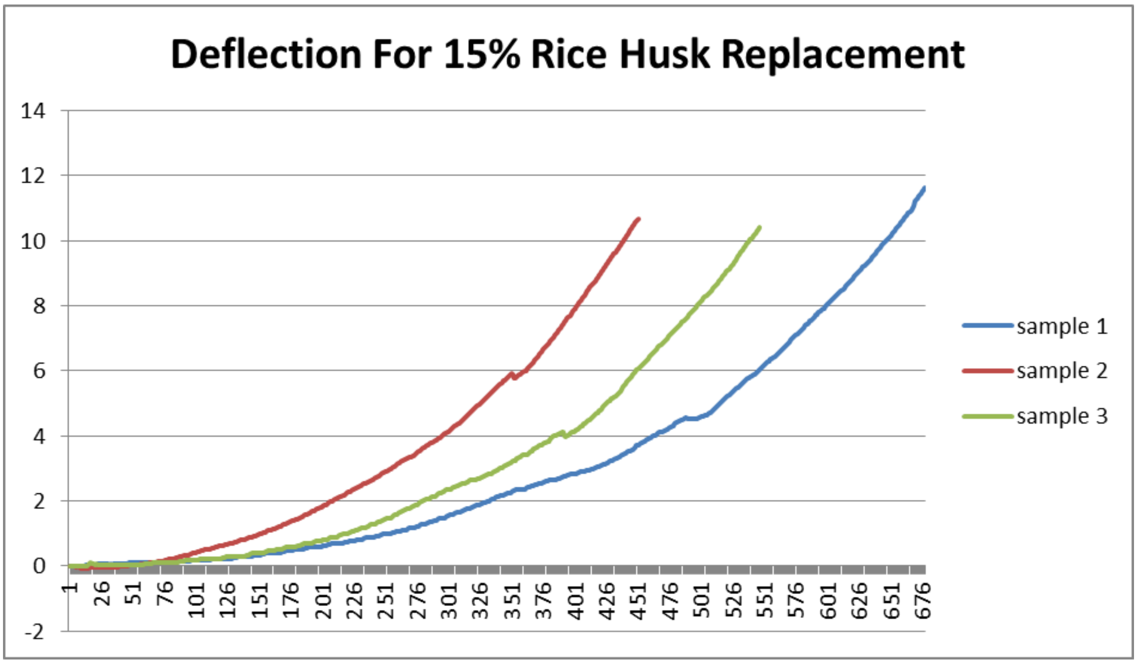


Figure 4.9: Deflection Comparison For 15% Beam

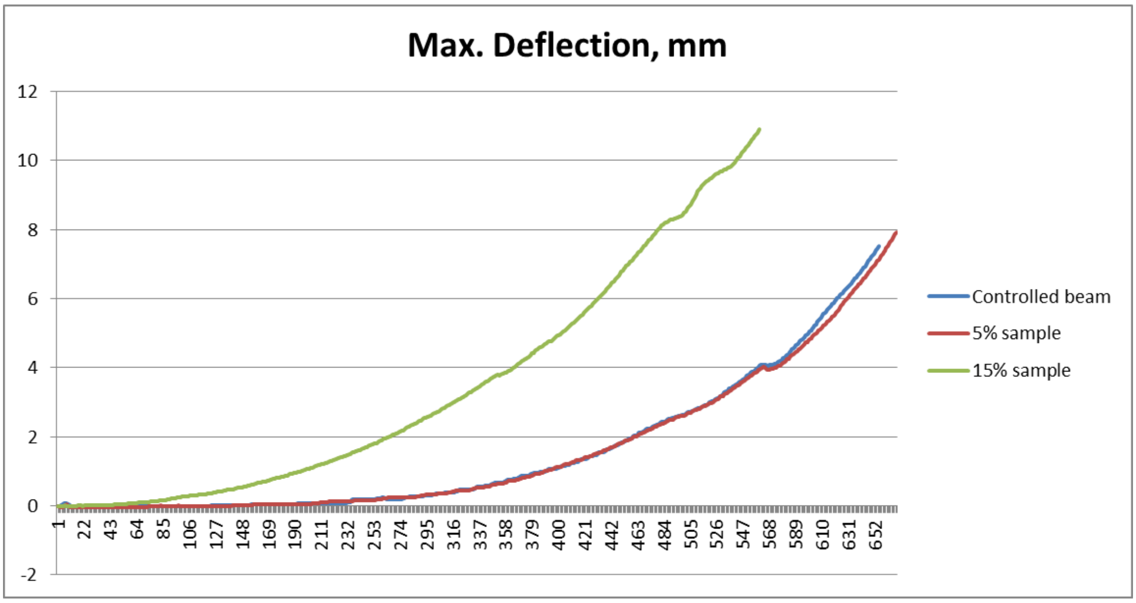


Figure 4.10: Average Maximum Deflection For All Percentage

The deflection behaviour of both samples shows similarities which are both achieves about 7 mm to 8 mm range of beam deflection. Based on the curves, the deflection of beam will continue increase when beam is applied by the load. It also shows that, there are no huge impact between controlled beam and beam with 5% rice husk replacement. Differ with other two samples, beam with 15% rice husk replacement have the highest deflection which is 10.896 mm and the maximum deflection occurred faster than other two samples.

4.3.3 Cracking Behaviour

General knows that concrete being weakest in tension. A concrete under an assumed working load will definitely crack at tension side, and the beam will be collapsed if no reinforcement is provided. The figure below shows the cracking behaviour of the beam samples between controlled beam and 5% rice husk replacement beam.

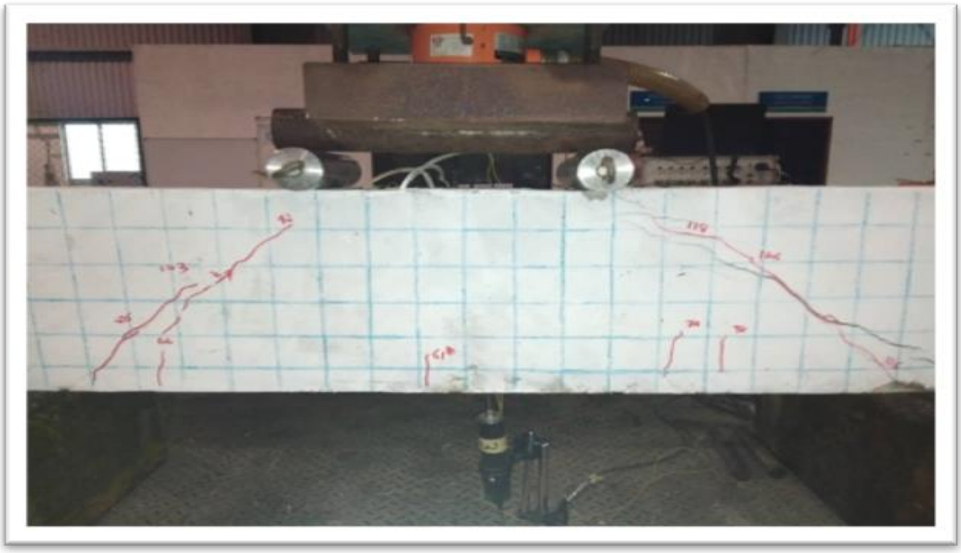


Figure 4.11: Cracking Of Controlled Beam Sample

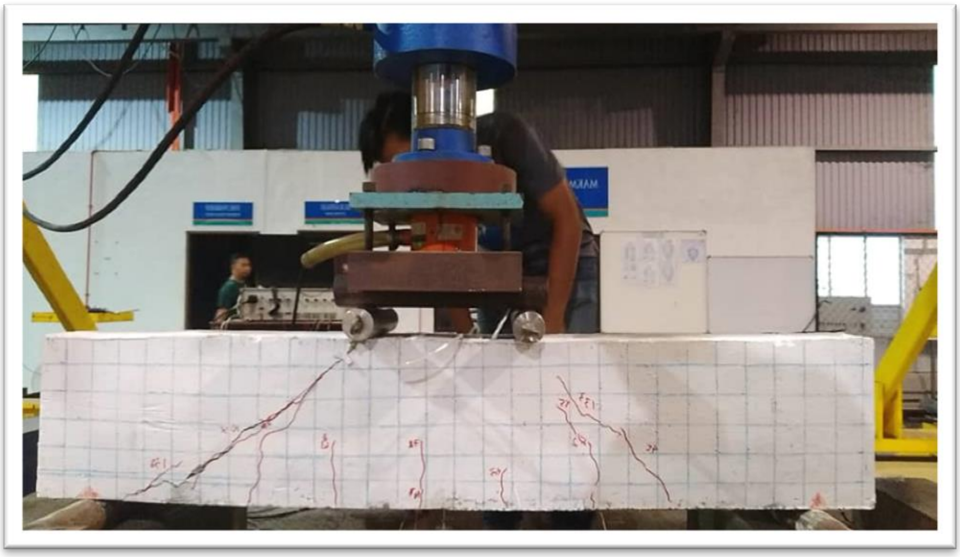


Figure 4.12: Cracking Of 5% Rice Husk Replacement Beam

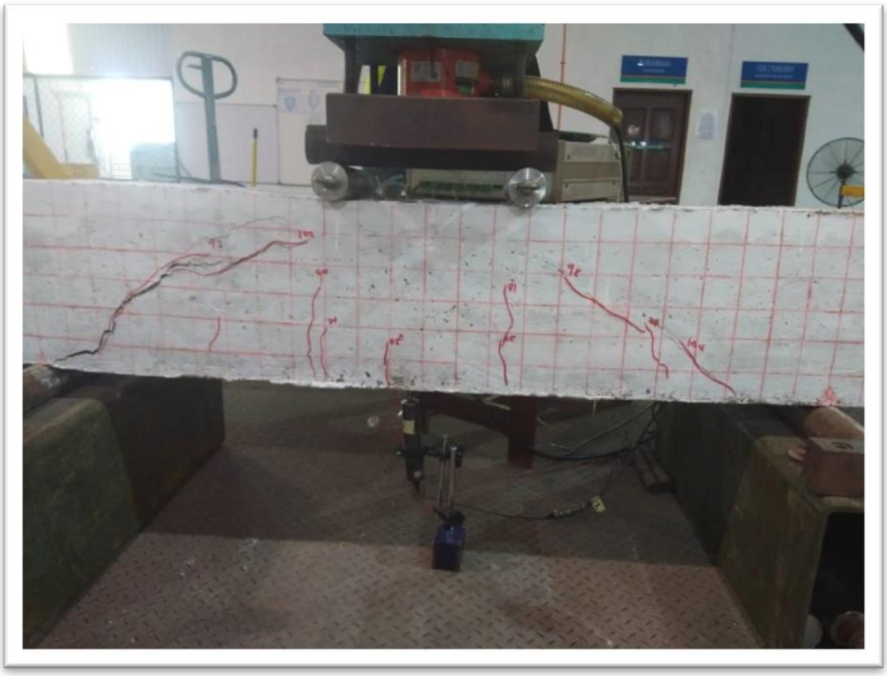


Figure 4.13: Cracking Of 15% Rice Husk Replacement Beam

From the previous cracking figure, it clearly shows that the beam of 5% and 15% rice husk replacement experience more tension crack rather than the controlled beam. There are 3 stages that can be obvious during the testing. Stage 1 is at zero external loads, where both samples only carried its own weight. During this stage, no crack was observed. Stage 2 comes when the load was incrementally applied to the samples. At this stage, deflection starts to occur slowly. As the results, both 5% and 0% sample experienced the first crack in the range of 55 kN to 65 kN of load while the first crack for 15% noticed at 47 kN. The minor first crack occur at the bottom side of the beam due to the slight deflection occurred. This also known as deflection crack or tension cracks because it happens at tension side of the beam. At stage 3, when the loads reach up to the range of 70 kN to 80 kN, all 3 sample start to show diagonal cracks about 45 degree angles. This happen due to the increasing of shear stress and it is also called as shear cracks.

4.3.4 Stress-Strain Steel

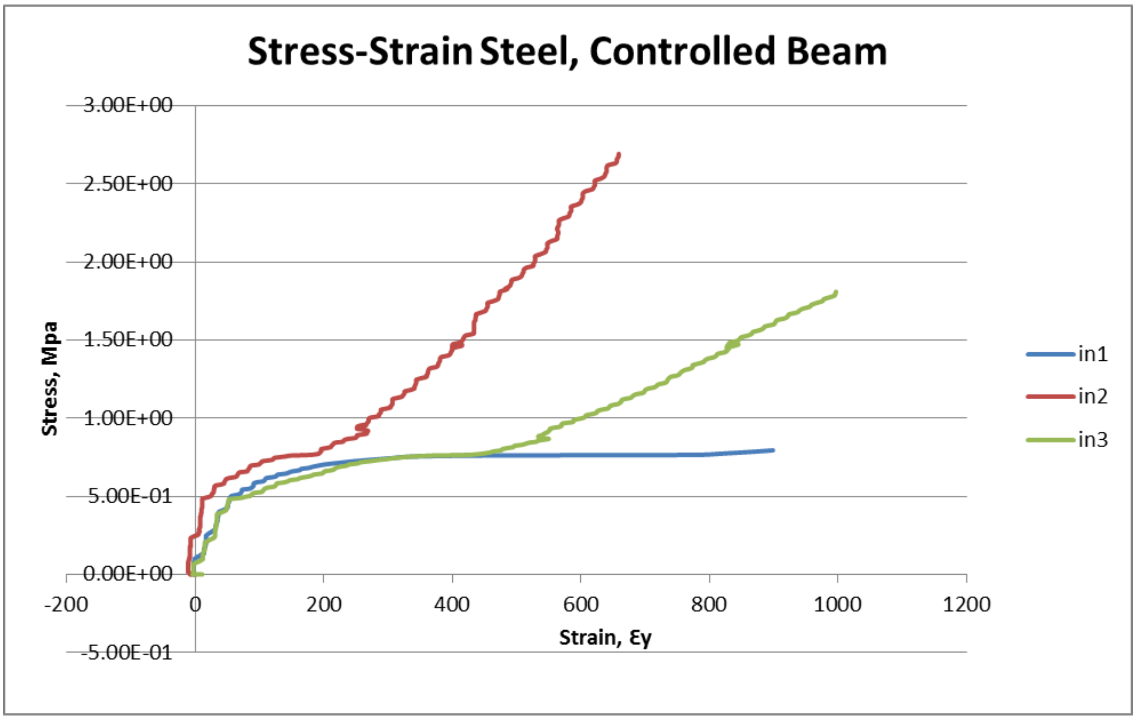


Figure 4.14: Average Stress-Strain Steel For Controlled Beam

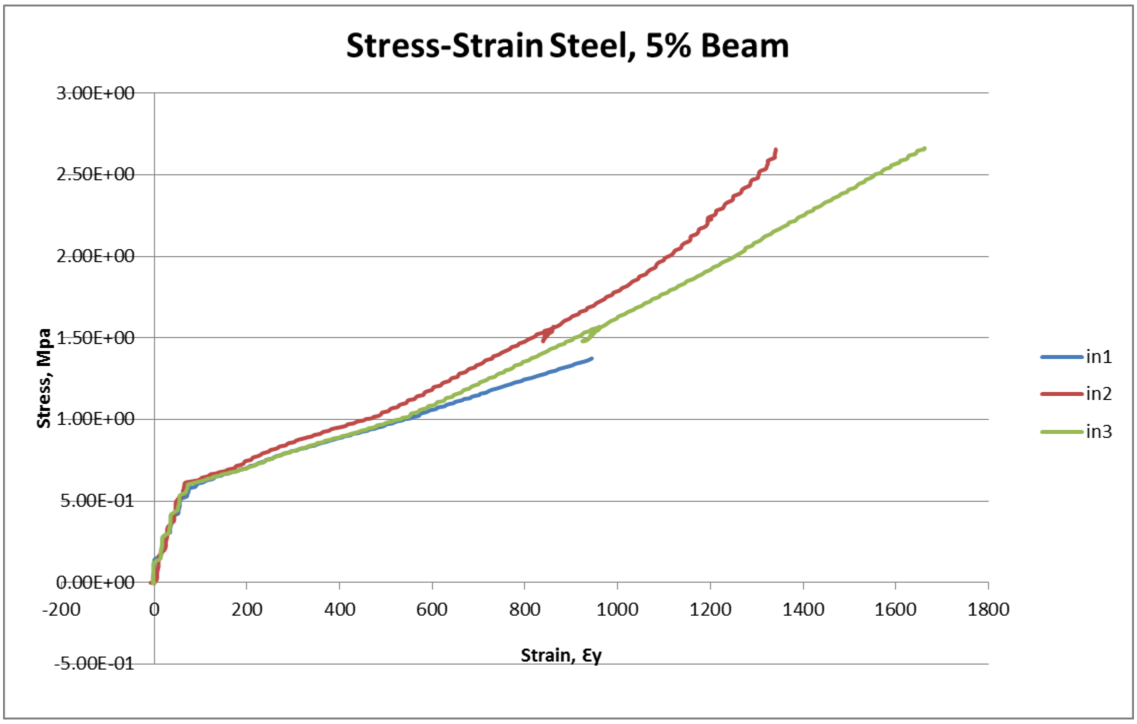


Figure 4.15: Average Stress-Strain Steel For 5% Beam Sample

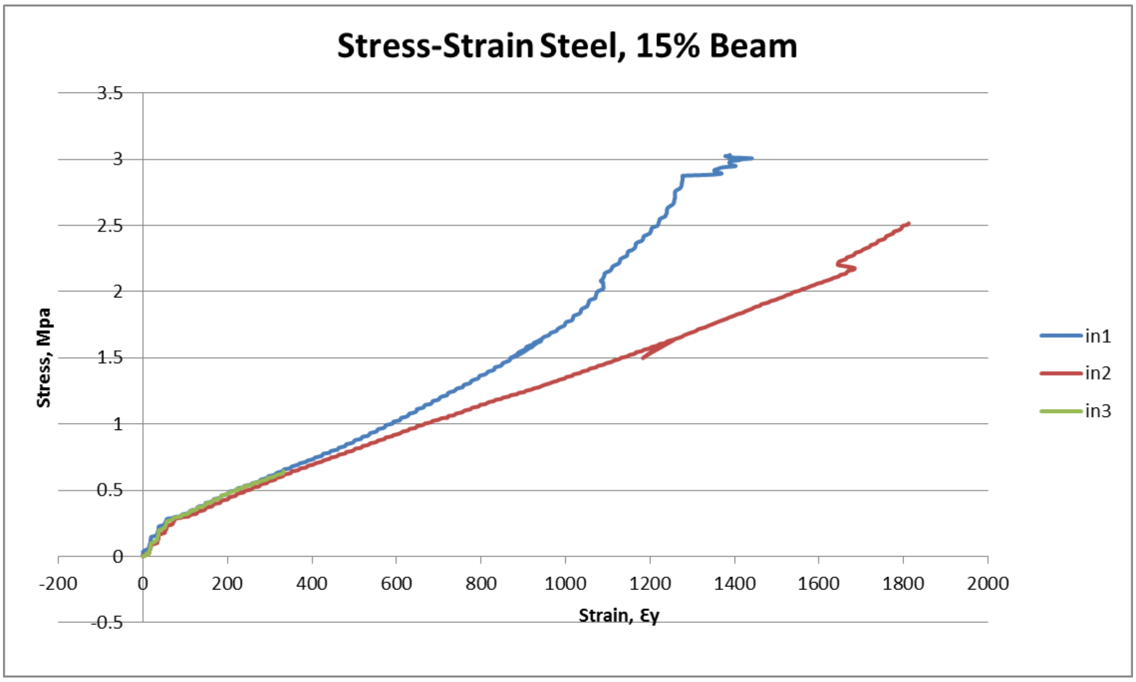


Figure 4.16: Average Stress-Strain Steel For 15% Beam Sample

Based on the stress-strain steel curve that had been plotted above, all samples can reach stress value up to 2.5 MPa before it failed. This is meant that, the replacement of rice husk does not affect the steel strain curve. However, it is difficult to get the exact value of strain due to the strain gauge might be torn inside the concrete beam.

4.3.5 Stress-Strain Concrete

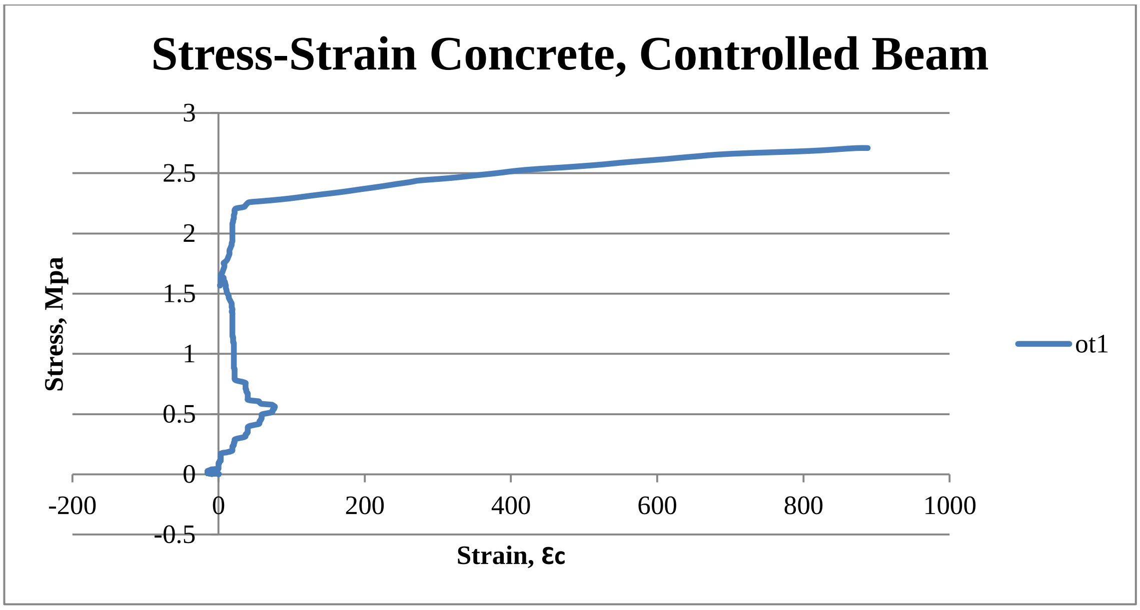


Figure 4.17: Average Stress-Strain Concrete For Controlled Beam Sample

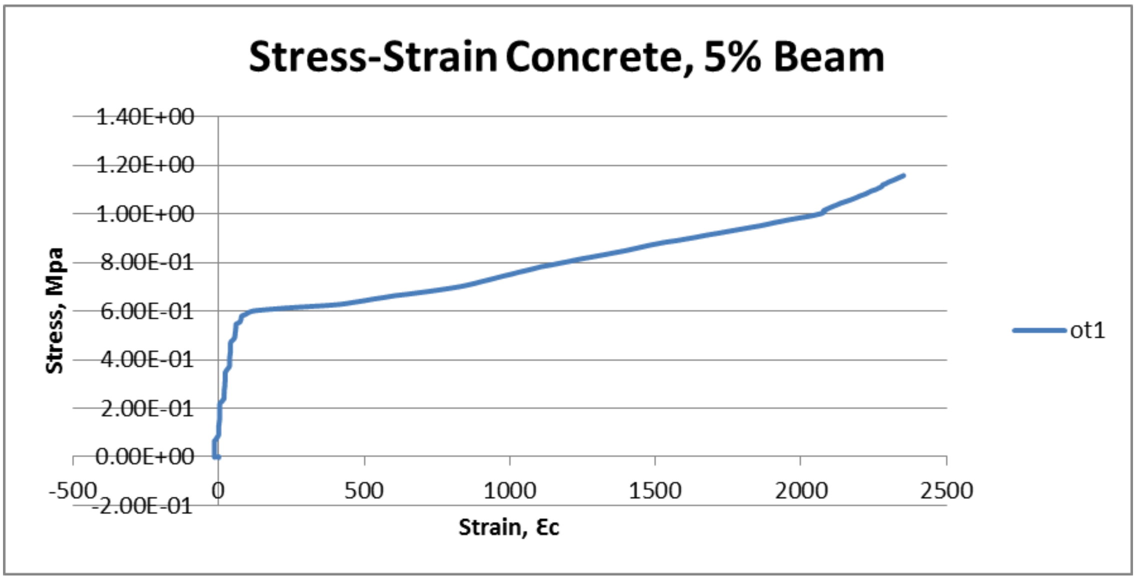


Figure 4.18: Average Stress-Strain Concrete For 5% Beam Sample

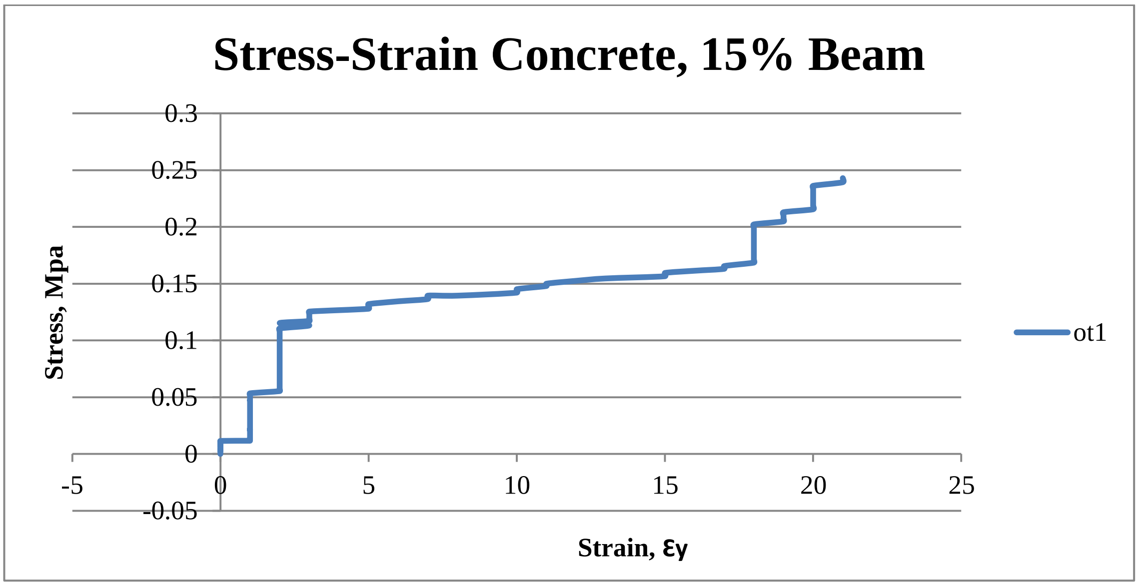


Figure 4.19: Average Stress-Strain Concrete For 15% Beam Sample

Differ with the steel strain, concrete strain shows the reaction of the concrete with the replacement of rice husk within sand in the concrete mix. Based on the graph plotted, it shows that the stress value is dropped when the percentage of rice husk replacement increased up to the 15%.

4.3.6 Maximum Moment Capacity

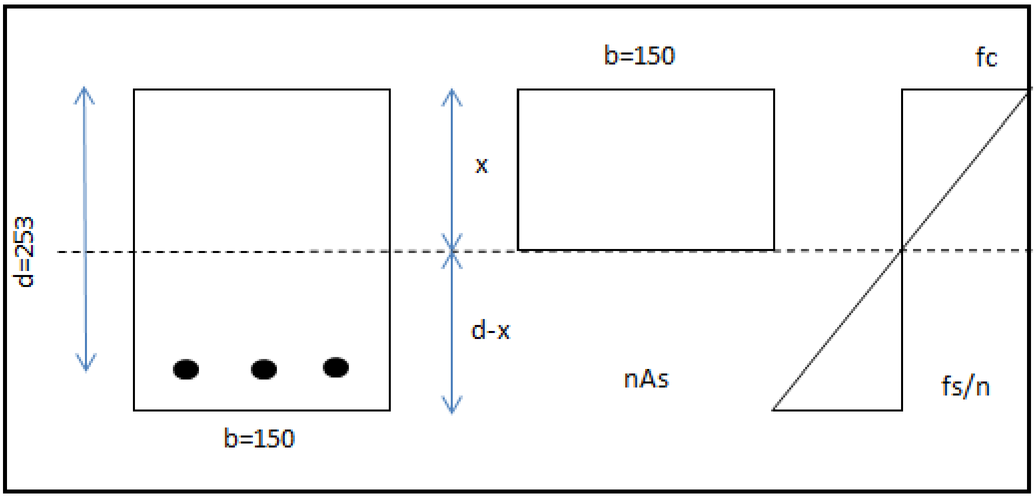


Figure 4.20: Moment Capacity Of Singly Reinforced Beam

$$Ec = 4700\sqrt{fck} = 4700\sqrt{25} = 23500\ Mpa$$

$$Es = 200000\ Mpa$$

Modular Ratio:

$$n = \frac{Es}{Ec} = \frac{200000}{23500} = 8.5$$

Allowable Stress:

fs = 140 Mpa for steel grade G275 ; fc = 0.45 (25) = 11.25 Mpa

Steel Area:

$$As = 3 \times \frac{1}{4}\pi(12^2) = 108\pi\ mm^2$$

$$nAs = 8.5(108\pi) = 918\pi\ mm^2$$

Moment Of Area:

$$150(x)\left(\frac{x}{2}\right) = nAs(d - x)$$

$$75x^2 = 918\pi(253 - x)$$

$$75x^2 + 918\pi x - 232254\pi = 0$$

$$x1 = 81.26, x2 = -119.72$$

Use x= 81.26 mm

Moment Inertia:

$$I_{NA} = \frac{150x^3}{3} + nAs(d - x)^2$$

$$I_{NA} = \frac{150(81.26^3)}{3} + 918\pi(253 - 81.26)^2$$

$$I_{NA} = 111890728\ mm^4$$

Moment Capacity Concrete:

$$fc = \frac{Mx}{I_{NA}}$$

$$11.25 = \frac{M(81.26)(1000^2)}{111890728}$$

$$M = 15.49\ kN.m$$

Moment Capacity Steel:

$$\frac{fs}{n} = \frac{M(d - x)}{I_{NA}}$$

$$\frac{140}{8.5} = \frac{M(253 - 81.26)(1000^2)}{111890728}$$

$M = 10.73\ kN.m$ **Use Safety Value Of Moment M,capacity = 10.73 kN.m**

CHAPTER 5

CONCLUSION

5.1 Introduction

The previous chapter shows all the data collected and have been analysis the effect of rice husk replacement between fine aggregate to the reinforced concrete beam. In this chapter, the overall experimental study were concluded and provided with several recommendations for future study or development. The main purpose of the study is to investigate whether rice husk replacement between fine aggregate is either acceptable or not in term of the maximum loading capacity, maximum moment capacity and the deflection.

5.2 Conclusion

There are some positive potential in order to solve the problem of running out of sand resources in this world especially in Malaysia, solve the landfill issue and also prevent from air pollution. Furthermore, the potential of reducing the construction price also might be achieved. Based on the result, several conclusions can be made;

I. Replacement of 5% amount of rice husk between fine aggregate in reinforced concrete beam can produce the same value of maximum loading capacity with controlled beam sample. Both maximum loading for 0% sample and 5% was 126.9 kN and 127.13 kN respectively for aged of curing 28 days. In other words, the 5% of rice husk replacement does not give huge impact towards the strength of structure. However, when the volume of rice husk replacement increase, the maximum loading capacity that can accept by the beam sample is decrease. In other word, the increase of raw rice husk in the beam up to 15% give impact towards the structure strength.

II. In term of deflection, both sample shows similarity where the range of beam deflection is between 7.5 mm to 8 mm. There was no big difference for the rice husk replacement beam. The deflection is acceptable due to the design allowable deflection is 21.60 mm. For the 15% beam sample, the deflection increases up to 10.896 mm although the maximum load is lower than other two samples. This shows that, the 15% rice husk replacement in beam tend to deflect more.

III. The replacement of 5% raw rice husk can be proposed to be used in construction industry of normal or lightweight structure such as single storey houses. However, the limitation or cut off for the replacement is at 15% due to the decreasing of maximum load and increasing in the deflection.

5.3 Recommendation

For the further study on this matter, some recommendation in this chapter might be help to ensure that the rice husk concrete can be used in structure. In order to improve this study, it is highly recommended to have specific coefficient of concrete design mix for certain percentage of rice husk replacement. Furthermore, the investigation of the design mix with additional of additive might be a good recommendation for future study so that the percentage of raw rice husk that can be replaced may improve up to 15% and the strength of the structure increase.

In addition, the workability of the rice husk replacement concrete also need to be improve as the workability of concrete containing rice husk is lower due to the properties of rice husk as a good water absorption. General worker will found it very difficult to handle it during the casting process because the fluidity of the concrete decreases as the percentage of rice husks increases.

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APPENDIX A

FLEXURAL TEST DATA (CONTROLLED BEAM SAMPLE)

Load,kN	Deflection,mm	Concrete Strain	Steel Strain 1	Steel Strain 2	Steel Strain 3
0	0	0	0	0	0
0	0	0	0	0	0
0.056	0.004	0	0	2	0
0.075	0.009	0	0	3	0
0.092	0.037	0	0	3	0
0.111	0.064	0	0	4	0
0.09	0.077	0	0	3	0
0.094	0.065	0	0	2	0
0.089	0.041	0	0	2	0
0.098	0.034	0	0	1	0
0.099	0.011	0	0	0	0
0.126	0	0	-1	-1	0
0.176	0	0	-2	-2	-1
0.163	0	0	-3	-3	-1
0.196	0.002	0	-4	-3	-1
0.177	0.001	0	-6	-5	-1
0.193	0.002	-1	-5	-6	-1
0.211	0.001	-1	-5	-7	-1
0.224	0.002	-2	-5	-8	-1
0.223	0.002	-3	-5	-8	-2
0.244	0.002	-3	-5	-8	-2
0.233	0.002	-4	-6	-9	-2
0.242	0.002	-5	-7	-9	-2
0.25	0.001	-5	-7	-9	-2
0.229	0	-6	-7	-9	-2
0.222	0	-7	-8	-9	-2
0.227	0	-7	-8	-9	-2
0.197	0	-7	-9	-9	-2
0.172	0	-8	-10	-9	-2
0.136	0	-9	-11	-9	-2
0.144	0	-9	-10	-9	-2
0.146	0	-10	-10	-9	-2
0.157	0	-9	-10	-9	-2
0.162	0	-9	-11	-9	-2
0.16	0	-8	-10	-9	-2
0.195	0	-10	-11	-9	-2
0.189	0	-10	-12	-9	-2

0.194	0	-11	-12	-9	-2
0.208	0	-11	-12	-9	-2
0.205	0	-10	-12	-9	-2
0.207	0	-10	-12	-9	-2
0.202	0	-11	-12	-9	-2
0.196	0	-11	-12	-9	-2
0.223	0	-11	-12	-9	-2
0.195	0	-11	-12	-9	-2
0.205	0	-11	-13	-9	-3
0.207	0	-10	-12	-9	-2
0.22	0	-10	-12	-9	-2
0.238	0	-10	-12	-9	-2
0.217	0	-10	-12	-9	-2
0.218	0	-11	-13	-9	-2
0.236	0	-11	-12	-9	-2
0.223	0	-11	-12	-9	-2
0.235	0	-10	-13	-9	-2
0.232	0	-11	-12	-9	-2
0.247	0	-10	-13	-9	-2
0.26	0	-10	-13	-9	-2
0.271	0	-10	-13	-9	-2
0.261	0	-11	-13	-9	-2
0.251	0	-11	-13	-9	-2
0.249	0	-12	-13	-9	-2
0.252	0	-11	-13	-9	-2
0.247	0	-11	-13	-9	-2
0.245	0	-11	-14	-9	-2
0.238	0	-10	-14	-9	-2
0.254	0	-8	-13	-7	-2
0.263	0	-8	-12	-7	-2
0.283	0	-9	-12	-7	-2
0.277	0	-10	-12	-8	-2
0.28	0	-11	-12	-8	-2
0.281	0	-11	-13	-9	-2
0.282	0	-11	-13	-9	-2
0.276	0	-10	-12	-9	-2
0.273	0	-9	-13	-9	-2
0.3	0	-9	-13	-9	-2
0.294	0	-9	-13	-8	-2
0.308	0	-10	-12	-7	-2
0.311	0	-11	-12	-8	-2
0.314	0	-11	-12	-7	-2
0.322	0	-11	-12	-7	-2
0.303	0	-11	-12	-7	-2

0.306	0	-11	-12	-7	-2
0.327	0	-11	-12	-6	-2
0.338	0	-11	-12	-7	-2
0.334	0	-11	-12	-6	-2
0.333	0	-11	-12	-6	-2
0.361	0	-11	-13	-6	-2
0.355	0	-11	-13	-5	-2
0.357	0	-11	-14	-6	-2
0.345	0	-11	-14	-6	-2
0.351	0	-11	-14	-5	-2
0.354	0	-11	-14	-5	-2
0.36	0	-12	-14	-6	-2
0.344	0	-12	-14	-6	-2
0.358	0	-11	-14	-5	-2
0.363	0	-11	-14	-5	-2
0.334	0	-12	-14	-6	-2
0.325	0	-12	-14	-6	-2
0.328	0	-12	-14	-5	-2
0.365	0.001	-11	-14	-3	-2
0.365	0.001	-11	-14	-3	-2
0.355	0	-13	-15	-3	-1
0.348	0.001	-13	-14	-4	-1
0.366	0	-14	-15	-5	-1
0.389	0.001	-13	-14	-5	-1
0.406	0	-14	-14	-4	-1
0.378	0.001	-13	-14	-3	-1
0.379	0.001	-14	-15	-2	-1
0.394	0	-15	-15	-2	-1
0.386	0.001	-14	-15	-2	-1
0.409	0.002	-14	-14	-2	-1
0.394	0.002	-14	-15	-2	-2
0.38	0.001	-14	-15	-3	-2
0.364	0.001	-14	-15	-2	-2
0.387	0.001	-14	-15	-2	-2
0.42	0.002	-14	-15	-2	-2
0.427	0.001	-14	-15	-1	-2
0.419	0.001	-15	-15	-1	-2
0.392	0.001	-15	-15	-2	-1
0.417	0.001	-15	-15	-3	-2
0.455	0.001	-15	-15	-1	-1
0.461	0.004	-15	-15	-29	-1
0.434	0.015	-15	-15	-104	-1
0.434	0.012	-15	-15	-104	-1
0.41	0.005	-15	-15	-104	-1

0.408	0.008	-14	-15	-104	-1
0.443	0.006	-15	-15	-104	-1
0.456	0.01	-15	-15	-104	-1
0.464	0.015	-15	-15	-104	-1
0.469	0.016	-15	-15	-104	-1
0.468	0.012	-15	-15	-104	-1
0.455	0.011	-15	-15	-103	-1
0.455	0.012	-15	-15	-103	-1
0.462	0.012	-15	-15	-103	-1
0.481	0.015	-15	-15	-103	-1
0.494	0.018	-15	-15	-103	-1
0.492	0.018	-15	-15	-103	-1
0.487	0.018	-15	-15	-103	0
0.498	0.02	-15	-15	-103	0
0.508	0.022	-15	-15	-103	0
0.496	0.021	-15	-15	-103	-1
0.482	0.023	-15	-15	-103	0
0.492	0.022	-15	-15	-103	-1
0.48	0.022	-15	-15	-103	-1
0.492	0.024	-15	-15	-103	-1
0.499	0.02	-15	-15	-103	0
0.5	0.023	-15	-15	-103	0
0.532	0.025	-15	-15	-103	0
0.543	0.025	-15	-15	-103	0
0.529	0.027	-15	-15	-103	0
0.53	0.028	-15	-15	-102	0
0.545	0.03	-15	-15	-102	0
0.529	0.03	-15	-15	-102	0
0.532	0.031	-15	-15	-102	0
0.553	0.035	-15	-15	-102	0
0.594	0.038	-15	-15	-102	0
0.596	0.038	-15	-14	-102	0
0.586	0.04	-15	-15	-102	0
0.584	0.039	-15	-15	-102	0
0.6	0.038	-15	-15	-102	0
0.576	0.04	-15	-15	-102	0
0.592	0.039	-15	-15	-102	0
0.614	0.038	-15	-15	-102	0
0.615	0.039	-14	-15	-102	0
0.583	0.04	-14	-15	-102	0
0.604	0.039	-14	-15	-102	0
0.602	0.041	-15	-15	-102	0
0.629	0.042	-15	-15	-102	0
0.637	0.041	-15	-15	-102	0

0.66	0.042	-15	-15	-102	0
0.659	0.042	-15	-15	-102	0
0.679	0.045	-14	-15	-102	0
0.648	0.045	-14	-15	-102	0
0.635	0.044	-14	-15	-102	0
0.622	0.043	-14	-15	-102	0
0.662	0.043	-14	-15	-102	0
0.668	0.046	-14	-15	-102	0
0.707	0.045	-14	-15	-102	0
0.689	0.046	-15	-15	-102	0
0.663	0.047	-15	-15	-102	0
0.689	0.049	-15	-15	-102	0
0.711	0.051	-15	-15	-102	0
0.693	0.052	-15	-15	-102	0
0.708	0.052	-15	-15	-102	0
0.739	0.054	-15	-15	-102	0
0.751	0.054	-15	-15	-102	0
0.767	0.054	-15	-15	-102	0
0.797	0.057	-15	-15	-102	0
0.791	0.057	-15	-15	-102	0
0.79	0.06	-15	-15	-102	0
0.796	0.061	-15	-15	-102	0
0.805	0.063	-15	-15	-102	0
0.786	0.064	-15	-15	-102	0
0.8	0.065	-15	-15	-102	0
0.838	0.065	-15	-15	-102	0
0.861	0.066	-15	-15	-102	0
0.855	0.067	-15	-15	-102	0
0.872	0.073	-15	-15	-102	0
0.895	0.072	-15	-15	-102	0
0.887	0.074	-15	-15	-102	0
0.919	0.075	-15	-15	-102	0
0.925	0.077	-15	-15	-102	0
0.94	0.078	-15	-15	-102	0
0.967	0.079	-15	-15	-102	0
0.978	0.08	-15	-15	-102	0
0.975	0.08	-15	-15	-102	0
0.997	0.08	-15	-15	-102	0
1.03	0.08	-15	-15	-102	0
1.046	0.08	-15	-15	-102	0
1.104	0.081	-15	-15	-102	0
1.124	0.081	-15	-15	-102	0
1.134	0.081	-15	-15	-102	0
1.152	0.081	-15	-15	-102	0

1.193	0.081	-15	-15	-102	0
1.219	0.081	-15	-15	-102	0
1.227	0.081	-15	-15	-102	0
1.246	0.081	-15	-15	-102	0
1.26	0.081	-15	-15	-102	0
1.293	0.081	-14	-15	-102	0
1.305	0.081	-13	-15	-102	0
1.351	0.081	-12	-15	-102	0
1.399	0.082	-13	-15	-102	0
1.425	0.082	-13	-15	-102	0
1.444	0.083	-13	-15	-102	0
1.462	0.084	-12	-14	-102	0
1.472	0.084	-12	-14	-102	0
1.513	0.085	-12	-14	-102	0
1.526	0.085	-11	-13	-102	0
1.56	0.086	-10	-13	-102	0
1.567	0.088	-9	-12	-102	0
1.585	0.089	-10	-12	-102	0
1.628	0.09	-8	-11	-102	0
1.633	0.095	-9	-11	-102	0
1.675	0.1	-8	-10	-102	0
1.713	0.15	-9	-11	-102	0
1.735	0.179	-9	-12	-102	0
1.806	0.178	-10	-11	-102	0
1.866	0.179	-8	-8	-102	0
1.905	0.179	-6	-7	-102	0
1.941	0.179	-5	-5	-102	0
1.976	0.179	-2	-4	-102	0
2.012	0.18	-1	-2	-101	0
2.023	0.18	-1	-2	-101	0
2.064	0.187	0	-1	-101	0
2.062	0.194	0	-1	-101	0
2.099	0.195	0	-1	-100	0
2.118	0.195	0	-1	-99	0
2.173	0.195	0	0	-98	0
2.195	0.195	0	0	-98	0
2.225	0.195	0	0	-97	0
2.265	0.195	0	0	-97	0
2.313	0.195	0	0	-96	0
2.357	0.195	0	0	-94	0
2.437	0.197	0	0	-94	0
2.463	0.206	0	0	-94	0
2.519	0.211	0	0	-93	0
2.554	0.217	0	0	-93	0

2.599	0.226	0	0	-93	0
2.627	0.233	0	0	-93	0
2.704	0.24	0	0	-91	0
2.746	0.256	0	0	-90	0
2.773	0.22	0	0	-91	0
2.81	0.196	0	0	-89	0
2.861	0.195	0	0	-90	0
2.928	0.194	0	0	-91	0
2.968	0.195	0	0	-92	0
2.988	0.195	0	0	-93	0
3.061	0.195	0	0	-94	0
3.089	0.195	0	0	-92	0
3.133	0.195	0	0	-93	0
3.187	0.195	0	0	-93	0
3.248	0.195	0	0	-93	0
3.311	0.195	0	0	-93	0
3.351	0.196	0	0	-93	0
3.372	0.199	0	0	-93	0
3.454	0.209	0	0	-92	0
3.479	0.222	0	0	-91	0
3.546	0.233	0	0	-91	0
3.592	0.243	0	0	-90	0
3.665	0.257	0	0	-91	0
3.73	0.265	0	0	-89	0
3.765	0.273	0	0	-88	0
3.824	0.275	0	0	-88	0
3.848	0.276	0	0	-87	0
3.926	0.276	0	0	-87	0
3.965	0.276	0	0	-87	0
4.033	0.276	0	0	-87	0
4.072	0.277	0	0	-86	0
4.137	0.278	0	0	-86	0
4.173	0.28	0	0	-86	0
4.219	0.283	1	0	-86	0
4.267	0.287	1	0	-86	0
4.315	0.291	1	0	-86	0
4.398	0.293	1	0	-86	0
4.454	0.293	1	0	-86	1
4.508	0.293	1	0	-86	1
4.559	0.293	1	0	-86	1
4.659	0.295	1	0	-86	1
4.74	0.305	2	0	-86	1
4.793	0.32	2	0	-86	1
4.847	0.333	2	0	-86	1

4.889	0.347	2	0	-86	1
4.953	0.361	2	0	-86	1
5.03	0.37	2	0	-86	2
5.077	0.373	3	0	-86	2
5.147	0.374	2	0	-86	3
5.207	0.374	3	0	-86	3
5.274	0.374	3	0	-86	4
5.333	0.375	3	0	-86	3
5.388	0.377	3	1	-86	4
5.499	0.38	3	1	-86	5
5.586	0.385	3	1	-85	6
5.65	0.389	3	1	-85	6
5.723	0.39	3	1	-85	7
5.79	0.391	3	1	-85	6
5.86	0.391	3	1	-85	6
5.956	0.398	3	1	-85	7
6.006	0.414	3	1	-85	7
6.084	0.429	3	1	-85	7
6.164	0.444	3	1	-85	7
6.244	0.461	3	1	-84	7
6.347	0.47	3	1	-84	6
6.426	0.471	3	1	-84	7
6.513	0.472	3	1	-84	7
6.574	0.472	3	1	-84	7
6.652	0.474	3	2	-84	8
6.74	0.477	3	2	-84	8
6.842	0.482	3	2	-84	9
6.909	0.487	3	1	-84	10
7.013	0.488	3	2	-84	10
7.041	0.488	3	2	-84	11
6.758	0.488	3	1	-84	8
7.003	0.502	3	2	-84	10
7.19	0.533	3	2	-83	11
7.304	0.559	3	2	-83	12
7.443	0.568	3	2	-83	13
7.557	0.569	3	3	-83	14
7.649	0.569	3	3	-83	15
7.746	0.571	3	3	-83	15
7.828	0.573	4	3	-83	15
7.922	0.579	5	3	-83	16
8.016	0.585	6	3	-83	16
8.098	0.586	9	3	-83	16
8.176	0.586	11	3	-83	16
8.286	0.589	12	3	-83	16

8.408	0.609	15	3	-83	16
8.5	0.632	15	3	-83	16
8.591	0.654	17	3	-83	16
8.689	0.666	18	3	-83	16
8.823	0.667	19	3	-83	16
8.921	0.667	19	3	-83	16
9.063	0.67	19	3	-83	16
9.136	0.676	19	3	-83	16
9.255	0.683	19	3	-83	16
9.358	0.684	19	3	-81	16
9.448	0.685	19	3	-80	16
9.579	0.7	19	3	-77	16
9.711	0.724	19	3	-76	16
9.81	0.751	19	3	-76	16
9.891	0.764	19	3	-74	16
10.019	0.764	19	3	-72	16
10.132	0.766	19	3	-71	17
10.247	0.769	19	4	-69	17
10.389	0.778	19	4	-68	17
10.508	0.781	20	5	-68	17
10.612	0.782	20	7	-68	17
10.761	0.797	20	9	-68	17
10.9	0.822	21	10	-68	18
10.977	0.845	21	12	-68	18
11.119	0.86	21	14	-68	18
11.254	0.862	21	14	-68	18
11.4	0.864	21	17	-68	18
11.58	0.868	21	18	-68	18
11.713	0.877	21	18	-68	18
11.858	0.879	21	18	-68	18
11.984	0.88	22	19	-67	19
12.159	0.895	22	19	-67	19
12.326	0.917	22	19	-67	19
12.512	0.941	22	19	-66	19
12.656	0.957	22	19	-66	19
12.82	0.96	22	19	-66	19
12.967	0.96	22	19	-65	19
13.098	0.963	23	19	-65	19
13.289	0.968	25	19	-65	19
13.479	0.975	28	20	-65	19
13.654	0.977	31	20	-65	19
13.816	0.977	34	21	-65	19
14.008	0.98	36	21	-65	19
14.163	0.998	37	21	-65	19

14.35	1.022	37	21	-65	19
14.534	1.046	37	21	-65	20
14.725	1.057	37	21	-65	22
14.893	1.057	37	21	-65	25
15.082	1.059	38	22	-64	27
15.28	1.063	39	22	-61	29
15.472	1.071	39	22	-58	31
15.655	1.074	40	22	-57	33
15.873	1.075	40	22	-52	34
16.089	1.089	40	22	-49	34
16.284	1.113	40	24	-49	34
16.488	1.14	40	26	-49	34
16.718	1.154	40	29	-49	35
16.926	1.155	40	31	-49	35
17.138	1.157	40	35	-49	35
17.419	1.163	40	37	-48	36
17.624	1.171	40	37	-48	36
17.844	1.172	41	37	-47	36
18.084	1.189	43	37	-47	37
18.316	1.214	47	38	-46	37
18.561	1.241	51	38	-46	37
18.784	1.252	55	39	-46	37
19.013	1.254	56	39	-46	37
19.289	1.258	56	40	-46	37
19.561	1.268	56	40	-46	37
19.798	1.272	56	40	-46	37
20.053	1.296	57	40	-46	37
20.364	1.328	58	40	-46	38
20.627	1.349	58	40	-46	38
20.867	1.351	59	40	-46	38
21.132	1.354	59	40	-44	40
21.442	1.364	59	40	-41	44
21.717	1.367	59	42	-37	47
22.039	1.379	59	46	-34	49
22.325	1.413	59	50	-32	51
22.584	1.443	62	53	-31	53
22.875	1.448	68	55	-31	53
23.189	1.451	73	56	-30	53
23.487	1.461	74	56	-30	53
23.765	1.465	74	56	-29	53
24.083	1.479	74	57	-28	53
24.392	1.51	76	58	-28	54
24.7	1.543	76	58	-28	54
25.053	1.546	77	59	-28	55

25.353	1.553	77	59	-28	55
25.676	1.562	75	61	-27	56
26.005	1.566	73	68	-23	56
26.313	1.597	59	75	-12	56
26.613	1.636	57	94	8	57
26.924	1.643	56	109	24	69
27.28	1.649	55	119	31	72
27.563	1.659	45	141	48	86
27.881	1.667	40	163	64	106
28.22	1.703	40	171	76	111
28.53	1.738	40	185	82	122
28.922	1.742	40	190	87	128
29.262	1.749	40	204	99	131
29.575	1.758	40	212	106	146
29.908	1.775	40	231	126	160
30.265	1.822	40	247	143	176
30.551	1.839	39	261	157	188
30.925	1.845	38	273	170	202
31.282	1.855	38	281	176	211
31.625	1.865	38	295	191	221
31.984	1.903	37	302	195	227
32.338	1.935	37	316	210	239
32.669	1.939	37	322	215	247
33.077	1.952	37	336	230	259
33.442	1.965	37	352	241	271
33.829	2.005	37	367	250	280
34.149	2.034	37	382	266	295
34.517	2.038	33	396	276	307
34.873	2.05	27	413	288	317
35.227	2.064	23	429	303	333
35.613	2.109	22	445	310	348
35.988	2.131	22	455	322	355
36.345	2.137	22	465	324	368
36.743	2.148	22	473	330	372
37.084	2.157	22	483	340	385
37.425	2.196	22	491	342	389
37.766	2.228	22	501	346	395
38.088	2.233	22	507	358	406
38.439	2.244	22	519	360	409
38.749	2.248	22	521	361	422
39.058	2.274	22	534	362	426
39.359	2.307	22	539	373	434
39.692	2.326	21	543	377	443
39.977	2.331	21	556	379	445

40.329	2.341	21	559	380	458
40.685	2.345	21	572	389	462
40.998	2.369	21	576	395	464
41.302	2.4	21	583	397	478
41.642	2.423	21	593	398	481
41.968	2.428	21	596	401	487
42.288	2.438	21	609	413	498
42.631	2.442	21	613	415	500
42.987	2.468	21	618	417	510
43.305	2.508	21	630	421	517
43.641	2.522	21	633	432	519
43.928	2.526	21	645	434	530
44.256	2.536	21	649	435	536
44.55	2.539	21	651	436	537
44.747	2.544	21	653	444	540
44.877	2.564	21	664	450	551
44.973	2.586	21	666	451	553
44.986	2.606	21	667	451	553
45.088	2.619	21	667	451	554
45.367	2.62	21	669	451	556
45.705	2.624	21	672	453	558
46.038	2.635	21	684	454	570
46.363	2.638	21	687	457	573
46.684	2.663	21	688	468	574
46.974	2.694	21	698	470	583
47.294	2.717	21	705	472	590
47.601	2.72	21	707	472	592
47.851	2.73	21	714	473	593
48.107	2.735	21	722	484	604
48.434	2.754	21	725	488	609
48.767	2.783	21	726	490	611
49.067	2.813	21	737	491	612
49.358	2.816	20	741	493	623
49.667	2.824	20	742	504	628
49.947	2.832	20	744	507	630
50.269	2.841	20	748	508	633
50.576	2.871	20	759	509	645
50.872	2.905	20	761	512	647
51.214	2.914	20	762	523	648
51.562	2.923	19	764	525	657
51.913	2.93	19	776	527	664
52.345	2.954	19	780	529	667
52.775	2.993	19	775	541	674
53.19	3.011	19	709	544	683

53.584	3.021	19	704	546	685
54.038	3.029	19	704	549	693
54.457	3.061	19	704	561	702
54.849	3.101	19	704	564	705
55.286	3.111	19	704	565	717
55.718	3.123	19	680	574	721
56.166	3.14	19	601	581	724
56.63	3.178	19	593	583	736
57.108	3.206	19	594	584	740
57.558	3.229	19	595	596	744
57.979	3.295	19	595	629	757
58.427	3.308	19	596	639	759
58.879	3.321	19	602	645	763
59.37	3.35	19	610	654	776
59.864	3.392	19	611	657	778
60.36	3.405	19	613	658	790
60.833	3.419	18	614	670	795
61.328	3.447	19	614	674	800
61.853	3.49	19	622	676	812
62.365	3.505	18	630	683	815
62.87	3.516	18	631	691	825
63.368	3.549	18	632	694	832
63.874	3.593	18	633	694	837
64.388	3.606	17	638	703	850
64.902	3.625	16	647	711	852
65.451	3.671	15	649	713	865
66.02	3.699	14	651	719	870
66.591	3.718	14	651	729	879
67.146	3.763	13	658	731	888
67.735	3.795	12	666	736	893
68.339	3.812	11	667	747	905
68.948	3.85	11	667	750	907
69.505	3.887	10	669	752	916
70.074	3.898	10	678	764	925
70.661	3.914	10	686	767	928
71.208	3.954	9	688	768	941
71.725	3.99	9	693	774	944
72.216	4.009	8	704	784	949
72.697	4.048	7	706	786	960
73.135	4.084	7	707	787	962
73.485	4.087	7	707	787	963
73.711	4.094	5	707	789	963
73.24	4.096	3	705	787	962
71.654	4.083	3	688	774	947

70.508	4.048	2	672	766	939
70.513	4.048	2	670	765	938
71.069	4.079	3	675	766	942
71.617	4.087	3	685	768	943
72.1	4.091	3	686	768	944
72.544	4.097	3	688	769	945
72.966	4.102	3	688	780	955
73.444	4.109	3	696	785	961
73.971	4.135	3	704	787	963
74.577	4.171	3	706	795	975
75.304	4.189	5	714	804	981
76.068	4.2	6	722	812	994
76.822	4.233	7	724	822	1002
77.58	4.276	8	725	824	1016
78.222	4.293	8	725	834	1019
78.548	4.34	8	725	838	1023
78.951	4.382	7	730	839	1032
79.592	4.402	10	741	842	1037
80.28	4.453	12	740	845	1047
80.97	4.492	13	741	857	1055
81.661	4.549	14	741	860	1061
82.327	4.581	15	743	861	1073
82.979	4.605	15	744	861	1077
83.681	4.657	15	752	861	1090
84.384	4.681	16	759	861	1094
85.042	4.711	17	761	861	1108
85.719	4.763	18	762	869	1111
86.394	4.782	18	768	876	1122
87.069	4.819	19	778	877	1129
87.723	4.866	19	780	879	1135
88.369	4.886	19	781	879	1146
88.939	4.939	19	781	880	1149
89.517	4.976	19	787	881	1160
90.121	4.991	19	795	887	1166
90.558	5.041	19	796	889	1167
90.867	5.081	19	796	884	1168
91.402	5.137	19	798	891	1178
91.978	5.17	19	799	895	1183
92.57	5.213	19	800	896	1185
93.194	5.265	19	799	898	1196
93.754	5.342	19	802	898	1203
94.328	5.375	20	810	898	1206
94.972	5.427	20	815	908	1219
95.625	5.461	21	817	913	1222

96.27	5.499	21	818	915	1234
96.85	5.551	21	820	916	1240
97.487	5.579	22	830	916	1244
98.136	5.634	22	833	917	1257
98.77	5.669	22	834	920	1259
99.348	5.724	24	835	928	1271
99.929	5.757	35	836	932	1277
100.517	5.801	37	836	932	1283
101.106	5.848	39	836	932	1295
101.664	5.881	42	837	933	1299
102.24	5.934	66	843	933	1311
102.75	5.965	86	850	934	1314
103.31	6.019	104	852	935	1322
103.917	6.052	121	854	935	1331
104.572	6.095	140	855	935	1335
105.238	6.14	161	859	935	1349
105.904	6.169	179	869	941	1352
106.577	6.209	196	871	947	1257
107.211	6.242	213	872	950	-6321
107.861	6.275	229	873	951	-17028
108.501	6.323	244	878	952	-17597
109.161	6.351	261	888	953	-17597
109.811	6.4	275	889	953	-17597
110.416	6.444	304	891	953	-17597
111.03	6.499	329	891	954	-17597
111.648	6.536	349	891	957	-17597
112.252	6.577	371	891	964	-17597
112.855	6.625	390	891	969	-17597
113.447	6.662	408	892	969	-17597
114.054	6.715	434	892	971	-17597
114.645	6.755	469	898	972	-17597
115.225	6.812	499	907	972	-17597
115.832	6.854	527	908	972	-17597
116.412	6.902	549	910	973	-17597
116.911	6.941	571	910	977	-17597
117.377	6.996	592	910	980	-17597
117.852	7.035	614	913	986	-17597
118.419	7.097	636	922	987	-17597
118.963	7.145	660	926	988	-17597
119.498	7.206	683	927	989	-17597
120.063	7.249	727	928	990	-17597
120.6	7.306	787	928	990	-17597
121.047	7.35	824	929	990	-17597
121.497	7.41	849	929	990	-17597

121.897	7.453	872	929	990	-17597
121.928	7.519	888	929	990	-17597
121.081	7.599	875	920	984	-17597
120.567	7.67	871	911	972	-17597
120.447	7.736	862	910	972	-17597
120.33	7.806	855	910	971	-17597
120.154	7.873	854	910	970	-17597
120.036	7.933	852	910	969	-17597
120.043	8.001	847	910	969	-17597
120.04	8.065	837	910	969	-17597
119.966	8.127	836	910	967	-17597
119.521	8.204	834	908	955	-17597
118.993	8.28	825	903	953	-17597
118.023	8.365	816	890	942	-17597
117.312	8.446	803	880	934	-17597
116.774	8.514	798	873	931	-17597
115.714	8.599	786	861	917	-17597
114.674	8.682	778	846	906	-17597
113.826	8.765	763	835	897	-17597
113.071	8.846	759	823	889	-17597
112.346	8.926	744	815	879	-17597
111.936	8.999	743	811	878	-17597
111.649	9.072	740	801	876	-17597
111.407	9.144	731	799	872	-17597
111.208	9.211	725	799	863	-17597
111.039	9.28	725	798	861	-17597
110.811	9.345	723	797	861	-17597
110.416	9.388	716	788	860	-17597
109.836	9.409	707	780	850	-17597
109.476	9.419	705	776	843	-17597
109.221	9.423	703	766	842	-17597
109.037	9.426	694	762	842	-17597
108.829	9.429	688	762	840	-17597
108.642	9.434	688	761	839	-17597
108.46	9.437	687	760	838	-17597
108.31	9.442	685	759	825	-17597
108.199	9.444	685	757	824	-17597
108.067	9.433	680	751	814	-17597
107.947	9.444	671	747	856	-17597

APPENDIX B

FLEXURAL TEST DATA (5% BEAM SAMPLE)

Load,kN	Deflection,mm	Concrete Strain	Steel Strain 1	Steel Strain 2	Steel Strain 3
0	0	0	0	0	0
0	0	0	0	0	0
-0.136	-0.03	0	0	-1	-1
-0.154	-0.035	0	0	-1	-2
-0.108	-0.029	0	0	-1	-2
-0.092	-0.017	0	0	-1	-2
-0.111	0.031	0	0	0	-2
-0.123	0.043	0	0	-1	-2
-0.092	0.026	0	0	-1	-2
-0.122	-0.001	0	0	-2	-2
-0.134	-0.03	0	0	-2	-2
-0.122	-0.033	0	0	-2	-2
-0.101	-0.032	0	0	-2	-2
-0.071	-0.031	0	0	-1	-2
-0.011	-0.031	0	0	0	-2
-0.024	-0.031	0	0	0	-2
-0.013	-0.03	0	0	-1	-2
-0.04	-0.03	0	0	-2	-2
-0.039	-0.031	0	0	-2	-2
0.002	-0.031	0	0	-2	-2
0.002	-0.031	0	0	-2	-2
-0.027	-0.031	-1	0	-3	-2
-0.032	-0.031	-1	0	-4	-2
-0.007	-0.031	-1	0	-4	-2
-0.008	-0.034	-1	0	-5	-2
0	-0.035	-2	0	-5	-2
0	-0.033	-3	0	-5	-2
-0.034	-0.033	-3	0	-5	-2
-0.056	-0.032	-5	0	-6	-2
-0.045	-0.031	-7	0	-6	-2
-0.031	-0.031	-6	0	-6	-2
-0.021	-0.032	-5	0	-6	-2
-0.055	-0.033	-5	0	-6	-2
-0.059	-0.032	-7	0	-7	-2
-0.067	-0.033	-7	0	-7	-2
-0.072	-0.032	-7	0	-7	-2
-0.057	-0.032	-8	0	-7	-2

-0.042	-0.031	-8	-1	-7	-2
-0.029	-0.031	-8	-1	-7	-2
-0.025	-0.032	-9	-1	-7	-2
-0.04	-0.032	-10	-1	-7	-2
-0.032	-0.032	-8	-1	-7	-3
-0.029	-0.032	-8	-1	-7	-3
-0.017	-0.032	-10	-1	-7	-3
-0.022	-0.033	-11	-1	-7	-3
-0.005	-0.032	-10	-1	-7	-3
-0.025	-0.032	-10	-1	-7	-3
-0.05	-0.032	-10	-1	-8	-3
-0.05	-0.032	-11	-1	-8	-3
-0.039	-0.031	-11	-1	-7	-3
-0.013	-0.031	-11	-1	-7	-3
-0.036	-0.031	-10	-1	-6	-3
-0.039	-0.031	-12	-1	-6	-3
-0.042	-0.032	-12	-1	-6	-3
-0.068	-0.032	-12	-1	-7	-3
-0.043	-0.032	-12	-1	-6	-3
-0.019	-0.032	-12	-1	-7	-3
-0.029	-0.032	-12	-1	-6	-3
-0.014	-0.03	-12	-1	-7	-3
0.013	-0.03	-13	-1	-6	-3
0.019	-0.028	-13	-1	-6	-3
-0.01	-0.027	-13	-1	-6	-3
-0.007	-0.03	-13	-1	-6	-3
0.014	-0.027	-13	-1	-5	-3
0.029	-0.027	-13	-1	-5	-3
0.034	-0.028	-14	-1	-5	-3
0.036	-0.026	-15	-1	-5	-3
0.02	-0.027	-14	-1	-6	-3
0.025	-0.028	-14	-1	-6	-3
0.014	-0.027	-14	-1	-6	-3
-0.004	-0.027	-15	-1	-6	-3
-0.018	-0.024	-15	-1	-7	-3
-0.034	-0.022	-15	-1	-6	-3
-0.041	-0.023	-15	-1	-5	-3
-0.078	-0.021	-15	-2	-6	-3
-0.089	-0.019	-15	-1	-6	-3
-0.049	-0.02	-15	-1	-5	-3
-0.009	-0.021	-15	-1	-5	-3
-0.026	-0.02	-15	-2	-4	-3
-0.007	-0.019	-15	-2	-4	-3
-0.027	-0.018	-15	-1	-4	-3

-0.043	-0.004	-15	-1	-4	-3
-0.034	0.009	-15	-2	-4	-3
-0.059	0.002	-15	-2	-3	-3
-0.038	0.001	-15	-2	-4	-3
-0.027	-0.005	-15	-2	-4	-3
-0.042	-0.007	-15	-2	-4	-3
-0.049	-0.004	-15	-2	-4	-3
-0.009	0	-15	-2	-3	-3
-0.023	0.001	-15	-2	-3	-3
-0.021	0	-15	-2	-3	-3
-0.008	-0.001	-15	-2	-3	-3
-0.004	-0.002	-15	-1	-3	-3
0.008	-0.001	-15	-2	-2	-3
0.002	-0.002	-15	-2	-2	-3
0.021	0	-15	-2	-2	-3
0.039	0.017	-15	-2	-3	-3
0.034	0.003	-15	-2	-2	-3
0.044	0	-15	-2	-2	-3
0.025	-0.009	-15	-2	-1	-3
0.035	-0.007	-15	-2	-2	-3
0.038	-0.008	-15	-2	-1	-3
0.02	-0.009	-15	-2	-1	-3
0.011	-0.009	-15	-1	0	-3
0.025	-0.009	-15	-2	-1	-3
0.036	-0.008	-15	-2	-1	-3
0.032	-0.007	-15	-2	-1	-3
0.071	-0.006	-15	-2	-1	-3
0.07	-0.005	-15	-2	-1	-3
0.046	-0.004	-15	-2	-1	-3
0.05	-0.005	-15	-2	-2	-3
0.045	-0.004	-15	-2	-2	-3
0.049	-0.004	-15	-2	-2	-3
0.051	-0.004	-15	-2	-2	-3
0.073	-0.005	-15	-2	-1	-3
0.056	-0.006	-15	-2	-1	-2
0.064	-0.006	-15	-2	0	-2
0.072	-0.005	-15	-2	0	-2
0.063	-0.006	-15	-2	0	-3
0.087	-0.004	-15	-2	0	-3
0.094	0	-15	-2	0	-3
0.092	-0.002	-15	-2	0	-2
0.076	-0.001	-15	-2	0	-3
0.1	-0.001	-15	-2	1	-3
0.082	-0.001	-15	-2	1	-3

0.09	-0.001	-15	-2	0	-2
0.103	-0.001	-15	-2	1	-3
0.107	-0.001	-15	-2	1	-3
0.122	-0.001	-15	-2	1	-2
0.112	0	-15	-2	1	-3
0.156	0	-15	-2	1	-2
0.15	0.001	-15	-2	1	-2
0.146	0	-15	-2	1	-3
0.162	0.001	-15	-2	1	-3
0.167	0.001	-15	-2	1	-3
0.187	0.004	-15	-2	1	-3
0.153	0.003	-15	-2	1	-3
0.159	0.003	-15	-2	0	-3
0.174	0.004	-15	-2	1	-3
0.196	0.006	-15	-2	0	-3
0.194	0.007	-15	-2	0	-3
0.214	0.01	-15	-2	0	-3
0.196	0.012	-15	-2	0	-3
0.224	0.011	-15	-2	0	-3
0.24	0.013	-15	-2	0	-3
0.246	0.015	-15	-2	0	-3
0.239	0.018	-15	-2	0	-3
0.257	0.017	-15	-2	0	-3
0.234	0.02	-15	-2	0	-3
0.26	0.023	-15	-2	0	-3
0.292	0.024	-15	-2	1	-3
0.288	0.025	-15	-2	1	-3
0.315	0.028	-15	-3	1	-3
0.311	0.031	-15	-2	1	-3
0.329	0.031	-15	-2	1	-3
0.327	0.033	-15	-3	1	-3
0.32	0.036	-15	-2	1	-3
0.337	0.037	-15	-2	1	-3
0.349	0.038	-15	-2	0	-3
0.368	0.039	-15	-2	1	-3
0.379	0.041	-15	-2	2	-3
0.378	0.042	-15	-2	2	-3
0.394	0.042	-15	-2	2	-3
0.417	0.043	-15	-2	2	-2
0.405	0.043	-15	-2	2	-3
0.432	0.043	-15	-2	3	-3
0.448	0.043	-15	-2	4	-2
0.485	0.044	-15	-2	4	-2
0.502	0.043	-15	-2	3	-2

0.548	0.044	-15	-2	3	-2
0.552	0.044	-15	-2	3	-2
0.566	0.044	-15	-3	3	-2
0.61	0.044	-15	-2	3	-2
0.624	0.044	-15	-2	3	-2
0.634	0.044	-15	-3	4	-2
0.655	0.044	-15	-2	4	-2
0.719	0.044	-15	-2	4	-2
0.746	0.044	-15	-3	4	-3
0.737	0.045	-15	-3	4	-2
0.757	0.046	-15	-3	3	-2
0.764	0.046	-15	-2	4	-2
0.808	0.047	-15	-2	4	-3
0.838	0.047	-15	-3	5	-3
0.836	0.048	-15	-3	4	-2
0.862	0.048	-15	-2	4	-3
0.895	0.049	-15	-3	4	-3
0.932	0.051	-15	-3	4	-3
0.952	0.052	-15	-3	5	-3
0.98	0.054	-15	-3	5	-3
0.996	0.056	-15	-3	5	-3
1.033	0.058	-15	-3	5	-3
1.05	0.059	-15	-3	5	-3
1.065	0.06	-15	-2	5	-3
1.063	0.06	-15	-3	6	-2
1.11	0.06	-15	-3	6	-2
1.123	0.06	-15	-2	6	-2
1.151	0.06	-15	-2	6	-2
1.161	0.06	-15	-2	6	-2
1.228	0.06	-15	-3	6	-2
1.238	0.06	-15	-2	6	-2
1.23	0.06	-15	-2	6	-2
1.278	0.061	-15	-3	6	-2
1.307	0.061	-15	-3	6	-2
1.329	0.062	-15	-3	6	-2
1.352	0.064	-15	-2	6	-2
1.387	0.068	-15	-2	6	-2
1.416	0.074	-15	-3	6	-2
1.448	0.078	-15	-2	6	-2
1.51	0.085	-15	-2	6	-2
1.538	0.091	-15	-2	6	-2
1.577	0.094	-15	-3	6	-2
1.583	0.097	-15	-2	6	-2
1.634	0.1	-15	-2	6	-2

1.655	0.105	-15	-2	6	-2
1.645	0.11	-15	-2	6	-2
1.717	0.117	-15	-2	6	-2
1.774	0.123	-15	-2	6	-2
1.78	0.129	-15	-2	6	-2
1.807	0.132	-15	-2	6	-2
1.841	0.137	-15	-2	6	-2
1.908	0.139	-15	-2	6	-2
1.924	0.14	-15	-2	6	-2
1.954	0.141	-15	-2	6	-2
1.985	0.141	-15	-2	6	-2
2.034	0.141	-15	-2	6	-2
2.094	0.141	-15	-2	6	-2
2.144	0.141	-15	-2	6	-2
2.189	0.141	-15	-2	6	-2
2.204	0.141	-15	-2	6	-2
2.202	0.142	-15	-2	6	-2
2.242	0.142	-15	-1	6	-2
2.291	0.142	-15	-1	6	-2
2.301	0.143	-15	-2	6	-2
2.36	0.144	-15	-1	6	-2
2.416	0.145	-15	-1	6	-2
2.415	0.146	-15	-1	6	-2
2.434	0.147	-15	-1	6	-2
2.458	0.149	-15	-1	6	-2
2.541	0.151	-15	-1	6	-2
2.607	0.153	-15	-1	6	-2
2.65	0.155	-15	-1	6	-2
2.691	0.157	-15	-1	6	-2
2.74	0.158	-15	-1	6	-2
2.758	0.158	-15	-1	6	-2
2.809	0.158	-15	-1	6	-2
2.857	0.158	-15	-1	6	-2
2.876	0.158	-15	-1	6	-2
2.919	0.158	-15	-1	6	-2
2.98	0.158	-15	-1	6	-2
3.001	0.158	-14	-1	6	-2
3.035	0.16	-14	-1	6	-2
3.084	0.162	-13	-1	6	-2
3.123	0.165	-12	-1	6	-2
3.156	0.171	-10	-1	7	-2
3.231	0.18	-10	-1	7	-2
3.278	0.186	-10	0	7	-2
3.314	0.192	-9	0	7	-2

3.37	0.197	-8	-1	7	-2
3.445	0.202	-8	0	7	-2
3.461	0.208	-8	0	7	-2
3.525	0.215	-6	0	7	-2
3.563	0.223	-7	0	7	-2
3.625	0.231	-5	0	7	-2
3.669	0.236	-5	0	7	-2
3.717	0.237	-4	0	7	-2
3.77	0.238	-5	0	8	-2
3.8	0.239	-4	0	8	-2
3.85	0.239	-3	0	8	-2
3.903	0.239	-2	0	8	-2
3.954	0.239	-1	0	8	-2
4.007	0.239	-1	0	8	-2
4.038	0.24	-1	0	8	-2
4.11	0.241	-1	0	8	-2
4.151	0.242	0	0	8	-2
4.176	0.243	0	0	8	-2
4.242	0.245	0	0	8	-2
4.29	0.248	0	0	9	-2
4.352	0.251	0	0	9	-2
4.416	0.254	0	0	9	-2
4.491	0.255	0	0	9	-2
4.561	0.256	0	0	9	-2
4.621	0.256	0	0	9	-2
4.68	0.256	0	0	9	-2
4.714	0.256	0	0	9	-2
4.771	0.257	0	0	9	-2
4.824	0.26	0	0	9	-2
4.879	0.266	0	0	9	-2
4.946	0.276	0	0	9	-2
4.99	0.286	0	0	9	-2
5.039	0.291	0	0	9	-2
5.092	0.297	0	0	9	-2
5.15	0.305	0	0	9	-2
5.235	0.317	0	0	9	-2
5.285	0.326	0	0	9	-1
5.35	0.334	0	0	9	-2
5.425	0.335	0	0	9	-1
5.478	0.336	0	0	9	-1
5.552	0.337	0	0	9	0
5.592	0.337	0	0	9	1
5.639	0.337	0	0	9	2
5.709	0.339	0	0	9	2

5.793	0.34	0	0	9	3
5.862	0.343	0	0	9	3
5.899	0.347	1	0	9	4
6	0.351	1	0	9	4
6.073	0.353	1	0	9	5
6.135	0.353	1	0	9	6
6.196	0.353	1	0	9	7
6.263	0.354	1	0	9	9
6.361	0.355	1	1	9	10
6.469	0.365	2	1	9	12
6.547	0.379	2	3	9	12
6.633	0.388	2	4	10	13
6.699	0.394	2	4	9	13
6.751	0.405	2	5	10	13
6.816	0.42	2	7	10	14
6.907	0.43	3	7	10	14
6.964	0.434	3	7	10	14
7.036	0.434	3	9	10	14
7.12	0.434	3	8	10	14
7.204	0.435	3	10	10	14
7.299	0.437	3	12	11	14
7.39	0.439	3	12	11	14
7.522	0.443	3	13	11	14
7.628	0.449	3	14	12	14
7.709	0.451	3	15	12	14
7.797	0.451	3	15	13	14
7.86	0.451	3	15	13	14
7.943	0.453	3	15	14	14
8.045	0.462	3	15	14	14
8.128	0.478	3	15	15	14
8.213	0.489	3	15	16	14
8.345	0.5	3	15	16	14
8.421	0.521	3	15	16	14
8.535	0.53	3	15	17	14
8.622	0.532	3	15	18	14
8.741	0.532	3	15	19	15
8.815	0.534	3	15	20	15
8.916	0.536	3	15	21	15
9.021	0.542	3	15	22	15
9.104	0.548	3	16	22	15
9.188	0.549	3	16	22	15
9.343	0.549	3	16	23	16
9.452	0.554	3	16	24	16
9.551	0.571	3	16	24	16

9.662	0.587	3	16	24	16
9.767	0.606	3	16	24	16
9.865	0.625	4	17	24	16
9.966	0.629	4	17	25	17
10.046	0.63	6	17	25	17
10.151	0.631	8	17	25	17
10.255	0.634	11	18	25	17
10.361	0.641	12	18	25	17
10.513	0.646	13	18	25	17
10.603	0.646	15	18	25	17
10.718	0.649	17	18	25	17
10.824	0.664	18	18	25	17
10.974	0.682	18	18	25	17
11.082	0.699	18	18	25	17
11.216	0.72	18	18	25	17
11.348	0.727	18	18	25	17
11.474	0.727	18	18	25	17
11.622	0.73	18	18	26	17
11.722	0.734	18	18	26	17
11.827	0.742	19	18	26	17
11.996	0.744	19	18	26	17
12.099	0.745	19	19	27	17
12.259	0.759	19	19	27	17
12.391	0.779	19	19	27	17
12.521	0.797	19	19	27	17
12.677	0.819	20	19	28	19
12.825	0.825	20	20	28	21
12.994	0.826	20	22	28	23
13.148	0.83	21	24	28	24
13.272	0.838	21	26	28	26
13.449	0.842	21	27	28	28
13.602	0.843	21	30	28	30
13.707	0.863	21	31	28	32
13.848	0.884	21	34	28	32
13.974	0.911	22	34	28	32
14.161	0.922	22	34	28	32
14.368	0.924	22	34	28	32
14.52	0.928	22	34	28	32
14.66	0.937	22	34	28	32
14.809	0.939	22	34	28	32
14.974	0.945	22	34	28	33
15.166	0.97	22	34	29	33
15.314	0.993	22	35	29	33
15.468	1.017	22	35	30	33

15.639	1.02	22	35	31	34
15.811	1.023	24	36	33	34
15.984	1.032	26	36	34	34
16.209	1.037	29	36	35	35
16.371	1.04	31	37	37	35
16.532	1.063	34	37	39	35
16.741	1.084	36	37	40	35
16.892	1.111	37	37	42	35
17.128	1.118	37	37	42	35
17.311	1.12	37	37	43	35
17.5	1.128	37	37	43	35
17.681	1.135	37	37	43	35
17.883	1.137	37	37	43	35
18.119	1.163	37	38	43	35
18.341	1.182	37	40	43	35
18.563	1.211	38	43	43	35
18.75	1.215	38	45	43	36
18.944	1.218	39	50	44	37
19.195	1.226	39	52	45	41
19.431	1.232	40	52	45	43
19.655	1.236	40	52	46	46
19.877	1.258	40	52	46	49
20.138	1.278	40	53	46	51
20.388	1.306	40	53	46	51
20.624	1.313	40	54	46	51
20.83	1.316	40	54	46	51
21.091	1.324	40	55	46	52
21.341	1.33	42	55	46	52
21.595	1.332	47	55	46	53
21.868	1.355	52	55	46	53
22.141	1.378	55	55	47	54
22.414	1.406	55	55	47	54
22.646	1.411	56	56	49	54
22.945	1.415	56	56	50	54
23.212	1.425	57	59	52	54
23.497	1.428	58	65	55	54
23.769	1.442	58	70	58	54
24.039	1.468	59	71	60	55
24.337	1.498	59	71	62	59
24.623	1.508	60	72	62	64
24.912	1.512	71	73	62	68
25.163	1.522	74	74	62	69
25.462	1.525	76	74	62	69
25.758	1.541	77	74	63	70

26.101	1.566	79	77	64	71
26.412	1.597	93	88	64	72
26.719	1.606	102	90	65	72
27.04	1.612	121	92	65	72
27.315	1.622	174	93	65	80
27.636	1.628	248	104	68	89
27.969	1.657	350	110	83	100
28.262	1.688	419	114	95	109
28.602	1.704	462	126	100	114
28.908	1.709	497	129	102	126
29.217	1.719	531	130	112	128
29.515	1.725	567	144	118	140
29.86	1.752	606	148	121	146
30.119	1.784	647	160	134	157
30.443	1.801	692	166	140	165
30.8	1.806	742	179	154	180
31.15	1.818	786	185	158	184
31.473	1.828	823	196	170	199
31.802	1.856	853	203	175	202
32.12	1.888	879	206	176	212
32.463	1.899	903	219	186	219
32.807	1.906	929	222	192	222
33.138	1.917	953	229	194	235
33.496	1.932	978	239	196	238
33.838	1.961	1006	241	208	243
34.182	1.993	1029	253	211	255
34.516	1.999	1056	258	213	257
34.873	2.01	1083	263	223	265
35.218	2.017	1108	275	229	275
35.546	2.047	1142	278	232	279
35.896	2.078	1174	290	240	292
36.217	2.095	1205	296	248	295
36.554	2.101	1234	309	250	309
36.892	2.111	1268	314	261	313
37.206	2.123	1301	328	267	324
37.535	2.15	1333	333	270	331
37.857	2.182	1364	347	283	338
38.144	2.192	1393	351	286	348
38.451	2.2	1419	359	290	351
38.782	2.209	1447	369	302	365
39.12	2.224	1474	377	305	368
39.461	2.251	1506	387	312	381
39.767	2.284	1536	394	322	387
40.064	2.291	1574	405	330	400

40.385	2.303	1608	411	341	405
40.685	2.309	1641	424	344	416
41.025	2.337	1672	427	357	424
41.284	2.364	1701	441	361	432
41.594	2.387	1734	447	365	441
41.915	2.392	1767	460	377	447
42.218	2.403	1799	464	380	459
42.501	2.409	1828	477	387	461
42.758	2.437	1857	481	397	472
43.058	2.465	1883	492	408	479
43.371	2.485	1909	498	415	480
43.661	2.489	1936	500	417	494
43.93	2.5	1961	514	430	498
44.209	2.505	1990	518	434	504
44.48	2.532	2020	524	440	515
44.723	2.554	2044	534	451	517
44.916	2.58	2058	537	454	525
45.103	2.583	2073	541	457	532
45.281	2.587	2077	552	468	534
45.399	2.594	2081	553	470	535
45.45	2.599	2081	555	472	535
45.502	2.6	2077	555	472	537
45.682	2.606	2081	558	473	548
45.986	2.633	2093	570	483	551
46.316	2.659	2107	573	488	553
46.631	2.68	2122	574	490	554
46.948	2.685	2135	584	492	566
47.25	2.696	2152	591	504	571
47.549	2.708	2168	595	507	572
47.846	2.737	2183	607	509	579
48.127	2.766	2195	610	514	588
48.397	2.779	2206	615	524	590
48.67	2.786	2221	627	527	591
48.945	2.795	2231	629	528	603
49.258	2.812	2243	636	535	607
49.51	2.838	2257	646	543	609
49.781	2.871	2267	648	545	611
50.054	2.878	2278	656	546	623
50.331	2.888	2280	665	549	626
50.625	2.895	2293	668	561	628
50.867	2.922	2300	681	563	629
51.187	2.953	2315	684	565	641
51.452	2.974	2326	690	569	645
51.756	2.982	2339	701	580	646

52.096	2.99	2353	704	582	654
52.425	3.015	-3424	716	583	662
52.78	3.046	-16594	721	589	665
53.169	3.071	-16594	728	599	669
53.535	3.082	-16594	739	601	680
53.94	3.097	-16594	749	603	683
54.34	3.13	-16594	758	617	690
54.77	3.166	-16594	770	620	700
55.189	3.176	-16594	778	625	702
55.602	3.187	-16594	792	636	711
56.01	3.219	-16594	798	639	719
56.393	3.257	-16594	812	642	722
56.756	3.273	-16594	821	654	734
57.208	3.289	-16594	832	656	738
57.607	3.324	-16594	844	658	743
58.059	3.36	-16594	852	671	755
58.478	3.373	-16594	866	675	757
58.912	3.392	-16594	873	679	769
59.394	3.431	-16594	887	692	775
59.845	3.462	-16594	900	694	778
60.354	3.474	-16594	909	705	792
60.846	3.493	-16594	924	711	795
61.321	3.527	-16594	936	715	808
61.835	3.56	-16594	944	729	813
62.353	3.571	-16594	-3318	731	825
62.877	3.593	-16594	-17341	743	831
63.369	3.632	-16594	-18004	749	840
63.9	3.66	-16594	-18004	758	849
64.418	3.675	-16594	-18004	767	855
64.94	3.709	-16594	-18004	771	867
65.422	3.749	-16594	-18004	784	872
65.908	3.765	-16594	-18004	787	885
66.401	3.784	-16594	-18004	798	888
66.926	3.823	-16594	-18004	805	902
67.44	3.854	-16594	-18004	813	905
67.926	3.868	-16594	-18004	822	917
68.426	3.896	-16594	-18004	825	923
68.966	3.933	-16594	-18004	839	928
69.404	3.953	-16594	-18004	842	940
69.807	3.967	-16594	-18004	853	943
70.247	3.999	-16594	-18004	860	956
70.573	4.03	-16594	-18004	861	960
69.697	4.028	-16594	-18004	858	955
67.106	3.962	-16594	-18004	841	936

66.532	3.95	-16594	-18004	839	924
66.831	3.951	-16594	-18004	839	927
67.2	3.955	-16594	-18004	841	937
67.577	3.963	-16594	-18004	842	939
67.932	3.967	-16594	-18004	842	940
68.278	3.969	-16594	-18004	843	942
68.692	3.991	-16594	-18004	846	943
69.122	4.009	-16594	-18004	857	946
69.652	4.035	-16594	-18004	859	958
70.248	4.05	-16594	-18004	861	961
70.921	4.064	-16594	-18004	873	971
71.532	4.089	-16594	-18004	879	978
72.199	4.127	-16594	-18004	885	986
72.802	4.15	-16594	-18004	896	997
73.441	4.169	-16594	-18004	902	1002
74.058	4.211	-16594	-18004	915	1015
74.662	4.245	-16594	-18004	919	1022
75.196	4.265	-16594	-18004	932	1033
75.781	4.306	-16594	-18004	935	1040
76.378	4.343	-16594	-18004	948	1052
76.985	4.362	-16594	-18004	953	1058
77.582	4.402	-16594	-18004	962	1070
78.169	4.439	-16594	-18004	971	1075
78.792	4.456	-16594	-18004	976	1089
79.388	4.492	-16594	-18004	988	1093
79.974	4.533	-16594	-18004	991	1107
80.581	4.548	-16594	-18004	1004	1112
81.2	4.581	-16594	-18004	1009	1125
81.81	4.625	-16594	-18004	1020	1131
82.488	4.647	-16594	-18004	1027	1144
83.118	4.683	-16594	-18004	1033	1149
83.757	4.729	-16594	-18004	1044	1163
84.416	4.75	-16594	-18004	1047	1171
85.042	4.791	-16594	-18004	1060	1182
85.643	4.831	-16594	-18004	1064	1188
86.28	4.855	-16594	-18004	1070	1200
86.932	4.898	-16594	-18004	1081	1206
87.564	4.932	-16594	-18004	1083	1218
88.261	4.961	-4041	-18004	1088	1225
88.922	5.006	-10466	-18004	1099	1237
89.557	5.034	-16499	-18004	1102	1247
90.241	5.069	-16594	-18004	1114	1256
90.91	5.113	-16594	-18004	1120	1265
91.61	5.138	-16594	-18004	1124	1274

92.28	5.176	-16594	-18004	1136	1276
92.962	5.218	-16594	-18004	1138	1290
93.608	5.244	-16594	-18004	1144	1294
94.251	5.289	-16594	-18004	1155	1306
94.881	5.325	-16594	-18004	1157	1312
95.505	5.36	-16594	-18004	1158	1318
96.129	5.405	-16594	-18004	1170	1330
96.798	5.429	-16594	-18004	1174	1336
97.485	5.468	-16594	-18004	1176	1348
98.14	5.511	-16594	-18004	1188	1357
98.776	5.542	-16594	-18004	1193	1367
99.336	5.597	-16594	-18004	1194	1370
99.814	5.633	-16594	-18004	1194	1383
100.228	5.688	-16594	-18004	1202	1386
100.33	5.736	-16594	-18004	1197	1387
100.376	5.797	-16594	-18004	1194	1387
100.79	5.839	-16594	-18004	1197	1391
101.395	5.892	-16594	-18004	1209	1403
102.036	5.924	-16594	-18004	1212	1408
102.617	5.973	-16594	-18004	1213	1421
103.199	6.012	-16594	-18004	1226	1424
103.72	6.055	-16594	-18004	1229	1435
104.293	6.105	-16594	-18004	1231	1442
104.876	6.147	-16594	-18004	1237	1448
105.453	6.198	-16594	-18004	1247	1460
106.057	6.233	-16594	-18004	1249	1466
106.619	6.282	-16594	-18004	1250	1477
107.201	6.318	-16594	-18004	1262	1482
107.784	6.368	-16594	-18004	1267	1495
108.346	6.405	-16594	-18004	1268	1498
108.884	6.45	-16594	-18004	1274	1511
109.45	6.496	-16594	-18004	1284	1516
110.012	6.537	-16594	-18004	1286	1521
110.527	6.587	-16594	-18004	1287	1532
111.05	6.626	-16594	-18004	1290	1535
111.592	6.675	-16594	-18004	1302	1545
112.096	6.715	-16594	-18004	1303	1552
112.562	6.766	-16594	-18004	1305	1555
113.04	6.806	-16594	-18004	1305	1568
113.543	6.858	-16594	-18004	1308	1571
114.067	6.9	-16594	-18004	1319	1577
114.519	6.951	-16594	-18004	1321	1588
115.018	6.993	-16594	-18004	1322	1590
115.479	7.046	-16594	-18004	1324	1599

115.917	7.091	-16594	-18004	1324	1608
116.367	7.142	-16594	-18004	1324	1610
116.807	7.188	-16594	-18004	1331	1623
117.203	7.241	-16594	-18004	1339	1626
117.546	7.289	-16594	-18004	1339	1627
117.853	7.344	-16594	-18004	1339	1630
118.215	7.396	-16594	-18004	1339	1642
118.53	7.459	-16594	-18004	1340	1644
118.801	7.52	-16594	-18004	1340	1646
119.067	7.576	-16594	-18004	1341	1646
119.314	7.633	-16594	-18004	1341	1653
119.51	7.687	-16594	-18004	1341	1661
119.651	7.749	-16594	-18004	1340	1661
119.734	7.804	-16594	-18004	1339	1662
119.814	7.867	-16594	-18004	1339	1662
119.831	7.929	-16594	-18004	1338	1662
119.703	7.991	-16594	-18004	1327	1662
119.319	8.062	-16594	-18004	1324	1660
118.688	8.138	-16594	-18004	1322	1647
117.39	8.231	-16594	-18004	1306	1636
114.609	8.361	-16594	-18004	1278	1600
112.551	8.477	-15099	-18004	1256	1574
111.428	8.57	-10665	-18004	1246	1558
110.509	8.656	-16594	-18004	1231	1547
109.916	8.736	-16594	-18004	1228	1535
109.337	8.816	-16594	-18004	1215	1527
108.676	8.895	-16594	-18004	1211	1516
108.063	8.975	-16594	-18004	1200	1510
107.528	9.051	-16594	-18004	1194	1498
107.097	9.125	-16594	-18004	1192	1496
106.776	9.199	-16594	-18004	1187	1492
106.551	9.268	-16594	-18004	1176	1481
106.234	9.343	-16594	-18004	1176	1479
106.033	9.409	-16594	-18004	1175	1477
105.918	9.466	-16594	-18004	1175	1476
105.386	9.504	-16594	-18004	1171	1464
104.891	9.519	-16594	-18004	1158	1460
104.51	9.527	-16594	-18004	1157	1458
104.19	9.532	-16594	-18004	1156	1451
103.968	9.535	-16594	-18004	1154	1443
103.782	9.537	-16594	-18004	1154	1442
103.597	9.54	-16594	-18004	1149	1442
103.388	9.544	-16594	-18004	1140	1442
103.232	9.549	-16594	-18004	1139	1440

103.089	9.553	-16594	-18004	1139	1439
102.977	9.554	-16594	-18004	1139	1439

APPENDIX C

FLEXURAL TEST DATA (15% SAMPLE)

Load,kN	Deflection,mm	Concrete Strain	Steel Strain 1	Steel Strain 2	Steel Strain 3
0	0	0	0	0	0
0	0	0	0	0	0
0.043	0	0	0	0	0
0.108	0.001	0	0	0	0
0.12	0.002	0	0	0	0
0.123	0.003	0	0	0	0
0.125	0.003	0	0	0	0
0.141	0.003	0	0	0	0
0.141	0.004	0	0	0	0
0.164	0.004	0	0	0	0
0.162	0.005	0	0	0	0
0.137	0.005	0	0	0	0
0.146	0.005	0	0	0	1
0.138	0.01	0	0	0	3
0.144	0.01	0	0	0	2
0.156	0.025	0	0	0	1
0.168	0.081	0	0	0	2
0.167	0.095	0	0	0	3
0.189	0.062	0	0	0	3
0.186	0.058	0	0	0	3
0.206	0.042	0	0	0	5
0.207	0.074	0	0	0	5
0.213	0.044	0	0	0	4
0.236	0.019	0	0	0	4
0.256	0.014	0	0	0	5
0.283	0.014	0	0	0	6
0.317	0.014	0	0	0	5
0.303	0.014	0	0	1	4
0.325	0.014	0	0	0	5
0.324	0.014	0	0	0	7
0.328	0.014	0	0	0	6
0.327	0.014	0	0	0	4
0.316	0.014	0	0	1	5
0.332	0.015	0	0	0	6
0.355	0.014	0	0	0	5
0.368	0.014	0	0	0	4
0.383	0.014	0	0	0	4

0.405	0.014	0	0	1	6
0.408	0.014	0	0	0	7
0.418	0.014	0	0	1	6
0.408	0.014	0	0	1	4
0.432	0.014	0	0	2	5
0.457	0.015	0	0	1	7
0.462	0.015	0	0	1	7
0.464	0.015	0	0	2	7
0.48	0.016	0	0	2	7
0.516	0.017	0	0	3	8
0.522	0.017	1	0	4	8
0.523	0.024	1	0	7	8
0.523	0.022	1	0	6	11
0.523	0.025	1	0	9	10
0.538	0.027	1	0	9	8
0.554	0.03	1	0	9	9
0.586	0.035	1	0	11	11
0.634	0.037	1	0	11	11
0.672	0.041	1	0	9	9
0.684	0.044	1	0	10	9
0.693	0.046	1	0	11	11
0.742	0.048	1	0	12	11
0.758	0.052	0	0	11	10
0.822	0.054	1	0	11	9
0.835	0.059	1	0	12	11
0.857	0.061	0	0	12	11
0.899	0.072	0	0	13	11
0.936	0.073	0	0	14	11
0.993	0.084	0	0	14	12
0.979	0.093	0	0	13	11
0.938	0.095	0	0	12	10
1.039	0.095	0	0	13	9
1.093	0.096	0	0	13	10
1.14	0.097	0	0	14	12
1.201	0.097	0	0	14	12
1.254	0.099	0	0	15	14
1.32	0.1	0	0	15	15
1.382	0.102	0	0	15	14
1.413	0.103	0	0	15	14
1.483	0.106	0	0	15	15
1.516	0.109	0	0	15	15
1.603	0.111	0	0	15	15
1.641	0.111	0	0	15	15
1.672	0.112	0	1	15	15

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1.759	0.112	1	2	15	15
1.855	0.112	1	2	15	15
1.892	0.113	1	3	15	16
1.937	0.115	1	3	15	16
2.011	0.121	1	4	15	15
2.04	0.131	1	5	15	16
2.126	0.135	1	5	16	16
2.125	0.143	1	5	16	16
2.132	0.158	1	5	16	16
2.197	0.167	1	7	16	16
2.245	0.178	1	8	16	16
2.322	0.187	1	9	16	16
2.402	0.192	1	10	17	16
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2.558	0.192	2	12	17	17
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3.033	0.199	2	15	18	18
3.09	0.203	2	15	18	18
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3.239	0.209	2	15	19	18
3.296	0.209	2	15	19	18
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3.516	0.21	2	15	19	18
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3.801	0.21	2	15	19	18
3.824	0.21	2	16	19	18
3.904	0.21	2	16	19	18
4.004	0.213	2	16	20	18
4.079	0.218	2	16	22	18
4.156	0.226	2	16	24	19
4.246	0.23	2	16	26	19
4.346	0.243	2	17	28	19
4.412	0.253	2	17	30	19
4.499	0.261	2	17	32	19
4.55	0.273	2	17	33	21

4.625	0.28	2	17	34	22
4.722	0.288	2	18	34	24
4.799	0.289	2	18	34	26
4.869	0.29	2	18	34	27
4.977	0.29	2	18	34	28
5.095	0.291	3	18	34	27
5.189	0.292	2	18	34	29
5.269	0.293	3	18	34	30
5.344	0.295	3	18	35	31
5.423	0.299	3	18	35	32
5.558	0.303	3	18	35	33
5.645	0.306	3	18	35	33
5.756	0.307	5	18	36	34
5.863	0.307	5	18	36	34
5.941	0.308	5	19	36	34
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6.274	0.34	7	19	37	34
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6.395	0.382	10	19	37	34
6.53	0.387	10	19	37	35
6.658	0.388	11	20	37	35
6.748	0.388	11	22	37	35
6.862	0.39	12	25	37	35
6.957	0.393	13	28	37	36
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7.174	0.403	15	33	37	36
7.262	0.405	16	34	37	36
7.338	0.405	17	34	37	36
7.447	0.41	17	34	39	37
7.583	0.426	18	34	41	37
7.687	0.442	18	34	44	37
7.8	0.457	18	34	46	37
7.93	0.476	18	34	49	37
8.053	0.485	18	34	52	37
8.101	0.486	18	34	52	37
8.225	0.487	18	35	52	37
8.379	0.489	18	35	52	37
8.495	0.495	18	35	52	37
8.637	0.501	18	36	52	37
8.743	0.502	18	36	53	37
8.875	0.503	18	36	53	37
8.98	0.509	18	37	54	39
9.099	0.528	18	37	55	41

9.219	0.542	19	37	55	44
9.321	0.561	19	37	55	45
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9.581	0.583	19	37	55	48
9.698	0.583	20	37	56	50
9.833	0.584	20	37	56	52
9.952	0.587	20	37	56	52
10.11	0.592	20	37	56	53
10.277	0.598	20	39	56	53
10.375	0.6	20	42	57	53
10.522	0.6	20	45	59	54
10.629	0.607	20	47	62	54
10.771	0.625	21	51	67	54
10.933	0.639	21	52	69	55
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11.268	0.674	21	52	71	55
11.418	0.68	21	52	71	55
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11.736	0.683	21	53	72	56
11.886	0.686	21	54	73	56
12.032	0.693	21	55	74	59
12.173	0.697	21	55	74	62
12.331	0.698	21	55	74	66
12.482	0.701	21	56	74	69
12.667	0.72	21	56	74	71
12.828	0.735	21	58	75	71
12.983	0.754	21	67	82	72
13.187	0.774	19	72	91	74
13.383	0.778	14	74	94	82
13.543	0.779	8	84	107	90
13.725	0.782	3	90	109	91
13.896	0.787	2	91	111	92
14.111	0.794	2	92	111	93
14.271	0.795	2	93	116	99
14.5	0.798	2	99	126	107
14.678	0.818	2	107	127	108
14.87	0.839	2	108	129	110
15.062	0.866	1	110	129	111
15.247	0.876	1	111	130	111
15.408	0.878	0	111	132	111
15.61	0.882	0	113	142	118
15.831	0.891	0	121	145	124
16.028	0.893	-1	126	147	127
16.278	0.895	-1	127	148	129

16.475	0.916	-1	129	148	129
16.653	0.94	-1	129	149	130
16.845	0.967	-1	130	159	135
17.039	0.974	-1	133	163	143
17.244	0.976	-1	143	165	145
17.48	0.985	-1	146	166	147
17.716	0.991	-1	147	167	148
17.96	0.995	-4	148	171	148
18.171	1.017	-7	148	182	154
18.4	1.036	-9	157	183	162
18.633	1.064	-11	163	185	164
18.868	1.071	-12	164	185	166
19.116	1.074	-14	166	190	167
19.381	1.084	-15	167	200	169
19.618	1.088	-16	171	202	178
19.856	1.1	-16	181	203	182
20.104	1.125	-16	183	204	184
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20.625	1.168	-16	185	219	185
20.902	1.171	-16	191	221	191
21.178	1.179	-16	200	222	200
21.475	1.186	-16	202	228	203
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22.03	1.222	-16	204	240	211
22.297	1.251	-16	215	241	219
22.6	1.267	-16	220	250	221
22.865	1.27	-17	222	257	222
23.184	1.281	-17	225	259	231
23.474	1.284	-17	237	261	238
23.747	1.302	-18	239	274	240
24.03	1.332	-18	241	276	248
24.307	1.361	-18	253	278	257
24.619	1.365	-19	257	281	259
24.89	1.373	-19	259	292	261
25.194	1.382	-19	268	295	273
25.462	1.395	-19	275	296	277
25.707	1.417	-19	277	302	280
26.053	1.447	-19	278	312	291
26.356	1.462	-19	286	314	295
26.655	1.466	-19	294	315	296
26.959	1.477	-19	296	324	306
27.273	1.484	-19	297	331	313
27.6	1.513	-19	309	333	315
27.931	1.544	-21	313	336	323

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105.775	6.639	-54	1166	1722	-18615
106.263	6.672	-54	1166	1733	-18615
106.796	6.718	-54	1171	1738	-18615
107.266	6.753	-54	1180	1740	-18615
107.773	6.795	-54	1183	1752	-17446
108.244	6.839	-54	1184	1757	-18615
108.788	6.877	-54	1185	1759	-18615
109.347	6.926	-54	1193	1768	-18615
109.877	6.949	-54	1200	1776	-18615
110.375	6.992	-54	1201	1777	-18615
110.861	7.05	-54	1203	1788	-18615
111.377	7.095	-54	1203	1794	-18615
111.87	7.139	-55	1207	1796	-18615

112.348	7.189	-55	1217	1798	-18615
112.805	7.23	-55	1219	1810	-18615
113.235	7.253	-55	1220	1812	-18615
113.703	7.279	-54	1221	1744	-18615
114.177	7.325	-54	1222	1238	-18615
114.66	7.365	-55	1223	1020	-18615
115.123	7.413	-55	1229	1007	-18615
115.582	7.444	-55	1236	998	-18615
116.037	7.497	-55	1237	996	-18615
116.491	7.542	-55	1239	985	-18615
116.953	7.594	-55	1240	981	-18615
117.416	7.629	-55	1240	981	-18615
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118.316	7.717	-55	1241	926	-18615
118.735	7.759	-55	1244	925	-18615
119.198	7.81	-55	1249	925	-18615
119.666	7.848	-55	1254	924	-18615
120.088	7.889	-56	1256	923	-18615
120.543	7.928	-56	1257	923	-18615
120.981	7.964	-56	1257	923	-18615
121.402	8.008	-56	1258	923	-18615
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123.117	8.186	-56	1259	919	-18615
123.532	8.225	-56	1259	912	-18615
123.91	8.269	-56	1259	908	-18615
124.282	8.316	-56	1261	907	-18615
124.708	8.363	-56	1266	907	-18615
125.153	8.403	-56	1271	907	-18615
125.508	8.437	-56	1273	907	-18615
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126.344	8.523	-56	1275	907	-18615
126.745	8.559	-56	1275	907	-18615
127.138	8.613	-56	1276	906	-18615
127.505	8.662	-56	1276	906	-18615
127.918	8.7	-56	1277	907	-18615
128.293	8.75	-56	1277	907	-18615
128.67	8.8	-56	1277	923	-18615
129.024	8.847	-56	1277	910	-18615
129.383	8.894	-56	1277	907	-18615
129.71	8.939	-56	1341	907	-18615
130.102	8.99	-56	1369	907	-18615
130.376	9.037	-56	1365	907	-18615

130.729	9.086	-57	1354	907	-18615
131.062	9.132	-57	1352	907	-18615
131.402	9.183	-56	1353	906	-18615
131.711	9.23	-57	1360	888	-18615
132.011	9.285	-56	1365	885	-18615
132.306	9.341	-56	1375	885	-18615
132.652	9.387	-56	1402	888	-18615
132.981	9.443	-56	1394	889	-18615
133.242	9.517	-56	1392	888	-18615
133.563	9.584	-56	1388	888	-18615
133.854	9.633	-56	1388	887	-18615
134.126	9.683	-56	1388	888	-18615
134.389	9.732	-56	1392	888	-18615
134.633	9.784	-56	1408	889	-18615
134.857	9.834	-56	1414	889	-18615
135.043	9.885	-56	1420	889	-18615
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135.464	9.988	-57	1418	889	-18615
135.598	10.034	-56	1389	890	-18615
135.793	10.086	-56	1384	897	-18615
135.951	10.142	-56	1383	902	-18615
136.067	10.191	-57	1378	902	-18615
136.176	10.245	-57	1385	916	-18615
136.284	10.298	-56	1388	925	-18615
136.4	10.347	-56	1388	924	-18615
136.453	10.398	-57	1389	924	-18615
136.432	10.457	-57	1389	924	-18615
136.333	10.503	-57	1389	923	-18615
136.173	10.553	-57	1388	923	-18615
135.98	10.608	-57	1388	922	-18615
135.686	10.663	-58	1387	917	-18615
135.206	10.72	-59	1383	907	-18615
134.78	10.773	-60	1371	907	-18615
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133.747	10.897	-62	1360	901	-18615
132.959	10.952	-65	1350	888	-18615
131.472	11.014	-67	1329	875	-18615
127.428	11.102	-67	1275	825	-18615
122.19	11.208	-61	1196	758	-18615
119.626	11.296	-57	1158	724	-18615
118.263	11.368	-56	1139	708	-18615
117.363	11.461	-56	1127	700	-18615
116.794	11.594	-56	1118	686	-18615
116.142	11.662	-56	1109	683	-18615

115.599	11.73	-56	1099	673	-18615
115.031	11.792	-56	1092	666	-18615
114.234	11.849	-56	1082	656	-18615
113.039	11.881	-56	1064	642	-18615
111.977	11.897	-56	1051	629	-18615
111.251	11.927	-56	1037	621	-18615
110.678	11.915	-56	1033	611	-18615
110.215	11.915	-56	1021	609	-18615
109.823	11.915	-55	1018	608	-18615
109.467	11.92	-55	1016	601	-18615
109.166	11.951	-55	1015	592	-18615
108.865	12.012	-55	1007	592	-18615
108.632	12.015	-55	1000	592	-18615
108.396	12.011	-55	1000	591	-18615
108.182	12.011	-55	999	590	-18615
107.997	12.012	-55	998	589	-18615
107.838	12.013	-55	997	588	-18615
107.671	12.013	-55	997	581	-18615
107.545	12.013	-55	994	576	-18615
107.374	12.013	-55	989	574	-18615
107.243	12.013	-55	984	574	-18615
107.116	12.015	-55	981	574	-18615
107.009	12.017	-55	981	574	-18615
106.895	12.016	-55	981	574	-18615
106.775	12.016	-54	981	574	-18615

APPENDIX D

PICTURE OF THIS STUDY

Formwork Installation

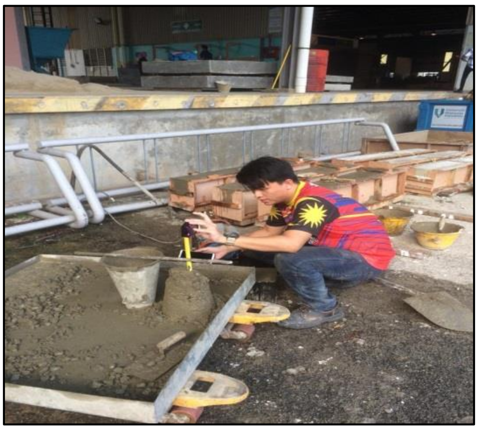
Reinforcement Bar Cutting

Reinforcement Bar Installation

Material Preparation

CONTINUED

Casting Beam Process



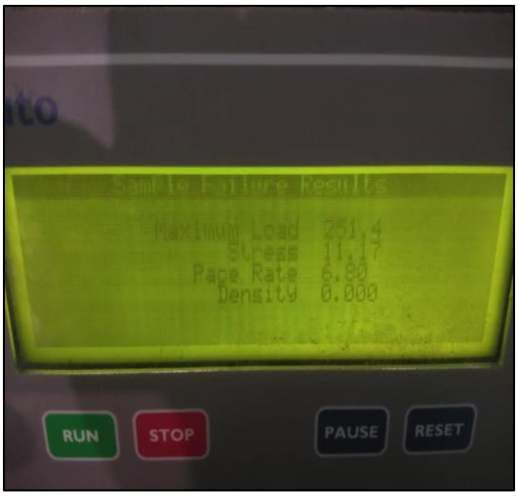
Slump Test

Removing Formwork

Curing Beam With Wet Gunny

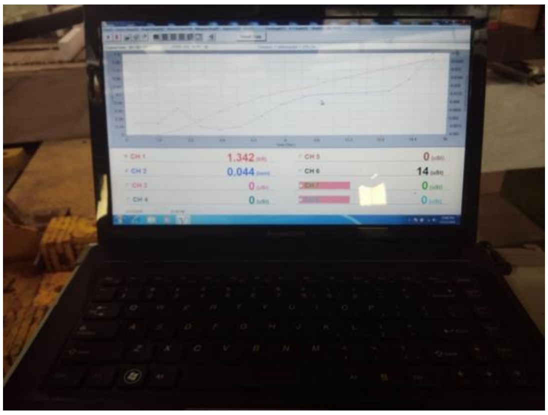
CONTINUED

Cube Compression Test



Cube Compression Reading

Flexural Test



Reading From Data Logger