COMPARATIVE STUDY OF STRENGTH OF TRUSS REINFORCED CONCRETE BEAM AND CONVENTIONAL REINFORCED CONCRETE BEAM

BY

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CERTIFICATION

I certify that this work, **"Comparative Study of Strength of Truss Reinforced Concrete Beam and Conventional Reinforced Concrete Beam"** was carried out by **Godfrey Chimezie Nwokorobia (Reg. No 20124766378)** in partial fulfillment for the award of Master of Engineering (M. Eng) in Structuresin the Department of Civil Engineering, Federal University of Technology, Owerri.

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DEDICATION

This work is dedicated to Almighty God

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DEFINITION OF NOTATIONS

NOTATIONS	MEANING
A_r	Area of circular face of ram
A_{sv}	Area of the stirrup
a	distance between beam end and stirrup/diagonal bar
f	length of diagonal bar in truss reinforcement
b	breadth of truss/conventional reinforcement
c	spacing of stirrups and triangles in beam
d	effective depth of beam
e	Truss or stirrup angle in beam
d_r	diameter of ram
P	point load
f_{yv}	characteristic strength of links
f_b	Flexural Strength of beam
f_{ck}	Compressive strength of concrete
M_{max}	Total maximum moment
q	Uniformly distributed load or Self weight of beam
Q	Shear Force
L	Clear distance between beam supports
h	Height of beam section
V	design shear force due to ultimate loads
Z	Modulus of section

ABSTRACT

This work presents comparative study of strength of truss reinforced concrete beam and conventional reinforced concrete beam. Two sets of 0.15 x 0.15 x 1m beams were cast. One set was cast using truss as a system of reinforcement at spacing of 100mm, 150mm and 200mm. The other set was cast using longitudinal bars and links at spacing of 100mm, 150mm, and 200mm as the conventional reinforcement. In all 27 truss and 27 conventional reinforcement beams were cast. Three mix ratios were used for this work, namely, 0.5:1:2:4, 0.55:1:2.5:5, and 0.6:1:3:6. Each mix ratio was used to cast nine truss reinforced concrete beams, nine conventional reinforced concrete beams, and three concrete cubes. The quantities of these mix ratios were calculated and batched by weight, mixed and placed in 0.15 x 0.15 x 1m beam mould and 0.15 x 0.15 x 0.15 cube mould. Fifty four beams and nine cubes were cast so as to determine the flexural strength of the beams and the compressive strength of the concrete cubes respectively. The cast beams and cubes were left for 24hrs before they were demolded and were totally submerged in an open curing tank for twenty eight days. The cubes were crushed using concrete compressive testing machine and the beams were also loaded to failure using Magnus frame at twenty eighth day. The loads that crushed each of the cubes were recorded and compressive strengths were calculated from their corresponding loads. Also the failure load of each of the beams was recorded and the flexural strength of the beams calculated using their corresponding loads. The 28-day compressive strength of the concrete was found to be 33.40N/mm^2 and flexural strength of the truss beam is 1292.27kN/m^2 against 1071.82kN/m^2 for conventional reinforcement. A computer program was written on truss analysis within the range of 1000mm span in which all the forces in the truss members were generated with the aid of a polynomial established from graph of spacing against points loads. From this study, the following conclusions were drawn: truss reinforced concrete beam has greater strength than the conventional reinforced concrete beam; the higher the compressive strength the higher the flexural strength of the beam; a computer program can be used as alternative to manual truss analysis. Further research should be carried out on this using sandcrete and flat bars reinforcement.

Keywords: Truss reinforcement, Conventional reinforcement, Granite, Concrete, Beam, Compressive strength, Flexural strength.

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

The styles of building construction are constantly changing with introduction of new materials and techniques of construction. Consequently, the work involved in the design and construction stages of buildings are largely that of selecting materials, components and structures that will meet the expected building standards and aesthetics on economy basis (Ayininuola, 2004).

Faulty design, poor execution of work and use of substandard materials have been identified as major causes of structural failures (Hall, 1984).

On the other hand, the deterioration of Reinforced Concrete could occur as a result of corrosion of the reinforcement caused by carbonation and chloride ingress, cracking caused by overloading, subsidence or basic design faults, and construction defects. Clients tend to save cost by poorly reinforcing structural members, using low quality materials and employing the services of quacks or incompetent professionals in building design and construction.

A wide range of techniques for shear strengthening of reinforced concrete components have been proposed and used in the past. Most of the studies have been carried out by adding external reinforcements to columns or beams, so as to increase their shear strength. These external reinforcements are added either before or after cracking or failure of the components. Some researchers have added reinforcement belts while some have added plates to strengthen Reinforced Concrete components. Fiber Reinforced Plastic (FRP) and other composite materials have also been used to strengthen RC components. In recent years, numerous research studies have been carried out to improve the strength and performance of RC beams and columns by attaching FRP and other composite materials to them (Mohammed, 2006). However, Fiber Reinforced Plastic is not readily available in developing nations in Africa, hence, this method of improving the efficiency of the beam will be expensive.

Vakas and Mundhada (2013) in their work, Comparative Study of Reinforced Cement Concrete (RCC) and Prestressed Concrete Flat Slab shows that RCC is cheaper than prestressed concrete flat slab for smaller spans. Without any semblance of doubt, RCC construction has been the most revolutionary construction technique of modern times. Combining the high compressive strength of concrete with high tensile strength and elasticity of steel resulted in a composite material that is strong, durable and economical.

A study of the feasibility of using bamboo as reinforcing material in concrete elements was conducted at the U.S. Army Engineer Waterways Experiment Station in 1964. Ultimate strength design procedures, modified to take into account the characteristics of the bamboo reinforcement were used to estimate the ultimate load carrying capacity of the precast concrete elements with bamboo reinforcing (Francis, 1966). This method of construction produced reinforced concrete beam with low flexural strength. The cost of this construction is cheap but quality cannot be sacrificed for economy.

1.2 Statement of Problem

There is need to develop an efficient system of reinforcement that will achieve the required strength. Conventional reinforced concrete beam has limitations in terms of flexural load carrying capacity. Thus other means of improving strength of concrete became imperative. However, most of the alternatives have different shortcomings – high cost, availability, low strength etc. At this point, the present study is curious to know whether the sought solution can be found in truss reinforcement of concrete.

1.3 Objectives

The main objective of this study is the comparative study of strength of truss reinforced concrete beam and conventional reinforced concrete beam.

The specific objectives include:

i. To determine the flexural strengths of truss reinforced concrete beam and conventional reinforced concrete beam.
ii. To determine the effect of compressive strength on the flexural strength of beams.
iii. To develop a computer program for truss analysis.

1.4 Justification of Study

i. The most important aspect of this research work is that the flexural strength of the reinforced concrete beam will be improved with truss system; hence the reduction in structural failure due to poor reinforcement, cheap substandard materials and poor construction methods.
ii. Another important benefit is the economic value to contractors, since the quantity of reinforcement is reduced through the truss system of reinforcement.
iii. The study will provide a resource material for practicing engineers and researchers in the area of structural design.

1.5 Scope of Study

This research studies the comparative study of strength of truss reinforced concrete beam and the conventional reinforced concrete beam. This work is limited to experimental studies with little theoretical analysis of the beam systems. This research work will only consider a rectangular beam of size 150mm x 150mm x 1000mm. Also cubes of size 150mm x 150mm x 150mm will be cast to determine the compressive strength of the concrete. The study entails an intensive review of literature where previous researches on the study will be critically reviewed. After the literature review, the methods and materials which will be used will be clearly defined. They involve fabrication of conventional and truss beam reinforcement, batching of materials, placing of concrete, curing for 28 days and conducting of compressive test and flexural test. The resulting concrete cubes and beams reinforced with truss and conventional reinforcement were tested and the results compared. A computer program will be written on truss analysis within the range of 1000mm span in which all the forces in the truss members were generated with the aid of a polynomial established from graph of spacing against points loads. This polynomial was modified and regarded as model used to predict approximation of the experimented method. Finally conclusions and recommendations were made based on the objectives of the study.

CHAPTER TWO

LITERATURE REVIEW

2.1Concrete –Concrete is a mixture of cement, fine and coarse aggregates, water, and sometimes some supplementary materials like fly ash, slag, and various admixtures. In its simplest form, concrete is a mixture of paste and aggregates. The paste, composed of Portland cement and water, coats the surface of the fine and coarse aggregates. Through a chemical reaction called hydration, the paste hardens and gains strength to form the rock-like mass known as concrete (ACI 701, 1987).

Concrete's durability, strength and relatively low cost make it the backbone of buildings and infrastructure worldwide—houses, schools and hospitals as well as airports, bridges, highways and rail systems. The most produced material on earth will only be more in demand. For example, developing nations become increasingly urban, extreme weather events necessitate more durable building materials and the price of other infrastructure materials continues to rise.

According to Agbede and Manasseh (2009), concrete is a combination of cement, fine and coarse aggregates and water, which are mixed in a particular proportion to get a particular strength. The cement and water react together chemically to form a paste, which binds the aggregate particles together. Concrete is the most commonly used material in building structures. In itself concrete is a very brittle anisotropic material with high compressive strength and low tensile strength.

2.1.1 Components of Concrete

2.1.1.1 Aggregate –Aggregates includes fine (those materials passing through a BS No. 4 sieve aperture that is less than 5mm) and coarse (those materials passing through sieve aperture greater than 5mm). Fine aggregates provides cohesion of concrete. It is important that fine aggregate should not contain clay or any chemical pollution. Also, fine aggregate has the role of space filling between coarse aggregates. Examples of coarse aggregate include river gravel, sand stone, and granite. Coarse aggregate comprise the strongest part of the concrete. It also has reverse effect on the concrete fineness. The more coarse aggregate, the higher is the density of the concrete produced. Aggregates in concrete make up to 70 to 75 percent of the total volume of concrete. It has two principal functions:

- To provide a mass of particles which are suitable for resisting the action of applied loads, abrasion, the peculation of moisture and the action of weather (Abrams, 1979).
- To provide a relatively cheap filler for cementing material.

Coarse aggregate type, quality, size, shape, gradation and nature could play a major role in the final properties of fresh and hardened concrete (Abdullahi, 2012; Aginam et al., 2013; Beshr et al., 2003; Chen et al., 2005; Echeta et al., 2013; Neptune and putmen, 2010; Rifath et al., 2006).

Abdullahi (2012) and Aginam et al. (2013) examined the effects of coarse aggregate types on the compressive strength of concrete. They both used three different types of coarse aggregates for their comparative experimental researches. Abdullahi worked with crushing quartzite, granite and river gravel and concluded that concrete containing crushed quartzite has the highest compressive strength at 28-day.

Beshr et al. (2003) probed the effect of coarse aggregate quality on the mechanical properties of high strength concrete. The study observed that concrete can be visualised as a multi-phase composite material made up of three phases; namely, the mortar, mortar/aggregate interface, and the coarse aggregate phase. The onset of failure is manifested by crack growth in the concrete. The study concluded that the strength of concrete at the interfacial zone essentially depends on the integrity of the strength of cement paste and the nature of the coarse aggregate.

While Rifath et al. (2006) worked on comparison of strength performance of concrete with uncrushed and crushed coarse aggregate, Neptune and Putmen (2010) reviewed the effect of aggregate size and gradation on previous concrete mixtures. Chen et al. (2005) researched on the influence of coarse aggregate shape on the strength of Asphalt concrete mixtures. Echeta et al. (2013) investigated the effect of partial replacement of granite with washed gravel on the characteristic strength and workability of concrete. They observed that the workability of concrete decreased with increase in gravel content. It was also observed that for all curing ages, as the percentage replacement level increased, the compressive strength of the concrete increased to a maximum at 20% replacement level.

2.1.1.1.1 Physical Properties of Aggregate

Aggregates are classified in terms of their shape. Some are rounded aggregates. Others are angular, elongated, irregular etc. in shape. The size of aggregates makes it a coarse or a fine aggregate. BS 3797(1964) and BS 877(1964) have it that aggregates 2mm and below are considered fine aggregates while the ones above 3mm are coarse aggregates. Some aggregates are smooth in texture while others are rough.

2.1.1.1.2 Mechanical Properties of Aggregate

Kashi et al. (2001) reported that aggregates are subdivided into three classes. They are lightweight aggregates, normal weight aggregates and heavyweight aggregates. Bulk density and specific gravity are normally used to classify an aggregate. The bulk density and specific gravity of normal weight aggregate should not be less than 1120km/m^3 and 2.2 respectively. The specific gravity ranged from 2.2 - 4.0. Bulk density ranges from 100kg/m^3 - 1600kg/m^3.For lightweight aggregate, the specific gravity is less than 2.2 and the bulk density is less than 960kg/m^3. The specific gravity and bulk density of heavyweight aggregate are respectively greater than 4 and 1600kg/m^3.

Another mechanical property of aggregate is water of absorption. According to ASTM C125 (2003) the water absorbed by aggregates is not considered as part of the free water in the free water/cement ratio. Hence, it is good practice to note the aggregate condition before concrete mixing. This will help to know the amount of water required to saturate the aggregate and that for concrete mixing. Spratt (1974) noted that lightweight aggregates have water absorption in the range of 5 to 25% by weight of dry aggregate. That for dense aggregates is about 2% by weight of dry aggregates. Kashi et al. (2002) studied the water absorption of some aggregates. The result showed that normal weight aggregates have water absorption of less than 2% and synthetic lightweight aggregates (S. L. A. - made with high composition of fly ash) have water absorption of the range 7%-21%. The aggregates made by polystyrene, and polypropylene with 0% of fly ash have water absorption of less than 1%. Eurolightcon (2000) said that water absorption is the most important mechanical property of lightweight aggregates. According to them, water absorption creates a “water tank” inside the lightweight aggregate. This makes it possible for continuation of hydration of concrete for a longer period. Park (1999) in his work found that newly recycled aggregates had absorption of 3.8%. He observed that water of absorption of “greywacke” aggregates is approximately 0.5% - 0.7%. He also found that the “basalt” aggregates have water of absorption of approximately 3.5 –4.0%. He went further to say that it is necessary to keep aggregates stockpiles wet above saturated surface dry (S. S. D.) to prevent the problems that would arise if on the contrary. This is because during mixing, the aggregates will first of all absorb enough quantity of water from the free water content used in the mixing to reach S. S. D thereby reducing the free water content. Dean (2003) in his own contribution said that before lightweight aggregates should be used in a concrete mixture, it will be wise to wet them for a period of not less than 24 hours to the time of mixing. This according to him will enable the aggregate particle not to segregate during handling. To this effect he concluded by saying that it is a wrong practice to batch lightweight aggregates directly in a concrete mixture. If this is done the aggregate particles will continue absorbing the free water from the concrete mixture to a point it will cause the mixture to segregate or stiffen before placement. From the outcome of the above scholars, two things are learnt. That is, in a concrete mix the designer should consider free water content and the total water content. The free water content is the quantity of water required in a concrete mixture to satisfy the hydration needs of the cement and workability of the concrete. Total water content on the other hand is the summation of the free water content and water of absorption. If the aggregates are at S. S. D. then the water for design consideration is free water content. On the contrary the water for design consideration becomes total water content.

Aggregate strength is another important mechanical property of aggregate. Different aggregates vary in strength. Some are strong and hard while other are soft and weak. The strength of aggregates goes a long way to determine the strength of concrete made by it. Eurolightcon (2000) compared the difference between fracture paths of Normal weight aggregate (NWA) and lightweight aggregate (LWA) when used in concrete. The result showed that for LWA the fracture path passes through aggregates particle. On the other hand, the fracture path passed around the aggregate particles for NWA. According to them, the concrete matrix is stronger than the lightweight aggregate and as a result the concrete collapsed by crushing of the aggregates. The strength of aggregates can be evaluated in accordance to BS 812 (1967). Here the ability of aggregate to withstand crushing is determined. This is also covered by ASTM C 131 (2003). Park (1999) conducted crushing value test on different aggregates and at the same time tests the compressive strengths of the concrete made the aggregates. It was surprising to obtain a lesser crushing value for old recycled concrete than new recycled concrete when the concrete that produced old recycled concrete was twice as strong as the concrete that produced new recycled concrete. From this finding one will see that the crushing value of an aggregate does not per se predict the compressive strength of concrete that will be made from it. Eurolightcon (2000) said it categorically that "there is no simple relationship between the crushing resistance of lightweight aggregate and the properties of the concrete." However, the crushing value can give an idea on how compressive strength of the concrete made from it will be.

2.1.1.2 Cement - Prior to year 2000, Cement properties, tests, and characteristics were being controlled by British Standard 12 (BS 12). BS 12specifies some tests that govern the quality of cement. They include fineness test, chemical composition test, setting time test, soundness test, strength test and heat of hydration test. The details can be obtained from the BS 12. Cement for concrete work should satisfy, at least, the minimum requirements of BS 12.

In the spirit of globalization, a new standard for cement was developed as EN 197-1:2000. The Standard Organization of Nigeria adapted from this standard, NIS 444-1:2003 which replaces NIS 439:2000. The NIS 444 defines Cement as "a hydraulic binder, that is, a finely ground inorganic material which when mixed with water, forms a paste which sets and hardens by means of hydration reactions and processes and which, after hardening retains its strength and stability even under water.” The Standard continues “Cement conforming to this standard, termed CEM cement, shall, when appropriately batched and mixed with aggregate and water, be capable of producing concrete or mortar which retains its work ability for a sufficient time and shall after defined periods attain specified strength levels and also possess long-term volume stability.” The Standard listed twenty-five types of cement broken down into five main groups identified as CEM I (Portland cement), CEM II (Portland-composite cement),CEM III (Blastfurnace cement), CEM IV (Pozzolanic cement) and CEM V (Composite cement).Over 90% of the cement used in the country is the CEM II type.The cement that is commonly used is the general normal setting or Ordinary Portland Cement (the colour resembles Portland stone, hence, the name).The principal chemical compounds of Portland cement are, tricalcium silicate (3CaOSiO2), dicalcium silicate (2CaOSiO2), tricalcium aluminate (3CaOAl2O3), and tetracalciumalumino ferrite (4CaO Al2O3Fe2O3). The most important of these are the dicalcium and tricalcium silicates. Low Heat Portland Cement, Super-Sulphate Portland Cement and High Alumina Cement are not covered by the Standard. Low heatcement is required when massive concreting is to be carried out such as Dam construction. During the process of hydration of the cement, a large amount of heat is generated as a result of the chemical reaction. In case of massive concreting, the large heat can lead to disintegration of the structure, hence, the need for low heat cement. To circumvent this, the concrete designer specifies the heat of hydration required and an agreement is made with the cement manufacturer to produce the cement of required heat of hydration. In the same vein, since the use of sulphate resisting cement are not very common, a discussion can be held with the cement manufacturer to produce, using appropriate additives, cement that can be used in such aggressive soils. High Alumina Cement is useful where early strength is required, like in war time. However, the development in the cement industry has advanced to a level that a desired high strength cement can be achieved from the normal cement once the manufacturer is properly briefed.This makes the production of High Alumina Cement (which is not a Portland cement) more or less obsolete.

In terms of strength the classes are 32.5N, 32.5R, 42.5N, 42.5R, 52.5N and 52.5R. The 32.5 grade must have strength between 32.5N/mm^2 and 52.5N/mm^2, while the 42.5 grade has its range between 42.5N/mm^2 and 62.5N/mm^2. The minimum strength of grade is 52.5N/mm^2. These are strength after28days. The appendage "**N**" refers to a class of cement with ordinary early strength while "**R**" refers to those with high early strength.

2.1.1.3 Water – The quality of water used in mixing the concrete must be such that the chemical reactions, which take place during the setting of the cement, are not impaired. In general, Portable water is suitable for concreting. Thus, the water should be free from impurities such as suspended solids, organic matters and salts etc. which may affect the setting of the cement (Oyenuga, 2005).

2.1.2 Properties of Concrete

2.1.2.1 Workability

A concrete is said to be workable if it is easily transported, placed, compacted and finished without any segregation. Workability is a property of freshly mixed concrete (Kosmalka and Panarese, 1988). The most important nature of workable concrete is its lubricating nature, and this has the following advantages:

i. It will exhibit little internal friction between particle and particle
ii. It will overcome the frictional resistance offered by the surface of the formwork and reinforcement contained in the concrete
iii. It can be consolidated with minimum compacting effort

The factors which help concrete to have more lubricating effect to reduce internal friction for easy compaction include:

i. Water content
ii. Aggregate/cement ratio
iii. Size of aggregate
iv. Shape of aggregate
v. Grading of aggregate
vi. Surface texture of aggregate
vii. Use of admixture

2.1.2.2 Compressive Strength of Concrete

Compressive strength may be defined as the measured maximum resistance of a concrete specimen to axial loading. It is generally expressed in mega pascals (Mpa) or pounds per square inch (psi) at an age of 28 days. One mega pascal equals the force of one newton per square millimeter (N/mm^2) or 1,000,000 N/m^2. Compressive strength of concrete is affected by the unit weight of the concrete. Also, it has been seen that more factors other than unit weight affect concrete. These factors according to Ibearugbulem (2006) include water-cement ratio, the type of aggregate, the cement type, and the technique employed during batching and placing. Ding and Zongjin (2004) showed that the type of aggregate as well as the aggregate/binder ratio affects the compressive strength of concrete. In the research, the aggregates used were river sand, dead burnt magnesia and sintered alumina. From their result, it was discovered that the higher the aggregate-binder ratio, the lesser the compressive strength. It was also discovered that the aggregate/binder ratio of the mix made with either magnesium sand or aluminium sand had higher compressive strength than that made with river sand. They also showed that the higher the water/cement ratio, the lesser the compressive strength. Their experimental result showed that on all aggregate/cement ratios, the compressive strength was smaller with increase in water/cement ratio and vice versa. The effect of water/cement ratio on lightweight aggregate is same with normal aggregate concrete.

Factors affecting strength of concrete

i. water-cement ratio
ii. Type of cementing material
iii. Amount of cementing material
iv. Type of aggregate
v. Air content
vi. Admixtures

2.1.2.3 Density

The density of concrete is a measure of its unit weight. A normal weight concrete weighs 2400 kg per cubic meter or 145 lbs per cubic foot (3915 lbs per cubic yard). The unit weight of concrete (density) varies depending on the amount and density of the aggregate, the amount of entrained air (and entrapped air), and the water and cement content.

The concrete weight can vary depending on the air and moisture content it contains. Cement density (weight) can be 830 – 1650 kg/m^3 or 52 – 103 lbs per cubic foot. Cement that is pneumatically loaded into silos is less dense while cement that has been transported, is denser. The rule of thumb is to consider that a 94 lb. bag of cement will make one cubic foot when it is freshly packed. Density is simply a mass to volume ratio. Perhaps the easiest and most accurate way to calculate the concrete density is to measure some into a container of known volume and weigh.

A reduced density of normal concrete always means a higher water content which means lower strength concrete. The strength can be done at 24 hrs, 7 days, and 28 days in a lab to predict possible strength downturns (or lower density). This is very important considering all the high strength projects (bridges, high risers, dams) concrete is used for (Mike, 2014).

2.1.2.4 Durability

Durability is the capability of concrete to resist weathering action, chemical attack and abrasion while maintaining its desired engineering properties. It normally refers to the duration or life span of trouble-free performance. Different concretes require different degrees of durability depending on the exposure, environment and properties desired. For example, concrete exposed to tidal seawater will have different requirements than indoor concrete.

Concrete will remain durable if:

i. The cement paste structure is dense and of low permeability
ii. Under extreme condition, it has entrained air to resist freeze-thaw cycle.
iii. It is made with graded aggregate that are strong and inert
iv. The ingredients in the mix contain minimum impurities such as alkalis, chlorides, sulphates and silt.

Therefore, the factors that affects durability of concrete include:

i. Cement content
ii. Compaction
iii. Curing
iv. Cover
v. Permeability

2.2 Reinforced Concrete – Concrete is a composite inert material comprising of a binder course (e.g. cement), mineral filler (body) or aggregates and water. Aggregates on the other hand consists of fine (sand) and coarse (gravel or crushed stone) aggregates. The aggregates are usually graded from fine sand to stones of say 20mm in diameter depending on the job to be executed.

Concrete is reinforced to give it extra strength; without reinforcement, many concrete buildings would not be possible. Reinforced concrete can encompass many types of structures and components, including slabs, walls, beams, columns, mats, frames and more. There are multiple ways of reinforcing concrete; the two main methods are conventional reinforcement (non-prestressed) and pre-stressed.

Reinforced concrete consists of two materials combined together in specific proportions and form. The materials are plain concrete, which is characterized by having high compressive strength but low tensile strength, and steel reinforcing bars or strands embedded in concrete to provide the needed strength in tension.

For thousands of years, humans have taken advantage of ductile materials with high tensile strength in the reinforcement of brittle materials with high compressive strength. The ductile reinforcement transfers tensile load in the structure, allowing the brittle material to crack without causing failure of the structure. Throughout the last two centuries, concrete has been developed into a construction material with ever increasing potential to support compressive forces. As the compressive capacity of concrete has increased and with it demands to support longer and larger structures, stronger, more ductile, and more tensile reinforcement has been required (Ward-Waller, 2004).

The primary aim of reinforcing concrete is to give the concrete extra strength. Without reinforcement many concrete can encompassed many types of structures and components including slabs, walls, beams, columns, foundation frames and more. Reinforced concrete can be either precast or insitu concretes.

Much of the focus on reinforcing concrete is placed on floor system. Designing and implementing the most efficient floor system is the key to creating optimal building structures. Small changes in the design of a floor system can have a significant impact on material cost, construction schedule, operating cost, ultimate strength, occupancy levels and end use of building.

Reinforced concrete is a strong durable building material that can be formed into many varied shapes and sizes ranging from a simple rectangular column, to a slender curved dome or shell. However both concrete and steel are really needed together, this is because concrete without steel reinforcement is not structurally sound. On the other hand, steel without solid concrete floor is likewise not a preferred building method.

2.2.1 Properties of Reinforced Concrete

According to Bill et al. (2007) the tensile strength of concrete is only about 10 percent of the compressive strength. Because of this, nearly all reinforced concrete structures are designed on the assumption that the concrete does not resist any tensile forces. Reinforcement is designed to carry these tensile forces, which are transferred by bond between the interfaces of the two materials. If this bond is not adequate, the reinforcing bars will just slip within the concrete and there will not be a composite action. Thus members should be detailed so that the concrete can be well compacted around the reinforcement during construction. In addition bars are normally ribbed so that there is an extra mechanical grip.

Table 2.1 Properties of Reinforced Concrete (Bill et al., 2007)

PROPERTIES	CONCRETE	STEEL
Strength in tension	Poor	Good
Strength in compression	Good	Good but slender bars buckle
Shear strength	Fair	Good
Durability	Good	Corrodes if unprotected
Fire resistance	Good	Poor-Suffers rapid loss of strength at high temperature

Some of the widely defined properties of these two materials are given in Table 2.1. It can be seen from Table 2.1 that the materials are more or less complementary. Thus, when they are combined, the steel is able to provide the tensile strength and probably some of the shear strength while the concrete, strong in compression, protects the steel to give durability and fire resistance. Reinforced concrete combines the tensile strength of steel and the compressive strength of concrete to withstand heavy loads.

In the analysis and design of the composite reinforced concrete section, it is assumed that there is a perfect bond, so that the strain in the reinforcement is identical to the strain in the adjacent concrete. This ensures that there is what is known as "compatibility of strains" across the cross-section of the member.

The coefficients of thermal expansion for steel and for concrete are of the order of $10\ x\ 10^{-6}$ per °C and $7 - 12\ x\ 10^{-6}$ per °C respectively. These values are sufficiently close that problems with bond seldom arise from differential expansion between the two materials over normal temperature ranges.

Wherever tension occurs it is likely that cracking of the concrete will take place. This cracking, however, does not detract from the safety of the structure provided there is good reinforcement bonding to ensure that the cracks are restrained from opening so that the embedded steel continues to be protected from corrosion.

When the compressive or shearing forces exceed the strength of the concrete, then steel reinforcement must again be provided, but in these cases it is only required to supplement the load – carrying capacity of the concrete. For example, compression reinforcement is generally required in a column, where it takes the form of vertical bars spaced near the perimeter. To prevent these bars buckling, steel binders are binders are used to assist the restraint provided by the surrounding concrete.

2.3 Fiber Reinforced Concrete

Concrete containing fibrous material which increases its structural integrity is called fibre-reinforced concrete. It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers – each of which lend varying properties to the concrete. For most structural and non-structural purposes, steel fibre is the most commonly used of all the fibres. Originally, it was assumed that tensile as well as flexural strengths of concrete can be substantially increased by introducing closely spaced fibers that would obstruct the propagation of micro-cracks, therefore delaying the onset of tension cracks and increasing the tensile strength of the material. But years of experimental studies showed that with the volumes and sizes of fibers that could conveniently be incorporated into conventional mortars or concretes, the fibre-reinforced products did not offer a substantial improvement in strength over corresponding mixtures without fibers (Mehta and Monteiro, 2013).

For several decades, structural lightweight aggregate concrete obtained from fibre-reinforced concrete has been used in many different applications including buildings, bridges, floors, partitions etc. (Hassanpor et al., 2012). According to Duzgun et al. (2005) and Tanyildizi (2008), this lightweight concrete is a popular material in construction industry due to some exclusive benefits such as good tensile capacity, low coefficient of thermal expansion and superior heat as well as sound insulation capacity.

2.4 Steel Reinforcement

Section 7 of BS 8110: Part 1: 1997, specifies that reinforcements should comply with BS 4449, BS 4461, BS 4462 or BS 4483 and that different types of reinforcement may be used in the same structural member.

Hence, for a beam, the main reinforcement might be high yield bars while mild steel bars are used for the links. It may be mathematically cumbersome to use two types of reinforcement as main bars since their strengths are not the same. Reinforcement should be kept clean by stacking them off the ground. Prior to usage reinforcements should be free from mud, oil, paint, loose rust, all of which weakens the bond with the concrete. Unless the bars are rigidly fixed in the correct position the reinforcement may be displaced during concreting, particularly where the concrete is to be vibrated. Special care should be taken in fixing top tension steel particularly in cantilevers.The correct amount of concrete cover should be maintained. It is important to ensure the correct placing and fixing of all reinforcements before concreting. Should there be any discrepancies between the bending schedule and the drawings, the design engineer should be contacted.

According to Ward-Waller (2004), Steel was developed in the 19th century as a stronger alternative to iron. Steel reinforcing bars are manufactured as plain or deformed bars. It has been used to reinforce concrete since nearly its advent as a modern construction material, and is manufactured in the form of bars, plates, wire, and mesh. Ductility, strength, and chemical bond to concrete are just a few of the advantages steel provides as a reinforcing material. The advantages these improved properties would provide in concrete reinforcement were recognized and steel in the form of reinforcing bars (rebar) became an effective method of providing ductility and tensile strength to concrete. Modern steel rebar has a young's modulus of 29 x 10^6 psi and behaves in an elastic-plastic manner (Ward-Waller, 2004).

Another advantage steel provides in reinforcing concrete is the ability to bond with the cement mortar matrix of the concrete. This bond strength is a significant property of reinforcing steel, allowing forces to be transferred through the steel and distributed evenly to the surrounding concrete material. Bond strength between steel and concrete is a product of the adhesion between the two material surfaces, the pressure or gripping effect provided by the concrete after drying shrinkage, physical interlocking of the concrete aggregate and bar deformation. The quality of the concrete, its strength in tension and compression, and the diameter, shape, and spacing of the rebar determine the bond properties above. The bond stress that develops at the material interface when either material is subject to stress is expressed as local shearing stress per unit area of the bar surface, and the bond stress limit can be determined by pullout test of the rebar embedded in the concrete. Much of the research and development on rebar throughout its history attempted to determine and increase the bond strength of reinforcing elements in concrete.

One early development that increased the bond strength between rebar and concrete came in the form of projections or “deformations” rolled onto the bars in order to increase the bond surface area. In addition to the increasing of the bond surface, the deformations provided a physical mechanism for interlocking the bars with the concrete aggregates. In 1940’s the deformed bar was standardized by ASTM with technical specifications for the light and spacing of bar deformations. Deformation properties are still being tested and improved on, and within the last decade experiments have shown that bond strength can be increased by enlarging the relative area of the deformations to the bar surface.

Steel is ideal for reinforcing concrete because it has high tensile strength and modulus of elasticity. These two attributes are essential if the reinforcement is to function effectively in the two principal roles that it normally has to play (Rolt, 2008).

These are:

i. Providing all the tensile strength required in the structural member. Since the concrete has almost no tensile strength, tensile stresses applied to the member will cause it to crack. Since the reinforcement can only comprise a small fraction of the cross section of the member, high tensile strength in the reinforcement is essential if it is to carry the total load.
ii. Minimizing the width of the cracks that exist in the concrete. Since cracks are usually inevitable in a structural member in tension, it is important to minimize their width, both for structural and aesthetic reasons. A high elastic modulus means that the full load can be borne by the reinforcement with only a small amount of associated strain, hence the cracks will only open a small amount. Limits are usually set for crack width for different purposes.

Rolt (2008) went ahead to explain that in order to determine the amount of reinforcement required it is necessary to know the safe level of stress that the reinforcement can tolerate. For steel, this is relatively easy because its properties are consistent; they do not change significantly with time, and they have been very well documented. Thus, the requirements for coping with long-term loads, short-term loads and repeated loads (i.e. creep properties, strength properties, fatigue properties and so on) are well known and reliable solutions to the design problems are available.

Roy (1996) stated the benefits of steel in reinforced concrete slabs to include:Simple placement, reduction in random cracking, reduction and control of crack width and maintenance of aggregate interlock, displacement and curling can be minimized when steel is provided in concrete, strength is increased with steel reinforced concrete, and even the smallest cross sectional area of steel reinforcement will provide reserve strength of 16 percent and more. He stated finally that admixtures are not an alternative to steel reinforcement but they both do different things in the concrete. Unfortunately, steel is subject to corrosion in wet and salty environments, and the resulting damage causes the steel to weaken and lose some of its valuable properties. Encasing of steel in concrete increases the length and time before initiation of corrosion starts by forcing the chlorides to diffuse through the concrete to the depth of the steel (Ward-Waller, 2004).

Several drawbacks of traditional steel rebar include loss of strength due to corrosion from moisture and chloride, and lack of resistance to severe heat and fire damage. These materials weaknesses have led to American Concrete Institute (ACI) specifications that require rebar to be entirely encased in concrete, with a minimum concrete cover and spacing between bars. The concrete cover provides limited fireproofing and corrosion resistance to the steel.

2.5Normal Weight Concrete

This is a concrete in which common ingredients i.e. aggregate, water, cement are used. It has a setting time of 30 – 90 minutes depending upon moisture in atmosphere, fineness of cement etc. The development of the strength starts after 7 days, the common strength values is between 10 MPa (1450 psi) to 40 MPa (5800 psi). At about 28 days 75 – 80% of the total strength is attained. Almost at 90 days 95% of the strength is achieved (Haseeb, 2010).

2.6 Composite Action of Reinforced Concrete

The tensile strength of concrete is 10 percent that of the compression strength (Mosley, 1999). Because of this many reinforced concrete structures are designed with the assumption that concrete does not resist any tensile forces. Reinforcement is designed to resist all the tensile forces (Mosley, 1999). Thus members should be detailed so that the concrete can be well compacted around the reinforcement during construction.

In addition, some bars are ribbed or twisted so that there is an extra mechanical grip. In the analysis and design of the composite reinforced concrete section, it is assumed that there is perfect bond, so that the strain in the reinforcement is identical to the strain in the adjacent concrete. This ensures that there is what is known as "compatibility of strains" across the cross – section of the member. A satisfactory and economic design of a concrete structure depends on a proper theoretical analysis of individual members sections as well as deciding on a practical overall layout of the structure, careful attention to detail and sound constructional practice (Fady, 2009).

2.7 Concrete Compression Machine

The compressive testing machine is used in the crushing of concrete cubes to determine the characteristics strength of concrete and is measured in KN. The concrete cube at 28 days strength is inserted in the machine and loadedby compressing the cube until it crushes. At this stage the load that caused the crushing is read off and was recorded. This load read off will then be used tocalculate the compressive strength of the cube. A picture of the machine is shown as Plates A.16 in Appendix A.

Volume of Concrete = 0.15 x 0.15 x 0.15 = 3.375 x $10^{-3}m^3$

Area of Concrete = 0.15 x 0.15 = $0.0225m^2$

Compressive Strength = $\frac{\text{Applied Load} \times 2.0 \times 1000}{\text{Area}}$ (N/mm^2)

2.8 Magnus Frame

The Magnus Frame is a twinned steel channel frame with high tensile bolted corners and spacers is 4.61m long, 2.53m high and 1.2m wide. The cross bearers at each end under the base distribute the self-weight of about 1 tonne to four anti-vibration leveling feet. The working spacer within the frame is 4m x 1.6m high and the clearance between the twin verticals of the frame is 600mm. The top channel members are used to carry a travelling carriage on which a 200KN ram is fixed. A comprehensive range of cross bearers, thick steel plates, half round and full round bearings, and height spacing units enables specimens to be set up quickly and easily. Steel load distribution plates are supplied to insert between beams and bearing to prevent crushing the beams. A set of G clamps is provided to hold parts in place. A set of hollow steel supporting beams is included to allow dial gauge to be mounted anywhere within the frame. A picture of the Magnus frame is shown as Plate A.18 in Appendix A. The hydraulic cylinder of the frame is shown in Figure 2.1.

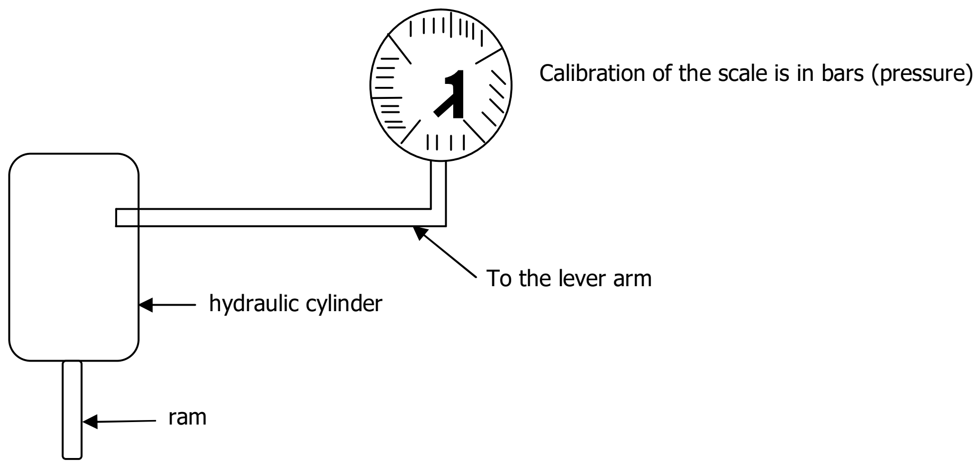


Fig. 2.1 Hydraulic cylinder of a Magnus Frame

$$10\ bar = 1N/mm^2$$

$$Effective\ Area\ of\ cylinder, A_r = \frac{3.142 \times d_r^{\ 2}}{4}$$

$$d_r = d_o - 2t$$

$where\ d_r = effective\ diameter$ of cylinder

$d_0 = external\ diameter\ of\ cylinder$

$t - thickness\ of\ cylinder$

$$Therefore, effective\ area\ of\ cylinder = \frac{3.142 \times 110^2}{4}$$

$$= 9504.55mm^2$$

$$Density = \frac{mass}{volume}(kg/m^3)$$

$$Unit\ weigth\ of\ beam - ((density \times 9.8)/1000) + 2\%$$

$$= ((1.02\ \times 9.8)/1000)KN/m^3$$

$$Self - weight\ of\ beam, q = Unit\ wt. of\ beam \times 0.15 \times 0.15\ KN/m$$

$$flexural\ strength = \frac{M}{Z}$$

$$where\ Z = Section\ Modulus\ of\ the\ beam = \frac{bh^2}{6}$$

$$Therefore, flexural\ strength = \frac{6M}{bh^2}\ KN/m^2$$

$$Load\ from\ the\ cylinder$$
$$= pressure\ (from\ the\ hydraulic\ machine)$$
$$\times Effective\ Area\ of\ the\ cylinder.$$

Note: The hydraulic machine is calibrated in bars (pressure). To get the force from this, one has to multiply the pressure by the area of the ram.

2.9 Methods of Truss Analysis

A truss is a structure that acts like a beam but with major components, or members, subjected primarily to axial stresses. The members are arranged in triangular patterns. Ideally, the end of each member at a joint is free to rotate independently of the other members at the joint. If this does not occur, secondary stresses are induced in the members. In addition, if loads occur other than at panel points, or joints, bending stresses are produced in the members.

Plane trusses are made up of short thin members interconnected at hinges to form triangulated patterns. A hinge connection can only transmit forces from one member to another member but not moment. For analysis purpose, the truss is loaded at the joints. Hence, a truss member is subjected to only axial forces and the forces remain constant along the length of the member. The forces in the member at its two ends must be of the same magnitude but act in the opposite directions for equilibrium.

In problems of stress analysis we discriminate between two types of structure; in the first, the forces in the structure can be determined by considering only its statical equilibrium. Such a structure is said to be statically determinate.The second type of structure is said to be statically indeterminate. In the case of the latter type of structure, the forces in the structure cannot be obtained by considerations of statical equilibrium alone. This is because there are more unknown forces than there are simultaneous equations obtained from considerations of statical equilibrium alone. For statically indeterminate structures, other methods have to be used to obtain the additional number of the required simultaneous equations; one such method is to consider compatibility.

Kumar-Roy and Charkrabarty (2009) gave some basic assumptions in the analysis of trusses and that while actual trusses are connected through gusset plates by rivets, bolts or welds, truss analysis assumes that

i. Members are connected at their ends by smooth frictionless pins
ii. Loads and reactions are applied to the truss at joints

iii. The centroidal axis of each member is straight and coincides with the line connecting the joint centers
iv. All members function as two force members i.e. they are subject to either tension or compression.

2.9.1 Two-Force Member Methods — Pin-Connected Truss

In the 1840s, a method of analyzing trusses as pin-connected assemblages was developed and is still in wide use today. This method is based on assuming that the truss joints are frictionless pins. This assumption means that as long as loads are applied to the joints and not along the member length, the only bending is caused by self-weight. Thus, the major force in the member is assumed to act along its length. This is often called a "two-force member." The two forces are the axial load at each end of the member.

Throughout the 19th century and even into the early part of the 20th century, it was common to use physical pins in truss joints in order to facilitate the interconnection of components of members, and also to replicate the mathematical assumptions. As a truss deflects under loads, the joints rotate through what are typically very small angles. If the pins truly were frictionless, the truss members would rotate relative to each other and no end moments would be developed on the members.

2.9.2 Method of Joints

As the name implies, the method of joints is based on analysis of free-body diagrams of each of the truss joints. As long as the truss is determinate, there will be enough joints and equations of equilibrium to find the force in all the members.This method can only be used to determine the internal forces in the members of statically determinate pin-jointed trusses. It consists of isolating each joint of the framework in the form of *a free-body diagram* and then by considering equilibrium at each of these joints, $\sum X=0$ and $\sum Y=0$ simultaneously and since no moment is applied at the joint, the moment equation $\sum M=0$ is automatically satisfied (Kumar Roy and Charkrabarty, 2009). The forces in the members of the framework can be determined. Initially, all *unknown forces* in the members of the framework are assumed to be in *tension,* and before analysing each joint it should be ensured that each joint does not have more than two unknown forces.

2.9.3 Method of Sections

The method of sections proceeds by identifying free-body diagrams which contain only two unknowns, so that equilibrium of the sum of the moment about one joint and the equilibrium of the sum of the shears through a panel are sufficient to determine the two unknown truss forces. The analysis then proceeds from section to section along the truss. As a practical matter, a combination of the method of section and the method of joints usually results in the most expeditious calculations. This method is useful if it is required to determine the internal forces in only a few members.

The process is to make an imaginary cut across the framework, and then by considering equilibrium, to determine the internal forces in the members that lie across this path. In this method, it is only possible to examine a section that has a maximum of three unknown internal forces, and here again; it is convenient to assume that all unknown forces are in tension.

2.10 Review of Other Works on Reinforced Concrete Beam

A study was carried out on a hollow beam in University of Glasgow. Here,tests were conducted on eight reinforced concrete hollow beams subjected to combined load of bending, shear and torsion. The beams were designed using the direct design method. All beams had an overall depth of 300mm with a wall thickness of 50mm. The overall length of the beam was 3800mm. The two main variables in the series were the ratio in the web of the maximum elastic shear stress due to twisting moment to elastic shear stress due to shear force. Good agreement was found between the design and experimental failure loads. All beams failed near the design loads and had undergone ductile behavior until failure. The results indicate that the direct method can be successfully used to design reinforced concrete box for the combined effect of bending, shear and torsion loads (Alnauimi,2008).

Another study was also carried out in the University of Glasgow to compare solid and hollow reinforced concrete beams. Comparison between test results of seven hollow and seven solid reinforced concrete beams were presented. All the fourteen beams were designed as hollow sections to resist combined load of bending, torsion and shear. Every pair (one hollow and one solid) was designed for the same load combinations and received similar reinforcement. The beams were 300 by 300mm cross-section and 3800 mm length. The internal hollow core for the hollow beams was 200 by 200 mm creating a peripheral wall thickness of 50 mm. The main variables studied were the ratio of bending to torsion which was varied between 0.19 and 2.62 and the ratio in the web of shear stress due to torsion to shear stress due to shear force which was varied between 0.59 and 6.84. It was found that the concrete core participates in the beams' behavior and strength and cannot be ignored when combined load of bending, shear and torsion are present. Its participation depends partly on the ratio of the torsion to bending moment and the ratio of shear stress due to torsion to the shear stress due to shear force. All solid beams cracked and failed at higher loads than their counterpart hollow beams. The smaller the ratio of torsion to bending the larger the differences in failure loads between the hollow and solid beams. The longitudinal steel yielded while the transverse steel experienced lower strain values (Alnauimi, 2008).

De Pavia and Siess (1965) investigated 19 small scale deep beams with depths varying from 178 mm to 330 mm and a span of 610 mm (span to depth ratios between 3.43 and 1.85). Positive anchorage was provided to the tension reinforcement by welding 51 mm by 12.7 mm steel plates to the end of the bars thus eliminating anchorage failure as a parameter. From their work they made the following observations:

- Increasing the amount of tension reinforcement increased the load capacity of the beams and tended to change the mode of failure from flexure to shear.
- Increasing the depth (while holding the cross-sectional area constant) increased the load capacity of beams failing in flexure, but did not show a proportional increase in shear strength.
- The presence of web reinforcement did not appear to influence greatly the capacity beyond cracking for the beams regardless of the mode of failure.

De Pavia and Siess used the results of their study to show that the ultimate flexural strength of moderately deep beams can be predicted by using the principles of shallow beam design if the limiting concrete strain is increased to 0.008. This empirically based method appears to give good results for beams failing in flexure. However, it over-estimates the failure load for the beams that do not reach their full flexural potential and fail in shear. Man and Hsu (1987) developed a softened truss model for the shear behaviour of deep beams, using the modified compression field theory.

In an unpublished research Beeby (2000) showed the difference in capacity between a truss and a beam with the same dimensions. It is non-intuitive that the truss has 1.5 times the capacity of the beam. According to Beeby, the beam is unable to act as a truss resulting by the cracks out of the bending of the beam.

The conclusion of Beeby for the different failure loads is the inability of the beam to transform into a truss by the cracks which occur by bending. The cracks caused by bending of the beam, cut the line of compression of the truss, which ensure that the beam is not able to convert into a truss. According to the research, a diagonally tensile failure crack occurs before beam can perform as a truss and that is what determines the real difference of these failure modes and why the beam is unable to transfer into a truss.

An analytical study by Van Den Hoogen (2013) describes the difference between the beam and a simplified truss mechanism. Linear analyses show the differences in stress distributions and deflections. The study shows the same difference in strength capacity as the experiments of Beeby (2000). In addition quite a difference is revealed in the displacements of both mechanism. The truss mechanism shows a larger deformation compared to the beam mechanism.

A dedicated shaped beam which has initially exactly the shape of a shear cracked beam without the concrete part below the crack, has a different strength capacity compared to a regular shear cracked beam. The dedicated shaped beam proves that the crack shape itself has no influence on the ability of converting into a truss. It turns out that in the regular beam it was impossible to develop a perfect truss mechanism after a flexural shear crack due to the concrete that was still present beneath the crack. The concrete beneath the crack causes a different stress distribution in the top of the beam compared to the dedicated shaped beam without this concrete. A hypothesis was given for the failure of the shear crack.

Van Den Hoogen (2013) concluded that the acquired knowledge of the influence of the concrete beneath the crack and the stiffness of the beam allows other design possibilities. It is possible to design a concrete truss, if among other, the yielding of steel, crushing of the concrete and the deformation capacity of the truss are taken into account.

Bing and Cao(2008) presented a truss model to predict the load–deflection response of reinforced concrete beams subjected to flexure and shear. The truss model which has struts at various angles is derived considering concrete contribution. The concrete contribution is then integrated into the modified truss model through the concept of equivalent stirrup reinforcement. The validity and applicability of the proposed truss model is evaluated by comparing results with experimental data. Good correlations with the experimental data have been obtained. This study shows that the truss model analogy, if properly treated, can be used to access both shear strength as well as the load–deflection response of reinforced concrete elements subjected to shear and flexure.

Bresler and MacGregor(1967) reviewed the mechanism and analyses of RC beams which failed in shear and gave graphical illustrations based on a classical truss model. This provides an initial concept for the modified truss model with struts at various angles. In this model, the chords are assumed to be parallel to each other. All shear must be carried by tension in the transverse reinforcement as neither chord can transmit any transverse load. However, to account for the experimentally observed shear capacity of concrete in a beam (with and without reinforcement),it may be assumed that the compression chord of the truss is curved. This is then known as the modified truss model. Although further analytical work on these models was not available at that time, they gave a very good conceptual basis for further research on truss model analogy. Paulay and Binney (1974) found that shear deformation was developed dueto truss action when estimating deformations of coupling beams after cracking.

A considerable portion of shear force was found to transfer from one support to the other through a truss formed by the stirrups and the diagonal concrete strut. An analogous truss model with tapered struts was used by Paulay and Binney(1974) to study theprincipal dimensions of the compression struts and deformation of a typical shear transfer linkage. Then from the compatibility condition, shear rotation of the analogous variable angle truss modelwasdetermined.Paulay and Binney (1974) in their worklaidthesolidfoundationforfurther detailed analysis with the truss model analogy. Attempts were made to develop strut-and-tiemodel formation procedure, which allowed the cyclic hysteretic response of RC structures to be examined. For this purpose, an idealized uniaxial fiber model was proposed to simulate the axial force–displacement characteristic of a combined concrete and steel reinforcing element. The model was subsequently employed as the top and bottom longitudinal chord members in the strut-and-tie model. The dimensioning of chords struts and ties and allowable strength of these members were briefly discussed too. The strut-and-tie model obtained from their suggested procedure gave satisfactory analytical results to the experimental evidences.

Yi et al. (2011) explains a new type of steel reinforced concrete (SRC) transfer beam. The steel truss reinforced concrete (STRC) transfer beam, is developed and applied to a 100 m tall building in Guangzhou City to solve the difficulty of two built subways being buried under the building. Experimental studies on mechanical behaviours of STRC composite transfer beams were carried out, and the structural characteristics and economic characters of the transfer beam were introduced. Experimental investigations verify that the STRC transfer beam is of high bearing capacity, large rigidity and good ductility. Compared with normal reinforced concrete transfer beam, the limit bearing capacity of the

STRC transfer beam can be enhanced 30–40%, and the rigidity can be improved 30–50%. In the STRC transfer beam, the strut-and-tie force transfer mode is followed, the loads are mainly transferred by compressive diagonal SRC struts from the loading point and abutments, SRC struts and horizontal ties form a self-balance system. The cost of material, fireproof and construction can be saved; more space for commercial function and convenient construction can be achieved by adopting STRC transfer beams.

Piyamahant (2002) showed that the existing reinforced concrete structure should have stirrup reinforcement equal to the minimum requirement specified in the code. The theoretical analysis shows that the amount of stirrup of 0.2% is appropriate. He concluded that small amount of web reinforcement is sufficient to improve the shear carrying capacity.

Noor (2005) presented several results of experimental investigation on six reinforced concrete beams in which their structural behaviour in shear was studied. The research conducted was about the use of additional horizontal and independent bent- up bars to increase the beam resistance against shear forces. The main objectives of that study were studying the effectiveness of adding horizontal bars on shear strength in rectangular beams, the effectiveness of shear reinforcement, and determining the optimum amount of both types of shear reinforcement to achieve a shear capacity similar to that of a normal links system. From experimental investigation of the system it was found that, the use of independent horizontal and bent-up bars as shear reinforcement were stronger than conventional shear reinforcement system. Abdul et al. (2013) in their study of improved shear performance of bent-up bars in reinforced concrete, beams presented a new type of shear reinforcement using rigid bent-up bars. These bent-up bars resisted shear in a plane rather than the tradition linear configuration. The experimental data showed that there is substantial improvement in shear performance of reinforced concrete beams.

Planck et al. (1993) investigated two schemes for strengthening the negative-moment regions of continuous composite bridges: (1) Post-compression of stringers; and (2) superimposed trusses attached to stringers. Both strengthening schemes were designed to resist negative moments and the resulting stresses from service loads. A series of tests was conducted on a full-scale mockup with each strengthening scheme in place. They concluded that he superimposed trusses system is a very practical strengthening system that with appropriate connection modifications can be used to strengthen the negative-moment regions of essentially any type of bridge.

Mark (2005) developed spatial truss models for the design of reinforced concrete beams subjected to biaxial shear forces. They are derived from a resolution of the vector of the resultant shear force and applied to beams with rectangular cross sections. The models consist of tensile struts of stirrups and longitudinal bars, spatially inclined shear struts as well as compressive struts stiffening the stirrup corners. They are further elaborated to derive charts for the stirrup design.

Monti and Petrone (2015) developed shear capacity equations for composite truss beams (CTBs). These equations are obtained from a purposely developed mechanics-based shear model. As opposed to commonly used approaches for the design of these structural elements, where the shear capacity is attained when the first pair of web steel bars yields, in this case the shear capacity is expressed as that causing *n* pairs of web steel bars to yield before concrete crushes. In this way, the performance of CTBs is maximized. Two different capacity equations are proposed: one, derived from an analytical method, explicitly takes into account the contribution of concrete to shear capacity, and the other, following most current codes, does not consider such contribution. The accuracy of the proposed capacity equations has been verified against the results of nonlinear analyses and experimental tests conceived and conducted to this aim. The comparison confirmed both the consistency of the proposed mechanical model with the experimental observations, and the capability of the capacity equations to predict the shear capacity of CTBs.

Trentadueet al. (2014) studied a special steel-concrete composite beam in which the resisting system is a truss structure whose bottom chord is made of a steel plate supporting the precast floor system. This system works in two distinct phases with two different resisting mechanisms: during the construction phase, the truss structure bears the precast floor system and the resisting system is that of a simply supported steel truss; once the concrete has hardened, the truss structure becomes the reinforcing element of a steel-concrete composite beam, where it is also in a pre-stressed condition due to the loads carried before the hardening of concrete. Within this framework, the effects of the diagonal bars on the bending stiffness of this composite beam are investigated. First, a closed-form solution for the evaluation of the equivalent bending stiffness is derived. Subsequently, the influence of geometrical and mechanical characteristics of shear reinforcement is studied. Results obtained from parametric and numerical analyses demonstrated that the shear reinforcementprovides a significant contribution to the final bending stiffness. As a consequence, ignoring suchcontribution can lead to over-conservative and anti-economical design solutions.

Yasser et al. (2015) workedon flexural characteristics of reinforced concrete beam using Styrofoam Filled Concrete (SFC) in tension zone. The concrete in the tension zone is neglected in the design. Therefore, it is reasonable if the concrete on the tension zone uses a low compressive strength concrete by mixing them with the Styrofoam grains. The concrete that filled with the concrete grains is named with Styrofoam Filled Concrete (SFC). Styrofoam as waste can be used as a filler to reduce the volume of concrete, especially for areas where the concrete section is neglected in design. SFC used in this study were with 30% Styrofoam volume fractions. Results indicated that normal beam (BN) had maximum flexural load of 38.8 kN, while vertical external reinforcement beams (BTL) had decreased load of 24.2 kN and truss system external reinforcement beam (BTR) 36.0 kN, close to the normal beam specimen. Loading test of the beam with SFC -30 using vertical reinforcement(BSC) and beam with SFC -30 using truss system reinforcement (BSCTR) had maximum load of 38.2 kN and 48.3kN, respectively. It can be concluded that the use of SFC in tension zone of the concrete beams showed a good agreement in performance compared to the normal reinforced concrete beams. The use of truss system of reinforcement can increase the strength of the loading capacity of the beam.

Altun and Aktas (2013) in their work on investigation of reinforced concrete beams behavior of steel fibre lightweight concrete stated that due to the use of lightweight concrete in construction, the dead load is reduced and so the earthquake forces do, and hence diminished hazards for human's life.

In 1964, Romualdi and Mandel reported on the tensile strength enhancement of concrete by steel fibers, and Batson et al. (1972) presented the shear strength enhancement of Steel Fibre Reinforced Concrete, SFRC beams based on the experimental tests on 102 SFRC beams with the key variables of shear span ratio and volume fraction of steel fibers. Later Swamy and Bahia (1979) reported that the shear strength was enhanced due to the steel fibers that deliver the tensile forces at the crack surface in the SFRC beams without shear reinforcement. Sharma (1986) performed the experimental study on SFRC beams with the hooked-types of steel fibers, and based on the experiment results, proposed the shear strength (vu) equation for the SFRC beams in a relatively simple form.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Materials

The materials used for the beam construction include – Water, Cement, River sand (fine aggregate), Granite (coarse aggregate) and Steel rods.

3.1.1. Water

The water used for this research was obtained from the borehole in Federal Polytechnic Nekede in Owerri, the water was colourless and free from suspended solids and organic matters. The water was fit for drinking.The water was pumped into drums in the school laboratory for mixing of the concrete and also pumped into the curing tank for curing the concrete cubes and beams.

3.1.2. Cement

The cement used was ordinary Portland cement. Prior to use, the cement was stored above the ground surface on planks in a moisture free part of the school's concrete laboratory. The quality of cement used was in conformity with specifications in BS 12 (1978).

3.1.3. River Sand

River sand was used in the concrete as fine aggregate. The river sand was obtained from Ota Mmiri River at Ihiagwa,Imo state with a bulk density of $1.51Mg/m^3$. The sand was free of silt, debris and other organic materials. The river sand were collected and spread to dry under the sun.

3.1.4. Granite

Granite was used in the concrete. The granite was obtained from Okigwe part of Imo state with a bulk density of 2.8Mg/m^3. The granite used was a normal weight aggregate free of debris and other organic materials. The granite was collected and stored in sacks. The granite is in accordance with BS 1881 (1970).

3.1.5. Reinforcement

High yield steel bar was used as reinforcement for the construction of beam truss system and conventional beam reinforcement. The steel bars were kept clean by stacking them off the ground. Prior to usage, the bars were kept free from mud, oil, paint, loose rust which all weaken the bond with the concrete. The steel bars were obtained from OgboOsisi market Owerri, Imo State.High yield Steel rods of 8mm diameter were used as the reinforcement bars to fabricate the conventional beam reinforcement and the truss system of reinforcement. The 8mm steel rods have characteristics strength of 410N/mm^2

3.2. Methods

3.2.1 Physical characterization tests of granite

Specific gravity, bulk density, water absorption, void ratio and sieve analysis of granite were tested. The apparatus used were a 20kg weighing machine, four plastic baths, a flat table, a calibrated cylindrical glass jar, hydrometer and scoop. Others were 16mm steel rod, a 150mm x 150mm steel cube container, three plastic buckets, three plastic baskets and four standard sieves (19.5mm, 14mm, 10mm and 5.6mm).

3.2.1.1 Specific Gravity

The test was conducted by collecting dry samples of granite using three plastic baths. The weighing machine with its tray was set to the zero point. At this point the weighing machine was used to weigh the three samples contained in the plastic baths. The masses of the samples were recorded. The hydrometer was used to measure the specific gravity of the water. The water was poured into the calibrated cylinder after recording its specific gravity. Water level in the cylinder was noted and recorded. After recording the water level, the first sample was gradually poured into the cylinder containing water. The final level of water was also noted and recorded. The content of the cylinder was now discharged into one of the plastic baskets. The process was repeated for the remaining two samples.

3.2.1.2 Bulk Density

The bulk density test was conducted for compacted and non-compacted samples. For non-compacted sample, the granites were loosely poured into the 150mm x 150mm steel cube container till it became over filled. The
16mm steel rod was used to level the sample by rolling it over the container. At this point the content of the container was discharged into the tray of the weighing machine, which had been set to the zero point already. The mass of the sample was weighed and recorded. This was repeated two more times and masses recorded.

For the compacted samples, the container was filled in three layers using the scoop. Each layer is about one - third of the volume of the container, when the first layer was poured in, the 16mm rod was used to tamp on it 25 times in accordance with ASTM C128-04a. This was done for the second and third layers.

The container was then over filled and 16mm rod used to level the sample by rolling it over the container. The process was also repeated for two more times and masses recorded.

3.2.1.3 Water Absorption

During this test, three dry samples of granite were collected using three plastic baths. The weighing machine with its tray was set to zero point. After setting the weighing machine, the masses of the three samples were weighed and recorded. The weighed samples were put back into the three plastic buckets and topped with distilled water of known specific gravity. The buckets were allowed to stay for 24hours, after which they were emptied into three different plastic baskets, which were allowed to stand for 1hour inside the laboratory. At the end of the 1hour the baskets were respectively emptied into the tray of the weighing machine and the respective masses weighed and recorded.

3.2.1.4 Void Ratio

The procedure for void ratio was covered by the procedures of specific gravity and bulk density.

Void ratio = 1 - (Bulk density / Specific gravity)

3.2.1.5 Sieve Analysis

The test was done in general accordance with BS 812 (1975). The first thing done was to set the weighing machine with its tray to zero point. Then a dry sample of granite was collected and poured into the tray of the weighing machine and the mass was weighed and recorded. At this point the weighed sample was poured into the 19.5mm sieve and by manual operation using hand the sample was sieved.

The portion that passed through the sieve was collected in the 14mm sieve and also manually sieved using hand. This process continued with sieves 10mm and

5.6mm in that order. The portion that passed through 5.6mm sieve was collected using the receiver. Masses of the portions retained on 19.5mm, 14mm, 10mm, 5.6mm and the receiver were respectively weighed using the weighing machine. Their various masses were recorded.

3.2.2 Mechanical Characterisation Tests of Granite

Impact value and Abrasion value of granite were tested. Steel cylindrical container (148mm diameter and 297mm height), a standard hammer (BS 812: part 3: 1975), and 20kg weighing machine and scoop were some of the apparatus used. Others were 14mm, 13.2mm, 11.2mm, 10mm, 2.36mm and 2.00mm standard sieves, 12 steel charges of 92.5g each and Los Angeles Abrasion test machine.

3.2.2.1Impact Value

This test was carried out in accordance with BS 812 (1975). The first thing done was to arrange the 14mm, 10mm sieves and the receiver in that order. The dry sample of the granite was collected using the scoop and put into the 14mm sieve. The actual sieving operation was manually done using hand. After handling the 14mm sieve, 10mm sieve was handled .The portion that passed 14mm sieve and did not pass through 10mm sieve was collected, and it was poured into the tray of the weighing machine, which had been set to the zero point initially. Mass of the collected sample was weighed and recorded. Then the weighed granites were poured into the steel cylinder where the impact was applied. The impact was applied using the standard hammer that fell 15 times under its own weight upon the granites in the container (cylinder). After the impact the content of the cylinder was emptied into the 2.36mm sieve where it was sieved by manual operation using hand. Masses of portions that passed the 2.36mm sieve and the one that was retained by it were weighed using the weighing machine and thus, recorded. This process was repeated two more time.

3.2.2.2Abrasion Value

This test was conducted in the Structural laboratory at Federal Polytechnics Nekede in accordance with ASTM C131.Sieves of 13.2mm and 11.2mm and the receiver were arranged in that order. Dry sample of granite was put in the 13.2mm sieve. Sieving was done manually using hand. The portion that passed through 13.2mm sieve and retained on the 11.2mm sieve was taken. Mass of the collected portion was weighed using the weighing machine and thus recorded. The weighed sample was poured into the Los Angeles abrasion test machine.
For abrasion test, the 12 steel charges were poured into the machine and the machine was closed. At this point the machine was rotated at a speed of about 32 revolutions per minute for 500 revolutions. At the end of the 500 revolutions the sample was removed from the machine and preliminarily separated using the 2.36mm sieves. Portion of the sample that passed through the2.36mm sieve was sieved manually also using hand with the 2.00mm sieve. All the portions that did not pass through the 2.00mm sieve were poured into the weighing machine and the mass was weighed and recorded.

3.2.3. Fabrication of Reinforcement

This truss beam reinforcement was fabricated using 8mm high yield steel. It has fourlongitudinal lengths of 960mm each. Its height and width are 110mm each with eighteen pieces of crossing bars of 94mm each. The truss box has 9 triangles for 100mm spacing, 6 triangles for 150mm spacing and 5 triangles for 200mm spacing in each side of the truss box. These dimensions are shown in Figure 3.1.

Full lengths of 8mm high yield steel were bought and were cut with the help of a hack saw. Four pieces of 960mm rod each were cut out of the full length of 8mm high yield tensile steel for the longitudinal bar of the box truss. Eighteen pieces of 94mm rod each were also cut out for the top and the bottom bracing of the box truss. Thirty six pieces of 106.47mm rod each were cut out for the side triangles of the box truss.

For the longitudinal side, the 960mm rods were placed flat and marked at intervals of 100mm, and then the 106.47mm rods were placed along the marked points and weldedat an angle of 62^0each from the horizontal such that 9 triangles were formed.

The same method was used to produce the second side of the box truss. The two sides with triangles were then positioned parallel to each other and were then joined together by welding the 94mm cut out rods to the nodes of the triangles at the top and bottom to form the box truss. 20mm metal thickness were welded at the bottom and sides of the truss so that the base and the sides of the truss would not rest on themould so that a concrete cover of 20mm will be maintained all over the truss.

Nineof this type of box truss at 100mm spacing was produced to be used in three different mix ratios. Nine box trusses were fabricated in the same manner at 150mm spacing and another nine box trusses at 200mm spacing. The box truss fabricated is shown as plate A.1in Appendix A using the dimensions in Table 3.1

The conventional beam reinforcement was fabricated by laying two lengths of 960mm horizontally at spacing of 94mm with stirrups positioned and tacked with binding wire at intervals of 100mm and finally another two lengths of 960mm rod is tacked with binding wire at the other two edges of the stirrups as

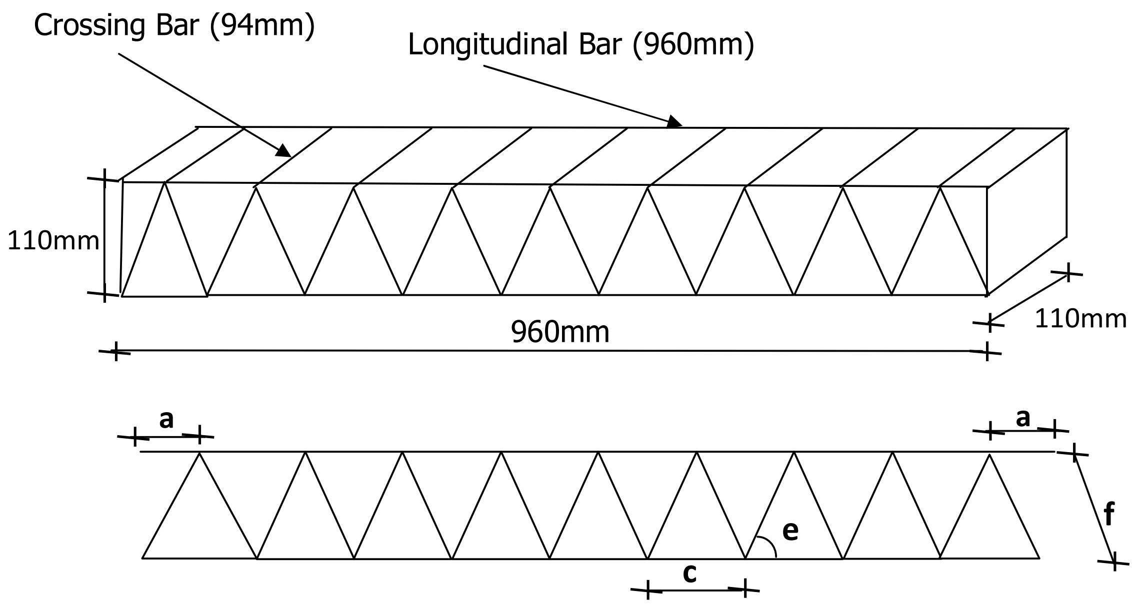


Figure 3.1 Illustration of Truss Reinforcement

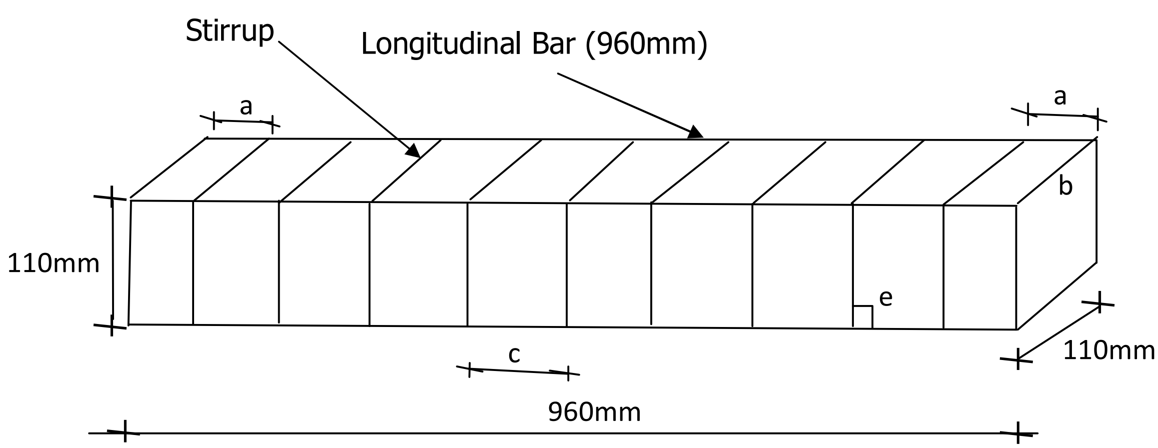


Figure 3.2 Illustration of Conventional Beam Reinforcement

shown in Figure 3.2. This is done repeatedly for another 8pieces of box beam reinforcement. This procedure is repeated for 9 pieces of box beam at a spacing of 150mm and another 9 pieces of box beam at 200mm spacing. These fabrications are shown in plates A.2 and A.3in Appendix A.

In all twenty seven box trusses were fabricated and another twenty seven conventional beam reinforcements were also fabricated, making a total of fifty four beam reinforcements. The following are defined as:

a = distance between beam end and first stirrup/triangle

b = breadth of beam

c = spacing of stirrups/diagonal bars in beam

e = diagonal bar / stirrup angle in beam reinforcement

Table 3.1 Dimensions of truss and conventional reinforcement

Test No	Description	a (mm)	b (mm)	c (mm)	e (degree)
1	9 triangles for 100mm spacing	30	106.47	100	61.99
2	6 triangles for 150mm spacing	30	120.25	150	51.41
3	4 triangles for 200mm spacing	80	137.24	200	43.23
4	9 stirrups	30	None	100	90
5	6 stirrups	30	None	150	90
6	4 stirrups	80	None	200	90

3.2.4 Concrete Materials Batching, Mixing, Placing, Curing and Crushing

3.2.4.1 Batching of Materials

Three (3) mix ratios were used for this work, namely,(A) 0.5:1:2:4,(B) 0.55:1:2.5:5 and (C) 0.6:1:3:6. Each mix ratio was used to cast nine truss reinforced beams, nine conventional reinforced beams, and three concrete cubes.

In all fifty four beams and nine cubes were cast. The batching method adopted was batching by weight. The batch weights were calculated as shown in Appendix Band weighed with the aid of 50kg weighing scale as shown in plates A.4, A.5 and A.6. The concrete mix ratios and component quantitiesare shown in Table 3.2.

Table 3.2 Concrete mix ratios and component quantities

Mix ratio	Water (kg)	Cement (kg)	Sand (kg)	Granite (kg)
A	26.64	53.22	106.44	212.76
B	25.66	43.80	109.56	219.12
C	23.98	37.26	111.78	223.56

The material batching calculations are shown in Appendix B.
Table 3.3 shows the beam test numbers and descriptions.

Table 3.3 Beam test numbers and description

Test No	Mix Ratio	Beam Description
1	A = 0.5:1:2:4	Truss Reinforcement
2	B = 0.55:1:2.5:5	Truss Reinforcement
3	C = 0.6:1:3:6	Truss Reinforcement
4	A = 0.5:1:2:4	Conventional Reinforcement
5	B = 0.55:1:2.5:5	Conventional Reinforcement
6	C = 0.6:1:3:6	Conventional Reinforcement

3.2.4.2 Mixing of Materials

The mixing was done on a concrete floor with the use of a spade. Before the mixing the floor was wetted with water.The quantities of these materials were gotten using values in Table 3.2. The river sand was first weighed out on a scale in batches not exceeding 50kg – the capacity of the scale. When the quantity of river sand required was gotten, the required quantity of cement was then weighed out in the same manner and mixed thoroughly with the river sand with the use of shovel. When the required quantity of coarse aggregate was achieved, the calculated quantity of water was measured and poured into the materials and the concrete was then mixed with a shovel as shown in Plate A.7 in Appendix A. The mixed concrete was put in a head pan and carried away for casting.

3.2.4.3 Workability Test

Workability is the ease with which concrete can be worked. Slump test was performed in this research on the three mixes. The slump cone was filled in three layers using scoop, with each layer being about one-third of the volume of the cone. For the first layer of concrete that was poured, 16mm rod was used to tamp it 25 times for proper compaction. This was repeated for the second and third layers accordingly. The cone was then overfilled and the tamping rod was used to level it. The cone was removed immediately after the levelling and the slum (reduction in height) was measured using 30cm ruler. The result of the test are given in section 4.

3.2.4.4 Placing of Concrete Cubes and Beams

The moulds 150mm x 150mm x 1000mm and 150mm x 150mm x 150mm for beams and cubes respectively were first cleaned with a metallic brush and then wiped clean with a clean dry rag to rid them of all dirt and debris.

With the use of a brush, the moulds were then greased with used engine oil to prevent concrete from sticking to the mould after casting and also to aid easy de-molding or removal of the cast concrete beams and cubes. The beam moulds wereplaced horizontally on a level concrete floor and the reinforcements placed in position inside the beam moulds. The concrete cover was maintained by placing 20mm pieces of steel on the bottom and side of the moulds to prevent direct contact between the mould and the reinforcement as shown in Plate A.8. The concrete was then brought and poured insidethe 150mm x 150mm x 1000mm beammoulds. Concrete from the same batch were also placed intothe 150mm x 150mm x 150mm cube mouldsand compacted. The concrete in beam moulds were compacted in three layers by ramming or tampering the concrete 100 times at each layer and the side of the mould with tamping rods to reduce air voids and ensure maximum contact with the moulds as shown in Plate A.9. The surface of the compacted beam was fine finished using trowel and marks were made for easy identification.Also concrete was poured in the cube mould in three (3) layers and compacted by ramming the concrete 25 times at each layer as shown in Plate A.10. The pouring of concrete and compaction of concrete were carried out continuously till the mould was filled to the brim. The top of the cast was then leveled with a trowel and leveler.

The cast beams and cubes were allowed to set in the mould for 24 hours. After 24 hours the beams and the cubes were de-molded and carried to an open curing tank for curing as shown in Plate A.11.

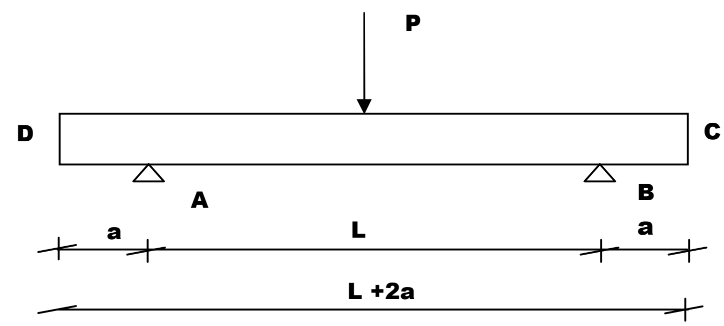
3.2.4.5 Curing of Concrete Beams and Cubes

The cast beams and cubes were totally immersed in the water-filled curing tanks immediately after de-molding to BS EN 12390 – 2:2009. The beams and cubes were left to cure in the water for 28 days. On the 28^{th} day, the beams and the cubes were brought out of the curing tank and kept outside waiting forcrushing as shown in Plates A.13 and A.14. The cubes were weighed and crushed immediately after they were brought out of the curing tank.

3.2.4.6 Crushing of Concrete Beams and Cubes

The crushing of the cubes was done to BS EN 12390 – 3:2009with the use of universal crushing machine and electric powered concrete compressive testing machine with a capacity of up to 2500KN. The cubes were placed in the machine and the machine was switched on to apply a compressive force which was deflected on its gauge. On failure of the cubes, the machine was switched off and the compressive force that crushed the cube was read off the gauge. This force was then used to calculate the compressive strength of the cubes. In all nine cubes were crushed and their compressive force recorded.

The beams were crushed using a Magnus Frame. The beams were placed on supports within the frame in such a way that the ram from the Magnus Frame would apply its force on the Centre of the beam as shown in Plate A.15. The machine was operated by manually pumping hydraulic till the ram of the Magnus Frame made contact with the beam and exerted continuous pressure on the beam till it failed by cracking at the bottom part as shown in plate E.1. The load that caused the failure of the beam was then read off the Bourdons gauge of the machine and recorded. This procedure was repeated for other beams and at the end fifty four beams were crushed. Twenty seven (27) of the beams were reinforced with truss whereas the other twenty seven (27) were reinforced with conventional reinforcement.The machine is calibrated to measure up to 160 Bars. The loading arrangement of beam is shown in Figure 3.3.



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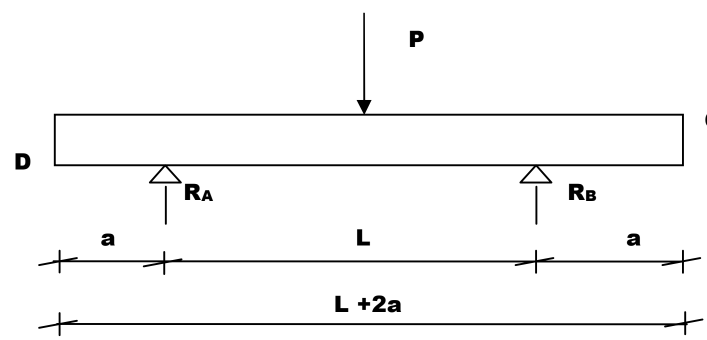
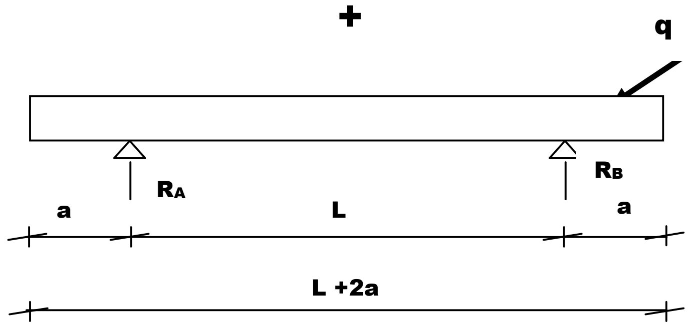


Loading with Point load

$$R_A = R_B = \frac{P}{2}$$

$$M_{max} = \frac{P}{2} \times \frac{L}{2} = \frac{PL}{4}$$

+



Loading with UDL

$$R_A = R_B = \frac{q(L + 2a)}{2}$$

$$M_{max} = \frac{q}{2}\left(\frac{L^2}{4} - a^2\right)$$

$$Total\ Max\ Moment = \frac{PL}{4} + \frac{q}{2}\left(\frac{L^2}{4} - a^2\right)$$

Fig. 3.3 Loading Arrangement of Beam

3.3 Theoretical Analysis of Truss

Here, method of joint was used in the analysis of the warren truss. In this method, the equilibrium of all the joints was considered. Only two equations of static equilibrium, $\sum f_x$ *and* $\sum f_y$ were used. The analysis starts with the joint having not more than two unknown forces. The analysis continues till all the forces in all the members of the truss are gotten. Tables 4.25, 4.26 and 4.27 show the results gotten from this analysis.

3.4 Computer Program of Truss Analysis

Java programing language was used in the truss analysis. Figure 3.4 shows java programing animation. The two strollers at top right are used to adjust the diagonal bars spacing and the truss height. When these two are adjusted the followings are generated: the number of bays; the angle the diagonal bars make with the horizontal; the point loads and the reactions at the supports. These changes will end up generating forces in the truss members as shown in Table 3.4. This java program can be used to generate member forces and point loads at the nodes for any spacing and height within the range of 1000mm span with the aid of polynomial (y = 0.0288x + 1.1067) generated from the graph of spacing against point load. The member forces generated from this computer program are shown in Tables 4.28, 4.29 and 4.30. The flow chat for this truss analysis is shown in Figure 3.5.

3.4.1 Truss Analysis Program Animation

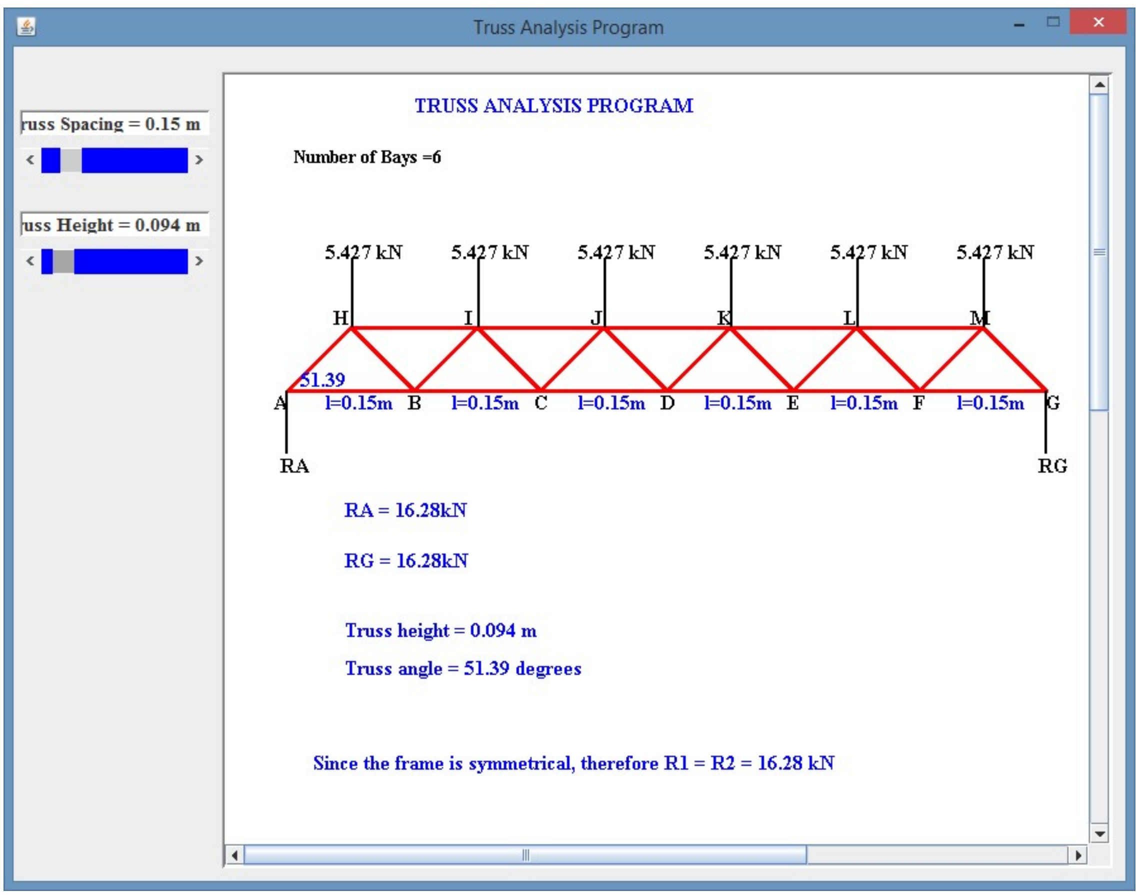
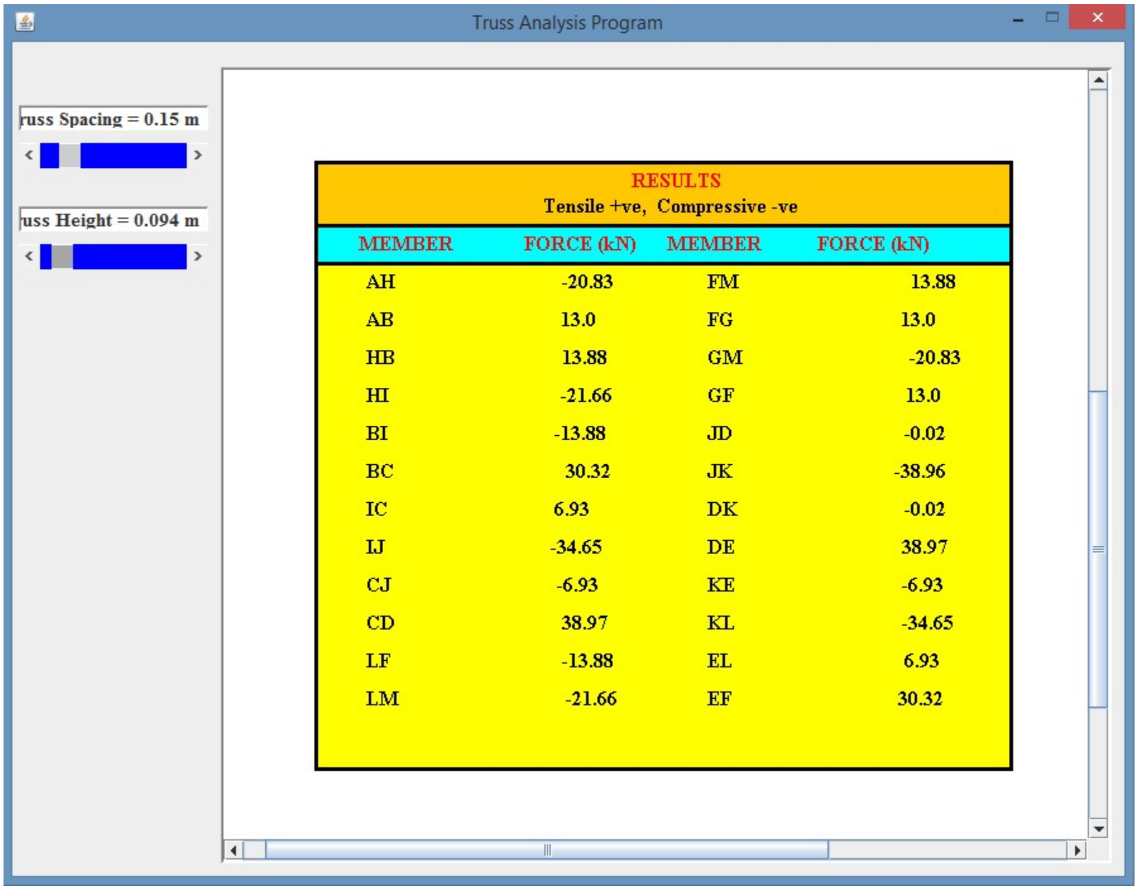


Table 3.4 Truss Program Animation Results



RESULTS

Tensile +ve, Compressive -ve

MEMBER	FORCE (kN)	MEMBER	FORCE (kN)
AH	-20.83	FM	13.88
AB	13.0	FG	13.0
HB	13.88	GM	-20.83
HI	-21.66	GF	13.0
BI	-13.88	JD	-0.02
BC	30.32	JK	-38.96
IC	6.93	DK	-0.02
IJ	-34.65	DE	38.97
CJ	-6.93	KE	-6.93
CD	38.97	KL	-34.65
LF	-13.88	EL	6.93
LM	-21.66	EF	30.32

3.4.2 Flow Chart of Computer Truss Analysis

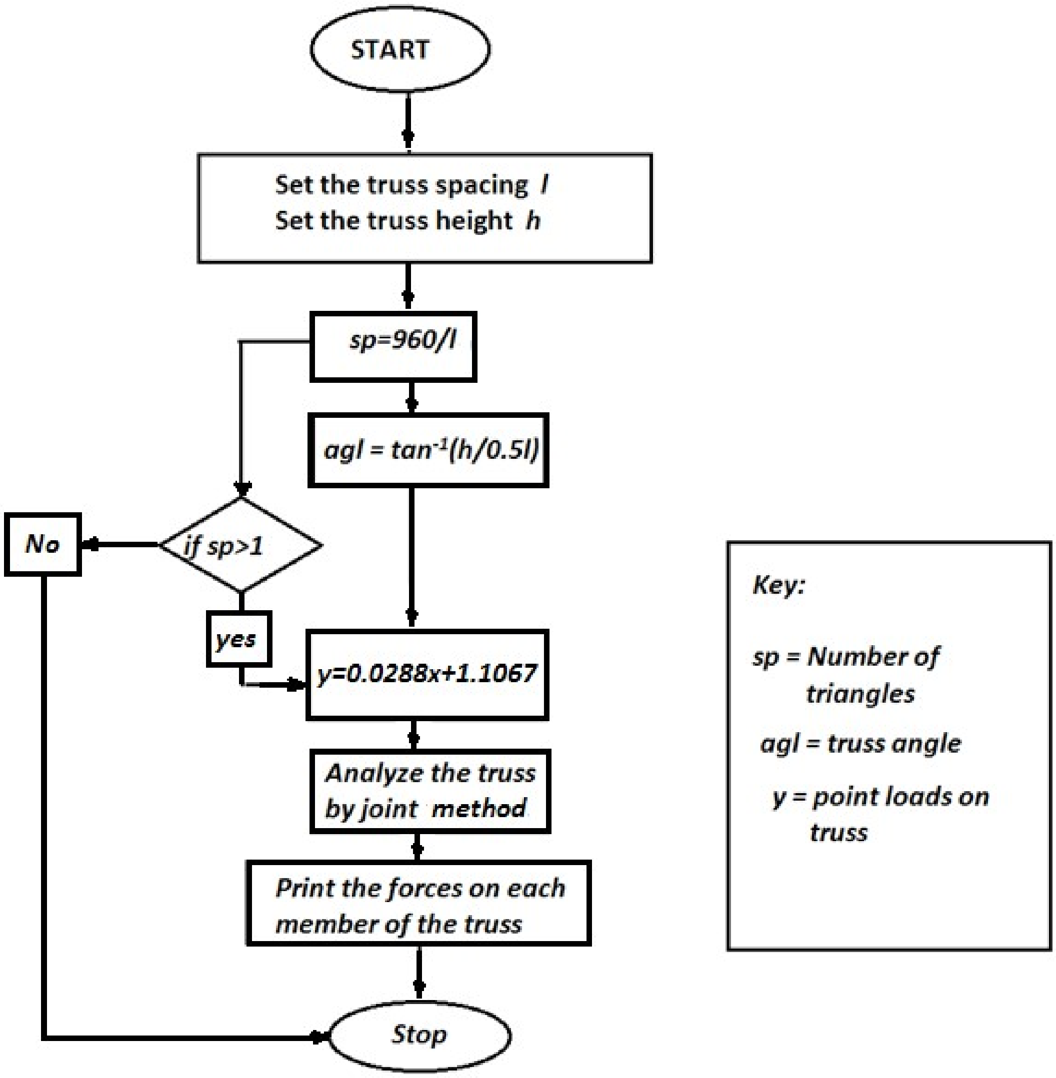


Figure 3.5 Flow Chat of Java Truss Analysis

3.4.3Computer Program Code for Truss Analysis

```
int ts = (int)(0.960/l);
else if (ts==4){
//g.drawLine(135,150,135,265);
```

```
double l2 =l;
 Font fb = new Font("Times New Roman",  Font.BOLD, 14);
g2.setFont(fb);
g2.drawString ("Number of Bays ="+(ts), 55, 70);
 Font fbj = new Font("Times New Roman",  Font.BOLD, 16);
g2.setFont(fbj);
//Draw the truss diagram
g2.setColor(Color.red);
Stroke drawingStrokef = new BasicStroke(3);
g2.setStroke(drawingStrokef);
g2.drawLine(100,200,400,200);
g2.drawLine(50,250,450,250);
g2.drawLine(50,250,100,200);
g2.drawLine(100,200,150,250);
g2.drawLine(150,250,200,200);
g2.drawLine(200,200,250,250);
g2.drawLine(250,250,300,200);
g2.drawLine(300,200,350,250);
g2.drawLine(350,250,400,200);
g2.drawLine(400,200,450,250);
double y = ((double)Math.round((((0.0288*l*1000)+1.1067) * 1000) / 1000);
//draw loads
// Change the colour to black
g2.setColor(Color.black);
```

```
// Draw the point load 1
int ss = (int)(y*10);
g2.fillRect(100,200-ss,2,0+ss);
g2.fillRect(200,200-ss,2,0+ss);
g2.fillRect(300,200-ss,2,0+ss);
g2.fillRect(400,200-ss,2,0+ss);
//Draw the supports reactions
//change the colour to black
g2.setColor(Color.black);
g2.fillRect(48,250,2,50);
g2.fillRect(449,250,2,50);
// Assign values to the loads
g2.drawString (""+(y)+" kN", 80, 200-ss);
g2.drawString (""+(y)+" kN", 180, 200-ss);
g2.drawString (""+(y)+" kN", 280, 200-ss);
g2.drawString (""+(y)+" kN", 380, 200-ss);
g2.drawString (" RA", 40, 315);
g2.drawString (" RG", 440, 315);
g2.drawString ("A", 39, 265);
 g2.drawString ("B", 145, 265);
 g2.drawString ("C", 245, 265);
g2.drawString ("D", 345, 265);
 g2.drawString ("E", 450, 265);
g2.drawString ("F", 86, 198);
```

```
g2.drawString ("G", 190, 198);

g2.drawString ("H", 290, 198);

g2.drawString ("I", 390, 198);

//change the colour to blue

g2.setColor(Color.blue);

g2.drawString ("l="+(l)+"m", 80, 265);

g2.drawString ("l="+(l)+"m", 180, 265);

g2.drawString ("l="+(l)+"m", 280, 265);

g2.drawString ("l="+(l)+"m", 380, 265);

double ag = ((double)Math.round(((Math.atan((gl/(l/2))))*(180/3.143)) * 100) /
100);

double agl = ((double)Math.round(((gl/(l/2))) * 100) / 100);

g2.drawString ("RA = "+((double)Math.round((((y*4)/2)) * 100) / 100)+"kN",
95, 350);

g2.drawString ("RG = "+((double)Math.round((((y*4)/2)) * 100) / 100)+"kN",
95, 390);

g2.drawString (""+(ag), 60, 247);

g2.drawString ("Truss height = "+(gl)+" m", 95, 445);

g2.drawString ("Truss angle = "+(ag)+" degrees", 95, 475);

double r1 = ((double)Math.round((((y*4)/2)) * 100) / 100);

double r2 = r1;

g2.drawString ("Since the frame is symmetrical, therefore R1 = R2 = "+
((double)Math.round((((y*4)/2)) * 100) / 100)+" kN", 70, 550);

//Draw the results Table

//Change the colour to orange

g2.setColor(Color.orange);
```

```
g2.fillRect(100,650,550,60);

g2.setColor(Color.red);

g2.drawString ("RESULTS", 350, 670);

g2.setColor(Color.black);

g2.drawString ("Tensile +ve,  Compressive -ve", 280, 690);

g2.setColor(Color.cyan);

g2.fillRect(100,700,550,30);

g2.setColor(Color.red);

g2.drawString (" MEMBER          FORCE (kN)     MEMBER          FORCE
(kN)", 130, 720);

//Change the colour to yellow

g2.setColor(Color.yellow);

g2.fillRect(100,730,550,330);

double aag= Math.toRadians(ag);

double af = ((double)Math.round((((-r1)/Math.sin(aag))) * 100) / 100);

double ab = ((double)Math.round((((-af*Math.cos(aag)))) * 100) / 100);

double bf = ((double)Math.round((((-y-(af*Math.sin(aag)))/(Math.sin(aag)))) *
100) / 100);

double fg = ((double)Math.round((((af*Math.cos(aag)))-(bf*Math.cos(aag))) *
100) / 100);

double bg = ((double)Math.round((((-bf*Math.sin(aag)))/(Math.sin(aag))) *
100) / 100);

double bc = ((double)Math.round(((ab+(bf*Math.cos(aag)))-
(bg*Math.cos(aag))) * 100) / 100);

double gc = ((double)Math.round((((-y-(bg*Math.sin(aag)))/(Math.sin(aag)))) *
100) / 100);
```

```
double gh = ((double)Math.round(((fg+(bg*Math.cos(aag)))-
(gc*Math.cos(aag))) * 100) / 100);

double ch =gc;

double cd =bc;

double hd =bg;

double hi =fg;

double di =bf;

double de =ab;

double ie =af;

//Change the colour to black

g2.setColor(Color.black);

g2.drawString ("          AF                    "+(af), 80, 750);

g2.drawString ("          AB                    "+(ab), 80, 780);

g2.drawString ("          FB                    "+(bf), 80, 810);

g2.drawString ("          FG                    "+(fg), 80, 840);

g2.drawString ("          BG                    "+(bg), 80, 870);

g2.drawString ("          BC                    "+(bc), 80, 900);

g2.drawString ("          GC                    "+(gc), 80, 930);

g2.drawString ("          GH                    "+(gh), 350, 930);

g2.drawString ("          CD                    "+(cd), 350, 750);

g2.drawString ("          HD                    "+(hd), 350, 780);

g2.drawString ("          HI                    "+(hi), 350, 810);

g2.drawString ("          DI                    "+(di), 350, 840);

g2.drawString ("          DE                    "+(de), 350, 870);

g2.drawString ("          IE                    "+(ie), 350, 900);
```

```
g2.drawLine(100,650,650,650);

g2.drawLine(100,700,650,700);

g2.drawLine(100,730,650,730);

g2.drawLine(100,1060,650,1060);

g2.drawLine(100,650,100,1060);

g2.drawLine(650,650,650,1060);

//Change the colour to blue

g2.setColor(Color.blue);

g2.drawString ("TRUSS ANALYSIS PROGRAM ", 150, 30);

 Font fbz = new Font("Times New Roman", Font.PLAIN , 16);

 g2.setFont(fbz);

//Change the colour to green

g2.setColor(Color.green);

g2.drawString("     (c) 2015, Paulibyte Technologies, All rights
reserved",10,1200);


//-----------------------------------------------------------------------------------

else if (ts==6){

//g.drawLine(135,150,135,265);

double l2 =l;

 Font fb = new Font("Times New Roman",  Font.BOLD, 14);

g2.setFont(fb);

g2.drawString ("Number of Bays ="+(ts), 55, 70);

 Font fbj = new Font("Times New Roman",  Font.BOLD, 16);

g2.setFont(fbj);
```

```
//Draw Truss diagram
g2.setColor(Color.red);
Stroke drawingStrokef = new BasicStroke(3);
g2.setStroke(drawingStrokef);
g2.drawLine(100,200,600,200);
g2.drawLine(50,250,650,250);
g2.drawLine(50,250,100,200);
g2.drawLine(100,200,150,250);
g2.drawLine(150,250,200,200);
g2.drawLine(200,200,250,250);
g2.drawLine(250,250,300,200);
g2.drawLine(300,200,350,250);
g2.drawLine(350,250,400,200);
g2.drawLine(400,200,450,250);
g2.drawLine(450,250,500,200);
g2.drawLine(500,200,550,250);
g2.drawLine(550,250,600,200);
g2.drawLine(600,200,650,250);

double y = ((double)Math.round((((0.0288*l*1000)+1.1067) * 1000) / 1000);
//draw loads
//Change the colour to black
g2.setColor(Color.black);
//Draw the point load 1
```

```
int ss = (int)(y*10);
g2.fillRect(100,200-ss,2,0+ss);
g2.fillRect(200,200-ss,2,0+ss);
g2.fillRect(300,200-ss,2,0+ss);
g2.fillRect(400,200-ss,2,0+ss);
g2.fillRect(500,200-ss,2,0+ss);
g2.fillRect(600,200-ss,2,0+ss);
//Draw the support reactions
//Change the colour to black
g2.setColor(Color.black);
g2.fillRect(48,250,2,50);
g2.fillRect(649,250,2,50);
// Assign values to the loads
g2.drawString (""+(y)+" kN", 80, 200-ss);
g2.drawString (""+(y)+" kN", 180, 200-ss);
g2.drawString (""+(y)+" kN", 280, 200-ss);
g2.drawString (""+(y)+" kN", 380, 200-ss);
g2.drawString (""+(y)+" kN", 480, 200-ss);
g2.drawString (""+(y)+" kN", 580, 200-ss);
g2.drawString (" RA", 40, 315);
g2.drawString (" RG", 640, 315);
g2.drawString ("A", 39, 265);
 g2.drawString ("B", 145, 265);
 g2.drawString ("C", 245, 265);
```

```
g2.drawString ("D", 345, 265);
 g2.drawString ("E", 445, 265);
 g2.drawString ("F", 545, 265);
 g2.drawString ("G", 650, 265);
g2.drawString ("H", 86, 198);
 g2.drawString ("I", 190, 198);
 g2.drawString ("J", 290, 198);
g2.drawString ("K", 390, 198);
 g2.drawString ("L", 490, 198);
g2.drawString ("M", 590, 198);
//Change the colour to blue
g2.setColor(Color.blue);
g2.drawString ("l="+(l)+"m", 80, 265);
 g2.drawString ("l="+(l)+"m", 180, 265);
 g2.drawString ("l="+(l)+"m", 280, 265);
g2.drawString ("l="+(l)+"m", 380, 265);
 g2.drawString ("l="+(l)+"m", 480, 265);
g2.drawString ("l="+(l)+"m", 580, 265);
double ag = ((double)Math.round(((Math.atan((gl/(l/2))))*(180/3.143)) * 100) /
100);
double agl = ((double)Math.round(((gl/(l/2))) * 100) / 100);
g2.drawString ("RA = "+((double)Math.round((((y*6)/2)) * 100) / 100)+"kN",
95, 350);
g2.drawString ("RG = "+((double)Math.round((((y*6)/2)) * 100) / 100)+"kN",
95, 390);
```

```
g2.drawString (""+(ag), 60, 247);

g2.drawString ("Truss height = "+(gl)+" m", 95, 445);

g2.drawString ("Truss angle = "+(ag)+" degrees", 95, 475);

double r1 = ((double)Math.round((((y*6)/2)) * 100) / 100);

double r2 = r1;

g2.drawString ("Since the frame is symmetrical, therefore R1 = R2 = "+
((double)Math.round((((y*6)/2)) * 100) / 100)+" kN", 70, 550);

//Draw the results Table

//Change the colour to orange

g2.setColor(Color.orange);

g2.fillRect(100,650,550,60);

g2.setColor(Color.red);

g2.drawString ("RESULTS", 350, 670);

g2.setColor(Color.black);

g2.drawString ("Tensile +ve,  Compressive -ve", 280, 690);

g2.setColor(Color.cyan);

g2.fillRect(100,700,550,30);

g2.setColor(Color.red);

g2.drawString (" MEMBER            FORCE (kN)     MEMBER          FORCE
(kN)", 130, 720);

//Change the colour to yellow

g2.setColor(Color.yellow);

g2.fillRect(100,730,550,400);

double aag= Math.toRadians(ag);

double ah = ((double)Math.round((((-r1)/Math.sin(aag))) * 100) / 100);
```

```
double ab = ((double)Math.round(((-(ah*Math.cos(aag)))) * 100) / 100);

double hb = ((double)Math.round((((-y-(ah*Math.sin(aag)))/Math.sin(aag))) *
100) / 100);

double hi = ((double)Math.round((((ah*Math.cos(aag))-(hb*Math.cos(aag)))) *
100) / 100);

double bi = ((double)Math.round((((-hb*Math.sin(aag)))/(Math.sin(aag))) *
100) / 100);

double bc = ((double)Math.round(((ab+(hb*Math.cos(aag))-
(bi*Math.cos(aag)))) * 100) / 100);

double ic = ((double)Math.round((((-y-(bi*Math.sin(aag)))/(Math.sin(aag)))) *
100) / 100);

double ij = ((double)Math.round(((hi+(bi*Math.cos(aag)))-(ic*Math.cos(aag)))
* 100) / 100);

double cj = ((double)Math.round((((-ic*Math.sin(aag)))/(Math.sin(aag))) * 100)
/ 100);

double cd = ((double)Math.round(((bc+(ic*Math.cos(aag)))-(cj*Math.cos(aag)))
* 100) / 100);

double lf =bi;

double lm =hi;

double fm = hb;

double fg = ab;

double gm = ah;

double gf = ab;

double jd = ((double)Math.round(((-y-(cj*Math.sin(aag)))/(Math.sin(aag))) *
100) / 100);

double jk = ((double)Math.round(((ij+(cj*Math.cos(aag)))-(jd*Math.cos(aag)))
* 100) / 100);

double dk =jd;
```

```
double de = cd;
double ke = cj;
double kl = ij;
double el = ic;
double ef = bc;
//Change the colour to black
g2.setColor(Color.black);
g2.drawString ("          AH                   "+(ah), 80, 750);
g2.drawString ("          AB                   "+(ab), 80, 780);
g2.drawString ("          HB                   "+(hb), 80, 810);
g2.drawString ("          HI                   "+(hi), 80, 840);
g2.drawString ("          BI                   "+(bi), 80, 870);
g2.drawString ("          BC                   "+(bc), 80, 900);
g2.drawString ("          IC                   "+(ic), 80, 930);
g2.drawString ("          IJ                   "+(ij), 80, 960);
g2.drawString ("          CJ                   "+(cj), 80, 990);
g2.drawString ("          CD                   "+(cd), 80, 1020);
g2.drawString ("          LF                   "+(lf), 80, 1050);
g2.drawString ("          LM                   "+(lm), 80, 1080);
g2.drawString ("          FM                   "+(fm), 350, 750);
g2.drawString ("          FG                   "+(fg), 350, 780);
g2.drawString ("          GM                   "+(gm), 350, 810);
g2.drawString ("          GF                   "+(gf), 350, 840);
g2.drawString ("          JD                   "+(jd), 350, 870);
```

```
g2.drawString ("            JK                              "+(jk), 350, 900);
g2.drawString ("            DK                                "+(dk), 350, 930);
g2.drawString ("            DE                               "+(de), 350, 960);
g2.drawString ("            KE                               "+(ke), 350, 990);
g2.drawString ("            KL                               "+(kl), 350, 1020);
g2.drawString ("            EL                                "+(el), 350, 1050);
g2.drawString ("            EF                              "+(ef), 350, 1080);
g2.drawLine(100,650,650,650);
g2.drawLine(100,700,650,700);
g2.drawLine(100,730,650,730);
g2.drawLine(100,1130,650,1130);
g2.drawLine(100,650,100,1130);
g2.drawLine(650,650,650,1130);
//Change the colour to blue
g2.setColor(Color.blue);
g2.drawString ("TRUSS ANALYSIS PROGRAM ", 150, 30);
 Font fbz = new Font("Times New Roman", Font.PLAIN , 16);
 g2.setFont(fbz);
//Change the colour to green
g2.setColor(Color.green);
g2.drawString("     (c) 2015, Paulibyte Technologies, All rights
reserved",10,1200);
//…………………………………………………………….................
else if (ts==9){
//g.drawLine(135,150,135,265);
```

```
double l2 =l;
 Font fb = new Font("Times New Roman",  Font.BOLD, 14);
g2.setFont(fb);
g2.drawString ("Number of Bays ="+(ts), 55, 70);
 Font fbj = new Font("Times New Roman",  Font.BOLD, 16);
g2.setFont(fbj);
//Draw Truss diagram
//Change the colour to red
g2.setColor(Color.red);
Stroke drawingStrokef = new BasicStroke(3);
g2.setStroke(drawingStrokef);
g2.drawLine(100,200,900,200);
g2.drawLine(50,250,950,250);
g2.drawLine(50,250,100,200);
g2.drawLine(100,200,150,250);
g2.drawLine(150,250,200,200);
g2.drawLine(200,200,250,250);
g2.drawLine(250,250,300,200);
g2.drawLine(300,200,350,250);
g2.drawLine(350,250,400,200);
g2.drawLine(400,200,450,250);
g2.drawLine(450,250,500,200);
g2.drawLine(500,200,550,250);
g2.drawLine(550,250,600,200);
```

```
g2.drawLine(600,200,650,250);
g2.drawLine(650,250,700,200);
g2.drawLine(700,200,750,250);
g2.drawLine(750,250,800,200);
g2.drawLine(800,200,850,250);
g2.drawLine(850,250,900,200);
g2.drawLine(900,200,950,250);
double y = ((double)Math.round((((0.0288*l*1000)+1.1067) * 1000) / 1000);
//draw the loads
//Change the olour to black
g2.setColor(Color.black);
//Draw the point load 1
int ss = (int)(y*10);
g2.fillRect(100,200-ss,2,0+ss);
g2.fillRect(200,200-ss,2,0+ss);
g2.fillRect(300,200-ss,2,0+ss);
g2.fillRect(400,200-ss,2,0+ss);
g2.fillRect(500,200-ss,2,0+ss);
g2.fillRect(600,200-ss,2,0+ss);
g2.fillRect(700,200-ss,2,0+ss);
g2.fillRect(800,200-ss,2,0+ss);
g2.fillRect(900,200-ss,2,0+ss);
//Draw the support reactions
//Change the colour to black
```

```
g2.setColor(Color.black);
g2.fillRect(48,250,2,50);
g2.fillRect(949,250,2,50);
//Assign values to the loads
g2.drawString (""+(y)+" kN", 80, 200-ss);
g2.drawString (""+(y)+" kN", 180, 200-ss);
g2.drawString (""+(y)+" kN", 280, 200-ss);
g2.drawString (""+(y)+" kN", 380, 200-ss);
g2.drawString (""+(y)+" kN", 480, 200-ss);
g2.drawString (""+(y)+" kN", 580, 200-ss);
g2.drawString (""+(y)+" kN", 680, 200-ss);
g2.drawString (""+(y)+" kN", 780, 200-ss);
g2.drawString (""+(y)+" kN", 880, 200-ss);
g2.drawString (" RA", 40, 315);
g2.drawString (" RG", 940, 315);
g2.drawString ("J", 39, 265);
 g2.drawString ("K", 145, 265);
 g2.drawString ("L", 245, 265);
g2.drawString ("M", 345, 265);
 g2.drawString ("N", 445, 265);
 g2.drawString ("O", 545, 265);
 g2.drawString ("P", 645, 265);
 g2.drawString ("Q", 745, 265);
 g2.drawString ("R", 845, 265);
```

```
g2.drawString ("S", 950, 265);
g2.drawString ("A", 86, 198);
g2.drawString ("B", 190, 198);
g2.drawString ("C", 290, 198);
g2.drawString ("D", 390, 198);
g2.drawString ("E", 490, 198);
g2.drawString ("F", 590, 198);
g2.drawString ("G", 690, 198);
g2.drawString ("H", 790, 198);
g2.drawString ("I", 890, 198);
//Change the colour to blue
g2.setColor(Color.blue);
g2.drawString ("l="+(l)+"m", 80, 265);
g2.drawString ("l="+(l)+"m", 180, 265);
g2.drawString ("l="+(l)+"m", 280, 265);
g2.drawString ("l="+(l)+"m", 380, 265);
g2.drawString ("l="+(l)+"m", 480, 265);
g2.drawString ("l="+(l)+"m", 580, 265);
g2.drawString ("l="+(l)+"m", 680, 265);
g2.drawString ("l="+(l)+"m", 780, 265);
g2.drawString ("l="+(l)+"m", 880, 265);
double ag = ((double)Math.round(((Math.atan((gl/(l/2))))*(180/3.143)) * 100) /
100);
double agl = ((double)Math.round(((gl/(l/2))) * 100) / 100);
```

```
g2.drawString ("RA = "+((double)Math.round((((y*9)/2)) * 100) / 100)+"kN",
95, 350);

g2.drawString ("RG = "+((double)Math.round((((y*9)/2)) * 100) / 100)+"kN",
95, 390);

g2.drawString (""+(ag), 60, 247);

g2.drawString ("Truss height = "+(gl)+" m", 95, 445);

g2.drawString ("Truss angle = "+(ag)+" degrees", 95, 475);

double r1 = ((double)Math.round((((y*9)/2)) * 100) / 100);

double r2 = r1;

g2.drawString ("Since the frame is symmetrical, therefore R1 = R2 = "+
((double)Math.round((((y*9)/2)) * 10000) / 10000)+" kN", 70, 550);

//Draw the results Table

//Change the colour to orange

g2.setColor(Color.orange);

g2.fillRect(100,650,550,60);

g2.setColor(Color.red);

g2.drawString ("RESULTS", 350, 670);

g2.setColor(Color.black);

g2.drawString ("Tensile +ve,  Compressive -ve", 280, 690);

g2.setColor(Color.cyan);

g2.fillRect(100,700,550,30);

g2.setColor(Color.red);

g2.drawString (" MEMBER            FORCE (kN)      MEMBER          FORCE
(kN)", 130, 720);

//Chaange the colour to yellow

g2.setColor(Color.yellow);
```

```
g2.fillRect(100,730,550,570);

double aag= Math.toRadians(ag);

double aj = ((double)Math.round((((-r1)/Math.sin(aag))) * 100) / 100);

double jk = ((double)Math.round(((-(aj*Math.cos(aag)))) * 100) / 100);

double ak = ((double)Math.round((((-y-(aj*Math.sin(aag))/Math.sin(aag)))) *
100) / 100);

double ab = ((double)Math.round((((aj*Math.cos(aag))-(ak*Math.cos(aag)))) *
100) / 100);

double kb = ((double)Math.round((((-ak*Math.sin(aag))/Math.sin(aag))) * 100)
/ 100);

double kl = ((double)Math.round(((jk+(ak*Math.cos(aag))-
(kb*Math.cos(aag)))) * 100) / 100);

double bl = ((double)Math.round((((-y-(kb*Math.sin(aag))/Math.sin(aag)))) *
100) / 100);

double bc = ((double)Math.round((((ab+(kb*Math.cos(aag)))-
(bl*Math.cos(aag)))) * 100) / 100);

double lc = ((double)Math.round((((-bl*Math.sin(aag))/(Math.sin(aag)))) * 100)
/ 100);

double lm = ((double)Math.round(((kl+(bl*Math.cos(aag))-(lc*Math.cos(aag))))
* 100) / 100);

//double cm = ((double)Math.round(((-y-(lc*Math.sin(aag)))/(Math.sin(aag))) *
100) / 100);

double cm = ((double)Math.round((((-y-(lc*Math.sin(aag)))/(Math.sin(aag)))) *
100) / 100);

double cd = ((double)Math.round(((bc+(lc*Math.cos(aag))-
(cm*Math.cos(aag)))) * 100) / 100);

double md = ((double)Math.round((((-cm*Math.sin(aag))/(Math.sin(aag)))) *
100) / 100);
```

```
double mn = ((double)Math.round(((lm+(cm*Math.cos(aag)))-
(md*Math.cos(aag))) * 100) / 100);

double dn = ((double)Math.round(((-y-(md*Math.sin(aag)))/(Math.sin(aag))) *
100) / 100);

double de = ((double)Math.round(((cd+(md*Math.cos(aag)-
(dn*Math.cos(aag))))) * 100) / 100);

double ne = ((double)Math.round((((-dn*Math.sin(aag))/(Math.sin(aag)))) *
100) / 100);

double no = ((double)Math.round(((mn+(dn*Math.cos(aag))-
(ne*Math.cos(aag)))) * 100) / 100);

double eo = ((double)Math.round(((-y-(ne*Math.sin(aag)))/(Math.sin(aag))) *
100) / 100);

double ef = de;

double of = dn;

double op = mn;

double fp = md;

double fg = cd;

double pg = cm;

double pq = lm;

double gq = lc;

double gh = bc;

double qh = bl;

double qr = kl;

double hr = kb;

double hi =ab;

double ri =ak;

double rs = jk;
```

```
double is =aj;

double sr =jk;

//Change the colour to black

g2.setColor(Color.black);

g2.drawString ("            AJ                          "+(Math.round((aj)*100)/100),
80, 750);

g2.drawString ("            JK                          "+(jk), 80, 780);

g2.drawString ("            AK                          "+(ak), 80, 810);

g2.drawString ("            AB                          "+(ab), 80, 840);

g2.drawString ("            KB                          "+(kb), 80, 870);

g2.drawString ("            KL                          "+(kl), 80, 900);

g2.drawString ("            BL                          "+(bl), 80, 930);

g2.drawString ("            BC                          "+(bc), 80, 960);

g2.drawString ("            LC                          "+(lc), 80, 990);

g2.drawString ("            LM                          "+(lm), 80, 1020);

g2.drawString ("            CM                          "+(cm), 80, 1050);

g2.drawString ("            CD                          "+(cd), 80, 1080);

g2.drawString ("            MD                          "+(md), 80, 1110);

g2.drawString ("            MN                          "+(mn), 80, 1130);

g2.drawString ("            DN                          "+(dn), 80, 1160);

g2.drawString ("            DE                          "+(de), 80, 1190);

g2.drawString ("            NE                          "+(ne), 80, 1220);

g2.drawString ("            NO                          "+(no), 80, 1250);

g2.drawString ("            EO                          "+(eo), 350, 750);

g2.drawString ("            EF                          "+(ef), 350, 780);
```

```
g2.drawString ("            OF                              "+(of), 350, 810);
g2.drawString ("            OP                              "+(op), 350, 840);
g2.drawString ("            FP                              "+(fp), 350, 870);
g2.drawString ("            FG                              "+(fg), 350, 900);
g2.drawString ("            PG                              "+(pg), 350, 930);
g2.drawString ("            PQ                              "+(pq), 350, 960);
g2.drawString ("            GQ                              "+(gq), 350, 990);
g2.drawString ("            GH                              "+(gh), 350, 1020);
g2.drawString ("            QH                              "+(qh), 350, 1050);
g2.drawString ("            QR                              "+(qr), 350, 1080);
g2.drawString ("            HR                              "+(hr), 350, 1110);
g2.drawString ("            HI                              "+(hi), 350, 1130);
g2.drawString ("            RI                              "+(ri), 350, 1160);
g2.drawString ("            RS                              "+(rs), 350, 1190);
g2.drawString ("            IS                              "+(is), 350, 1220);
g2.drawString ("            SR                              "+(sr), 350, 1250);
g2.drawLine(100,650,650,650);
g2.drawLine(100,700,650,700);
g2.drawLine(100,730,650,730);
g2.drawLine(100,1300,650,1300);
g2.drawLine(100,650,100,1300);
g2.drawLine(650,650,650,1300);
g2.setColor(Color.blue);
g2.drawString ("TRUSS ANALYSIS PROGRAM ", 150, 30);
```

```
 Font fbz = new Font("Times New Roman", Font.PLAIN , 16);

 g2.setFont(fbz);

//Change the colour to green

g2.setColor(Color.green);

g2.drawString("     (c) 2015, Paulibyte Technologies, All rights
reserved",10,1400);

//-------------------------------------------------------------------------------------

else {

 Font fbz = new Font("Times New Roman", Font.PLAIN , 30);

 g2.setFont(fbz);

//Change the colour to blue

g2.setColor(Color.blue);

g2.drawString ("TRUSS ANALYSIS PROGRAM ", 150, 100);

g2.drawString ("SELECTED VALUES OUT OF RANGE ", 150, 150);

   public static void main (String[] args) {

      JFrame frame = new JFrame ("SliderT3");

      frame.setDefaultCloseOperation (JFrame.EXIT_ON_CLOSE);

      frame.getContentPane().add (new SliderT3());

      frame.pack();

      frame.setVisible (true);
```

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. Material Test Results

4.1.1 Specific Gravity of Aggregates

The result of the specific gravity test is shown in Table 4.1. The specific gravity of river sand is 2.603. That ofgranite is 2.673. The specific gravity of most natural (normal weight) aggregates ranges between 2.4 – 2.7 (see Road Research (1959). This means that the river sand andgranite can be classified as natural aggregates.

Table 4.1 Specific Gravity of River Sand and Granite

Material	River Sand			Granite		
Bottle Number	A	B	C	A	B	C
Mass of sample used (g)	800	800	800	800	800	800
Volume of sample	307	310	305	300	298	300
Specific Gravity of Sample $= \frac{(Mass\ of\ Sample)}{Volume\ of\ sample)}$	2.606	2.581	2.623	2.67	2.68	2.67
Average Specific Gravity	2.603			2.673		

4.1.2 Bulk Density of Granite

The bulk density of the river sand and granite is shown in Tables 4.2. The mean compacted bulk density of the river sand and granite are1668.6Kg/m^{3}and 1449.01Kg/m^3 respectively. These values are far within the range specified by BS 3681 (1963) which gave the minimum bulk density of fine and coarse aggregate to be 1200 Kg/m^3 for fine aggregates and 960 Kg/m^3. Therefore, the aggregates used in this research work are in agreement with the given standard and can be classified as normal weight aggregates.

Table 4.2 Bulk Density of River Sand and Granite

Material	River Sand			Granite		
	A	B	C	A	B	C
Volume of Mould (cm^3)	1178	1178	1178	1178	1178	1178
Mass of Empty Mould, W_{tool} (g)	1770	1770	1770	1770	1770	1770
Mass of Mould + Sample, W_1 (g)	3740	3732	3735	3473	3480	3478
Average Mass of Sample, W_1-W_{tool} (g)	3735.7			3477.0		
Bulk Density (Kg/m^3)	1668.6			1449.01		

4.1.3 Water Absorption

The result of the water of absorption is shown in Table 4.3. The mean value of the water absorption of the river sand is 0.9% while that of granite is 0.11%. This value is within the range of values determined for different aggregates of different sizes by Newman (1959). This corresponds to a known fact that granite chippings have small pores sizes. Generally, aggregate material with low porosity will produce a strong and durable concrete.

Table 4.3 Water Absorption of River Sand and Granite

Material	River sand			Granite		
	A	B	C	A	B	C
Mass Before Test (g)	1000	1000	1000	1000	1000	1000
Mass After Test (g)	1008	1010.1	1009	1001	1001.2	1001.1
Mass of Absorbed Water (g)	8.0	10.1	9.0	1.0	1.2	1.1
Water Absorption (%)	0.8	1.0	0.9	0.1	0.12	0.11
Mean Water Absorption (%)	0.9			0.11		

4.1.4 Void Ratio

Void ratio was calculated from the mean values of the bulk density and specific gravity of the granite. The result is shown in Table 4.4.This means that void occupies more volume than the solid matter. Hence, moderate volume of filler (a mixture of cement paste and sand otherwise called mortar) will be required in a concrete mix using granite as coarse aggregate

Table 4.4 Void Ratio of River Sand and Granite

Material	River Sand	Granite
Specific Gravity of Sample	2.603	2.673
Relative Density of Sample	1.669	1.449
Void Ratio	0.359	0.458

4.1.5 Impact Value

The result of the impact value of granite is shown in Table 4.5. The mean value is 20.75.23%. BS 882 (1973) and BS 812 (1975) specified maximum values of 30% and 45% for aggregates to be used in road surfacing and other concrete works respectively. This means that granite can be used to make concrete for any pavement structure. Thus the value is good.

Table 4.5 Impact Value of Granite (Aggregate Size 10mm – 19mm)

Sieve size (mm)	Mass passing (g)	Mass retained (g)	Mass bigger than 2.00mm (g)
13.2	500	0	-
9.50	241	259	259
2.00	89	170	432
RECEIVER	0	89	-

$$\text{LA Abrasion Number} = \frac{(mass\ smaller\ than\ 2.00)}{(mass\ bigger\ than\ 2.00)} \times 100$$

$$= \frac{89}{429} \times 100 \quad = 20.75\%$$

4.1.6 Abrasion Value

The abrasion value of the graniteis 39.66%. The result can be seen in Table 4.6. ASTM C131 (2003) gave a Los Angeles Abrasion value of less than 30% for any aggregate suitable for all forms concreting operation. Fromthe result of Table 4.6, the granite used for this research work is suitable for structural concreting work.

Table 4.6 Abrasion value of SSDGranite

Sieve size (mm)	Mass passing (g)	Mass retained (g)	Mass bigger than 2.00mm (g)
13.2	500	0	-
9.50	287	213	213
2.00	142	145	358
RECEIVER	0	142	-

$$\text{LA Abrasion Number} = \frac{(mass\ smaller\ than\ 2.00)}{(mass\ bigger\ than\ 2.00)} \times 100$$

$$= \frac{142}{358} \times 100 \quad = 39.66\%$$

4.1.7 Sieve Analysis

The result of the sieve analysis of river sand can be seen inTable 4.7 and Figure 4.1. These show that the grading of theriver sandfell in the range of 150µmm – 6.7mm and zone 2 of the grading curve.

Table 4.7 Sieve Analysis of River Sand

BS Sieve Size	Mass Retained (g)	Cumulative Mass Retained (g)	Cumulative % Mass Retained	Cumulative % Passing
10mm	0	0	0	100
6.7mm	23	23	4.75	95.25
4.75mm	11	34	7.02	92.98
2.36mm	27	61	12.60	87.40
1.18mm	44	105	21.69	78.31
600µ	112	217	44.83	55.17
425µ	81	298	61.57	38.43
300µ	97	395	81.61	18.39
212µ	59	454	93.8	6.2
150µ	21	475	98.14	1.86
75µ	9	484	100.00	0.00
Pan	16	-	-	-
Total	1000		525.41	

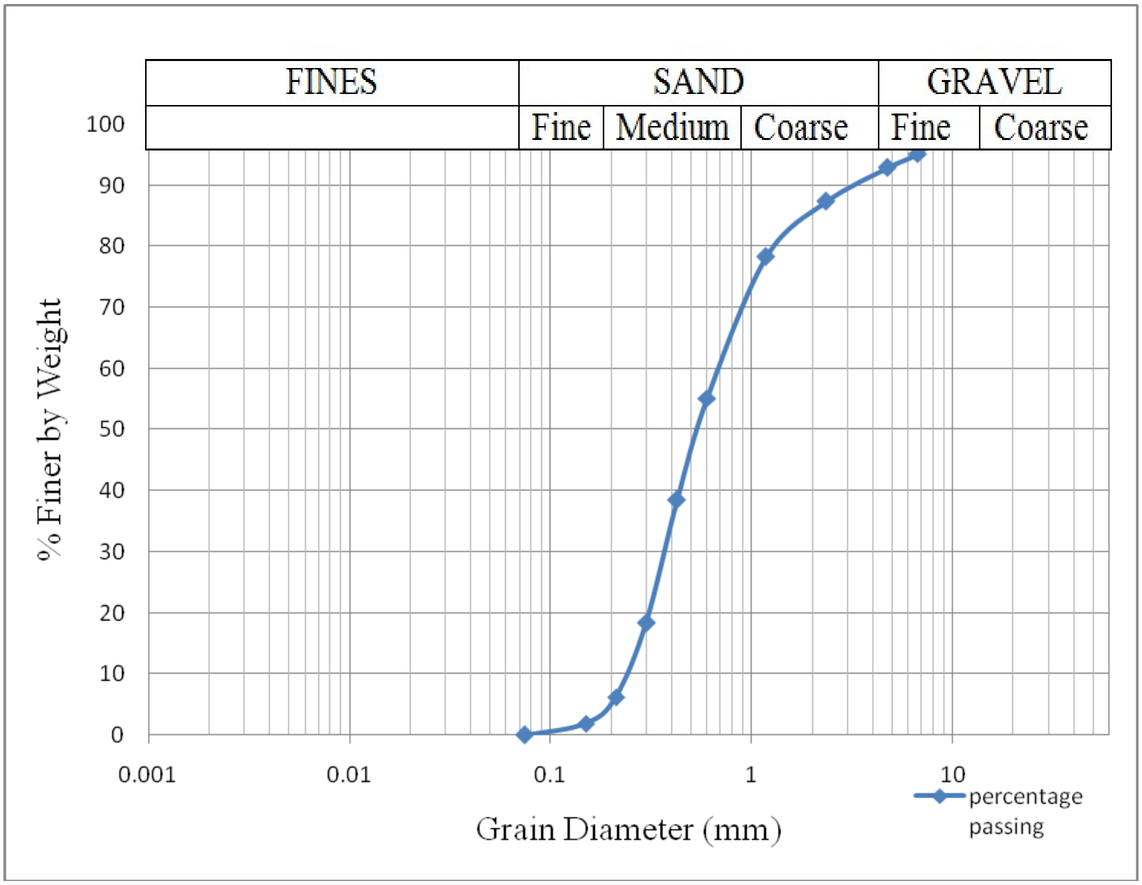


Figure 4.1 Grain Size Distribution of River Sand

The result of the sieve analysis of granite can be seen in Table 4.8. From the table, a graph for grain size distribution is plotted as shown in Figure 4.2.These show that the grading of sandstone fell in the range of 9.5mm – 25mm and zone 3 of the grading curve.

Table 4.8Sieve Analysis of Granite

BS sieve size	Mass retained (g)	Cumulative mass retained(g)	Cumulative % mass retained	Cumulative % passing
37.5mm	0	0	0	100
25mm	613	613	12.26	87.74
19mm	1695	2308	46.16	53.84
13.5mm	1174	3482	69.64	30.36
9.5mm	711	4193	83.86	16.14
6.7mm	364	4557	91.14	8.86
4.75mm	236	4793	95.86	4.14
2.36mm	146	4939	98.78	1.22
1.18mm	54	4993	99.86	0.14
Pan	7	-	-	-
TOTAL	5000		597.56	

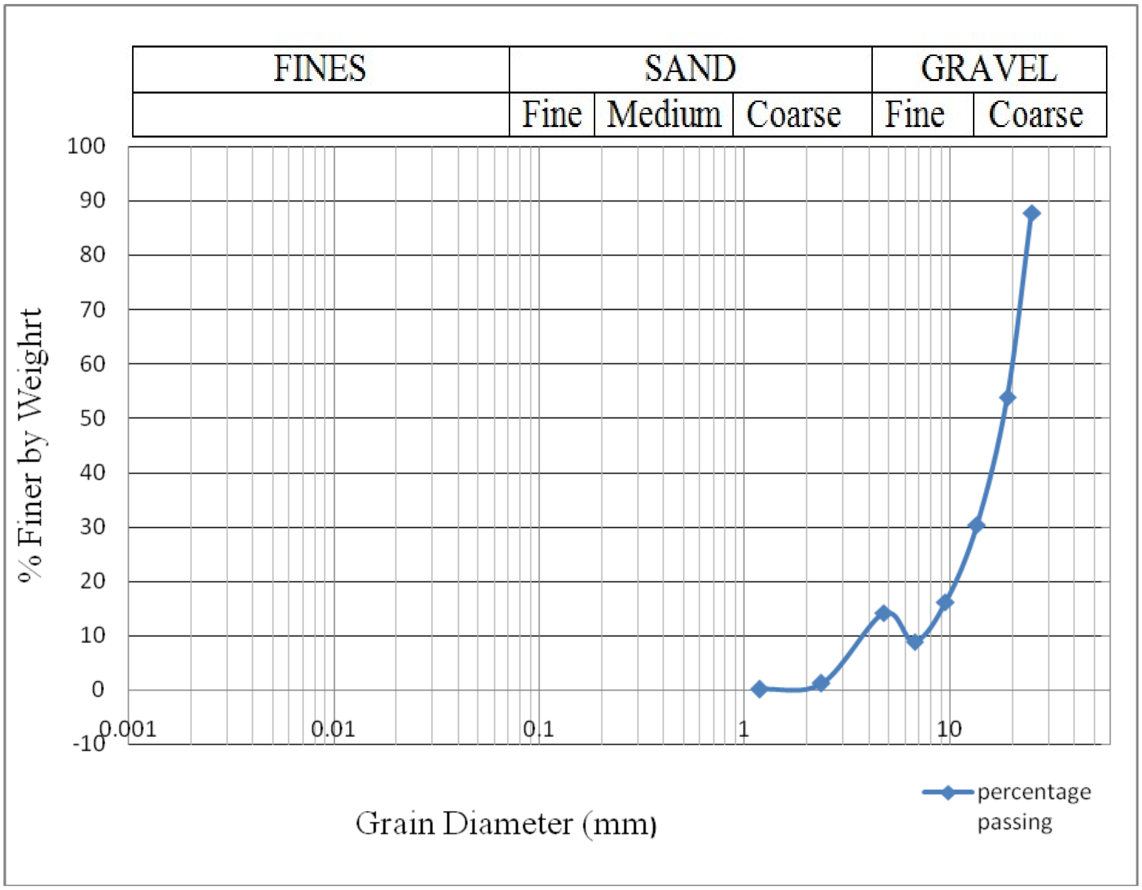


Figure 4.2 Grain Size Distribution of Granite

Table 4.9 presents a summary of the results obtained for coefficient of uniformity, coefficient of curvature and fineness modulus obtained for the different concrete aggregates used in the experiment.BS 812 (1975) gave values for coefficient of uniformity and curvature of a well graded aggregate as greater than 4.0 and 1.0 - 3.0 respectively. It can be deduced that the fine aggregate (river sand) used in this research work is poorly graded while the coarse aggregate (granite) is well graded.

Table 4.9 Coefficient of Uniformity and Fineness Modulus of Aggregates

Tested Samples	D10	D30	D60	Cu = $\frac{D_{60}}{D_{10}}$	Cc = $\frac{D_{30}{}^2}{D_{60}*D_{10}}$	Fineness Modulus
River Sand	0.25	0.37	0.68	2.72	0.81	5.25
Granite	3.80	14.50	20.10	5.29	2.75	5.98

4.1.8 Slump Test Result

Table 4.10 presents the slump values of the three different mix ratios, an optimum value of 13mm was obtained for the granite concrete at a mix ratio of 0.5:1:2:4. The least value of 5mm was achieved with 0.6:1:3:6 mix.

Table 4.10 Slump of Granite Concrete Mixes

S/N	Mix Ratio	Slum Value (mm)
1	0.5:1:2:4	7
2	0.55:1:2.5:5	5
3	0.6:1:3:6	3

4.2 Reinforced Concrete Test Results

4.2.1 Compressive Strength of Concrete Cubes at 28 days

Table 4.11 shows the various masses, loads, average loads, compressive strengths and average compressive strengths of cubes after 28 days strength

Table 4.11Results obtained from crushing concrete cubes at 28 days.

Test no	Sample	Mass (kg)	Load (n)	Average load (N)	Compressive strength (N/mm^2)	Average compressive Strength (N/mm^2)
1 and 4	1A	7.8	430.00		38.22	
	1B	7.4	393.82	375.69	35.01	33.40
	1C	7.8	303.26		26.96	
2 and 5	2A	6.5	360.00		32.00	
	2B	6.7	146.42	214.13	13.02	19.04
	2C	6.8	135.98		12.09	
3 and 6	3A	7.1	100.00		8.92	
	3B	7.2	295.27	157.45	26.25	14.00
	3C	6.9	77.07		6.85	

From the result obtained the densities were calculated. Table 4.12 shows the average density and compressive strength of concrete cubes at 28 days.

Table 4.12 Average density and compressive strength of concrete cubes at 28 days.

Test no	Mass (kg)	Density (Kg/m^3)	Load (KN)	Compressive strength (N/mm^2)
1 and 4	7.67	2271.60	375.69	33.40
2 and 5	6.67	1975.31	214.13	19.04
3 and 6	7.07	2093.82	157.46	14.00

4.2.2Flexural Strength Test on Beam at 28 days

The failure loads and self-weight of beams at 28 days are as shown in Tables 4.13, 4.14 and 4.15 for 100mm, 150mm and 200mm spacing respectively.

The calculations of thebeam loading are shown in Appendix C.

Table 4.13Failure loads and self-weight of beam at 28 days for 100mm spacing.

Test No	Pressure from the scale (N/mm^2)	Load, p (KN)	Average load, p (KN)	Unit wt of beam (KN/m^3)	Self wt of beam,q (KN/m)	Average self wt of beam, q (KN/m)
1	6.9	65.58	69.38	23.10	0.52	0.51
	6.6	62.73		21.92	0.49	
	8.4	79.83		23.10	0.52	
2	6.2	58.93	55.13	19.25	0.43	0.44
	6.2	58.93		19.84	0.45	
	5.0	47.52		20.14	0.45	
3	5.8	55.13	50.06	21.03	0.47	0.47
	5.4	51.32		21.32	0.48	
	4.6	43.72		20.44	0.46	
4	6.8	64.63	57.66	24.58	0.55	0.52
	5.0	47.52		22.51	0.51	
	6.4	60.83		22.21	0.50	
5	4.6	43.72	48.59	23.69	0.53	0.49
	4.4	41.82		22.51	0.51	
	6.6	60.22		19.25	0.43	
6	5.8	55.13	47.84	21.92	0.49	0.52
	4.4	41.82		23.69	0.53	
	4.9	46.57		24.29	0.55	

Table 4.14Failure loads and self-weight of beam at 28 days for 150mm spacing.

Test No	Pressure from the scale (N/mm^2)	Load, p (KN)	Average load, p (KN)	Unit wt of beam (KN/m^3)	Self wt of beam,q (KN/m)	Average self wt of beam, q (KN/m)
1	6.2	58.93	67.16	20.73	0.47	0.47
	7.4	70.33		19.84	0.45	
	7.6	72.23		21.92	0.49	
2	5.8	55.13	60.20	19.55	0.44	0.47
	7.6	72.23		22.21	0.50	
	5.6	53.23		21.32	0.48	
3	6.0	57.03	59.56	22.21	0.50	0.48
	6.0	57.03		20.44	0.46	
	6.8	64.63		20.73	0.47	
4	4.6	43.72	51.96	21.62	0.49	0.49
	6.2	58.93		21.32	0.48	
	5.6	53.23		21.92	0.49	
5	5.0	47.52	47.52	22.81	0.51	0.52
	4.0	38.02		22.51	0.51	
	6.0	57.03		23.69	0.53	
6	4.2	39.92	41.19	21.92	0.49	0.49
	4.8	45.62		22.21	0.50	
	4.0	38.02		21.62	0.49	

Table 4.15Failure loads and self-weight of beam at 28 days for 200mm spacing.

Test No	Pressure from the scale (N/mm^2)	Load, p (KN)	Average load, p (KN)	Unit wt of beam (KN/m^3)	Self wt of beam,q (KN/m)	Average self wt of beam, q (KN/m)
1	5.9	56.08	53.54	23.10	0.52	0.51
	5.6	53.23		21.32	0.48	
	5.4	51.32		23.10	0.52	
2	5.0	47.52	52.91	20.14	0.45	0.46
	5.8	55.13		21.32	0.48	
	5.9	56.08		20.44	0.46	
3	6.0	57.03	48.79	20.44	0.46	0.46
	4.6	43.72		21.03	0.47	
	4.8	45.62		20.44	0.46	
4	5.8	55.13	58.93	23.69	0.53	0.55
	6.4	60.83		23.69	0.53	
	6.4	60.83		23.10	0.52	
5	6.75	64.63	64.63	23.10	0.52	0.53
	6.2	58.93		22.51	0.51	
	7.4	7033		24.29	0.55	
6	5.2	49.44	58.93	25.18	0.57	0.53
	5.4	51.32		23.99	0.54	
	8.0	76.04		24.58	0.55	

The 28-day moment capacity and flexural strength of beams are shown in Tables 4.16, 4.17 and 4.18 for 100mm, 150mm, and 200mm spacing respectively.

Table 4.16 28-day moment capacity and flexural strength of beams for 100mm spacing.

Test No	Average self-weight, q (KN/m)	Average load, p (KN)	Moment (KNm)	Flexural strength (KN/m^2)	Flexural strength (N/mm^2)
1	0.51	69.38	7.2747	12932.8	12.93
2	0.44	55.13	5.7799	10275.38	10.28
3	0.47	50.06	5.2469	9327.82	9.33
4	0.52	57.66	6.0439	10744.71	10.74
5	0.49	48.59	5.0922	9052.8	9.05
6	0.52	47.84	5.0128	8911.64	8.91

Table 4.17 28-day moment capacity and flexural strength of beams for 150mm spacing.

Test No	Average self-weight, q (KN/m)	Average load, p (KN)	Moment (KN.m)	Flexural strength (KN/m^2)	Flexural strength (N/mm^2)
1	0.47	67.16	7.0424	12519.82	12.52
2	0.47	60.20	6.3116	11220.62	11.22
3	0.48	59.56	6.2442	11100.80	11.10
4	0.49	51.96	5.446	9681.78	9.68
5	0.52	47.52	4.9792	8851.91	8.85
6	0.49	41.19	4.3152	7671.47	7.67

Table 4.18 28-day moment capacity and flexural strength of beams for 200mm spacing.

Test No	Average self-weight, q (KN/m)	Average load, p (KN)	Moment (KN.m)	Flexural strength (KN/m^2)	Flexural strength (N/mm^2)
1	0.51	53.54	5.6115	9976	9.98
2	0.46	52.91	5.5464	9860.27	9.86
3	0.46	48.79	5.1138	9091.2	9.09
4	0.53	64.63	6.7756	12045.51	12.05
5	0.53	58.93	6.1771	10981.51	10.98
6	0.55	58.93	6.1767	10980.80	10.98

Tables 4.19, 4.20, and 4.21 show summaries of failure loads and moment capacities of the beams for 100, 150, and 200mm spacing respectively.

Table 4.19Summary of failure loads and moment capacities of beams for 100mm spacing**.**

Test No	Point Load, p (KN)	Weight of Beam (KN/m^3)	Uniformly Distributed Load, q (KN/m)	Maximum Moment (KNm)
1	69.38	22.71	0.51	7.2747
2	55.13	20.93	0.47	5.7799
3	50.06	19.74	0.44	5.2469
4	57.66	23.30	0.52	6.0439
5	48.59	23.10	0.52	5.0922
6	47.84	21.82	0.49	5.0128

Table 4.20 Summary of failure loads and moment capacities of beams for 150mm spacing.

Test No	Point Load, p (KN)	Weight of Beam(KN/m^3)	Uniformly Distributed Load, q (KN/m)	Maximum Moment (KN.m)
1	67.16	20.83	0.47	7.0424
2	60.20	21.13	0.48	6.3116
3	59.56	21.03	0.47	6.2442
4	51.96	23.00	0.52	5.446
5	47.52	21.92	0.49	4.9792
6	41.19	21.62	0.49	4.3152

Table 4.21 Summary of failure loads and moment capacities of beams for 200mm spacing.

Test No	Point Load, p (KN)	Weight of Beam (KN/m^3)	Uniformly Distributed Load, q (KN/m)	Maximum Moment (KNm)
1	53.54	22.51	0.51	5.6115
2	52.91	20.63	0.46	5.5464
3	48.79	20.64	0.46	5.1138
4	64.63	24.58	0.55	6.7756
5	58.93	23.49	0.53	6.1771
6	58.93	23.30	0.53	6.1767

4.2.3 Comparison of flexural strength of truss and conventional reinforced concrete beams.

Table 4.22 Comparative Table of Truss and Conventional Beam flexural strengths for 100mm spacing

Mix Ratio	Flexural strength of truss beam reinforcement(N/mm^2)	Flexural strength of conventional beam reinforcement(N/mm^2)	Difference in percentage (%)
A	12.93	10.74	20.39
B	10.28	9.05	13.59
C	9.33	8.91	4.71

Table 4.23 Comparative Table of Truss and Conventional Beam flexural strengths for 150mm spacing

Mix Ratio	Flexural strength of truss beam reinforcement(N/mm^2)	Flexural strength of conventional beam reinforcement(N/mm^2)	Difference in percentage
A	12.52	9.68	29.34
B	11.22	8.85	26.78
C	11.10	7.67	44.72

Table 4.24 Comparative Table of Truss and Conventional Beam flexural strengths for 200mm spacing

Mix Ratio	Flexural strength of truss beam reinforcement (N/mm^2)	Flexural strength of conventional beam reinforcement (N/mm^2)	Difference in percentage
A	9.98	12.05	17.18
B	9.86	10.98	10.20
C	9.09	10.98	17.21

4.2.4 Graphs of Compressive strength, Flexural Strength, Mix Ratio and Reinforcement Spacing

Figures 4.3-4.14 show the graphs of flexural strength, cube compressive strength, mix ratio and reinforcement spacing for this research work.The tables for these graphs are shown in Appendix D.

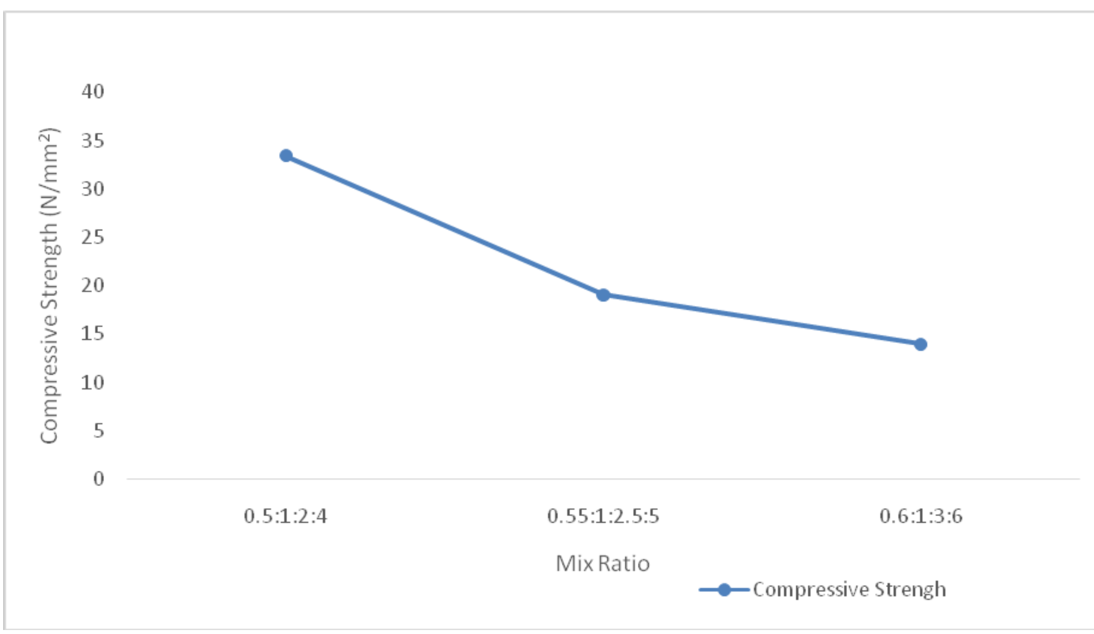


Figure 4.3 Mix Ratio against compressive Strength

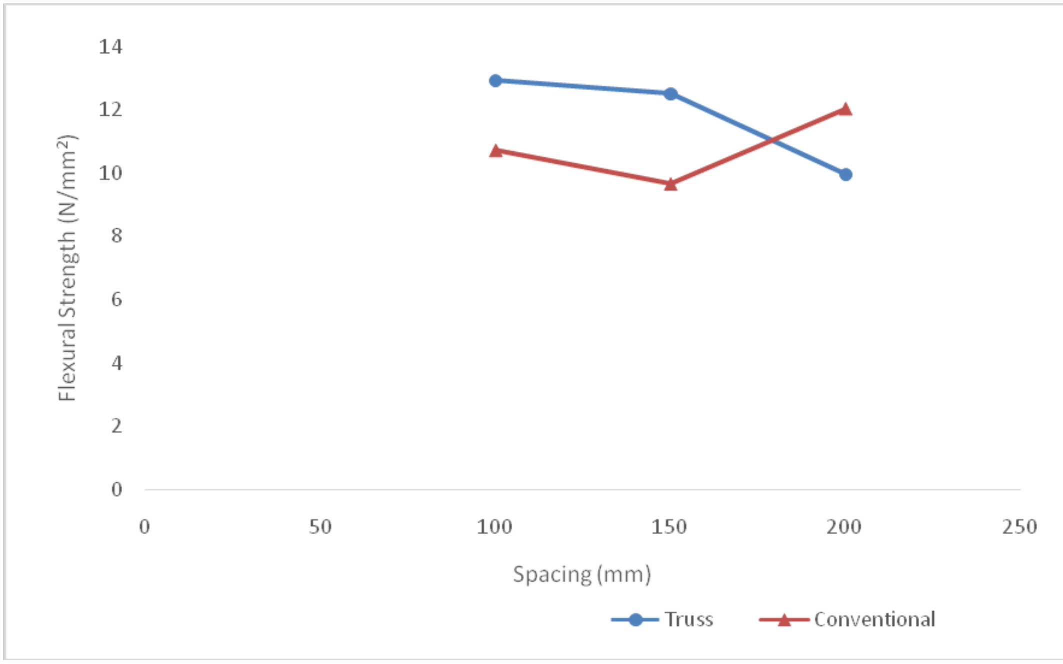


Figure 4.4 Flexural strength against truss and conventional reinforced concrete beam for different spacing for mix ratio 0.5:1:2:4

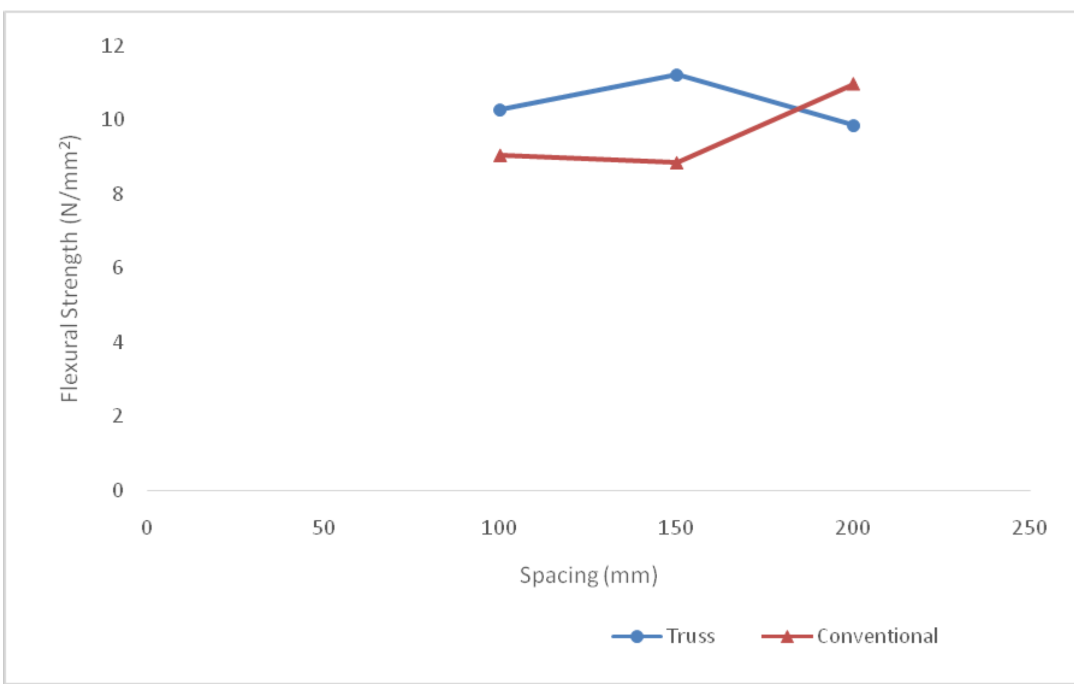


Figure 4.5 Flexural strength against truss and conventional reinforced concrete beam for different spacing for mix ratio 0.55:1:2.5:5

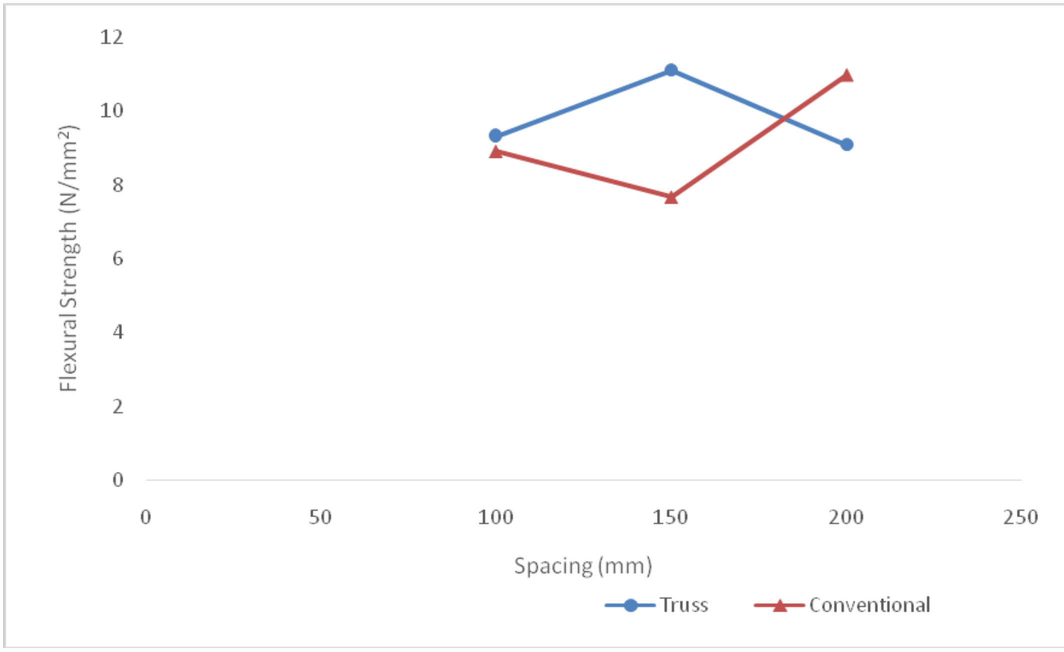


Figure 4.6 Flexural strength against truss and conventional reinforced concrete beam for different spacing for mix ratio 0.6:1:3:6

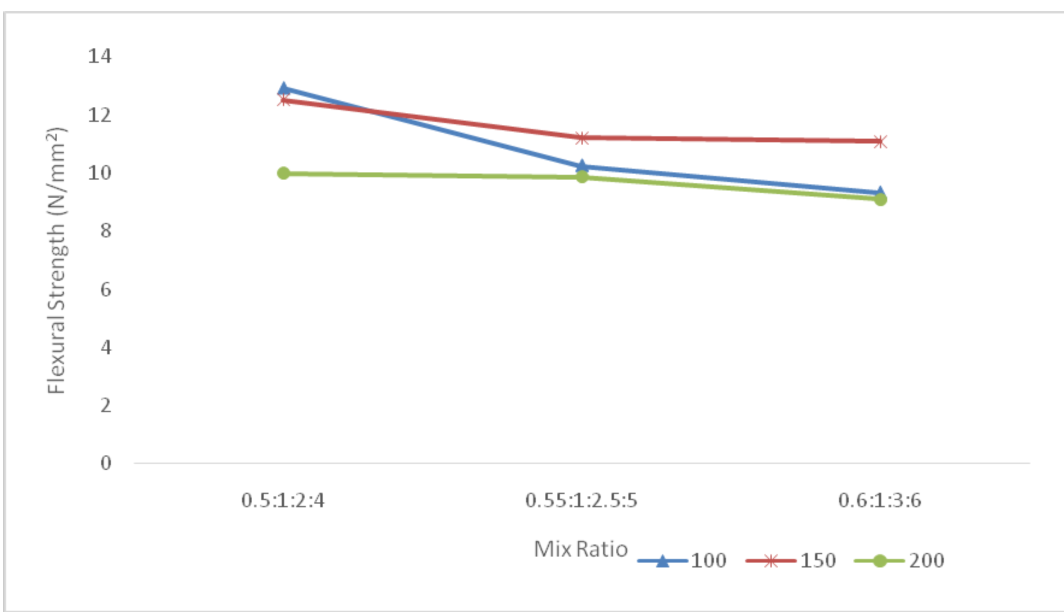


Figure 4.7Mix ratio against flexural strength of truss reinforced concrete beam for different spacing

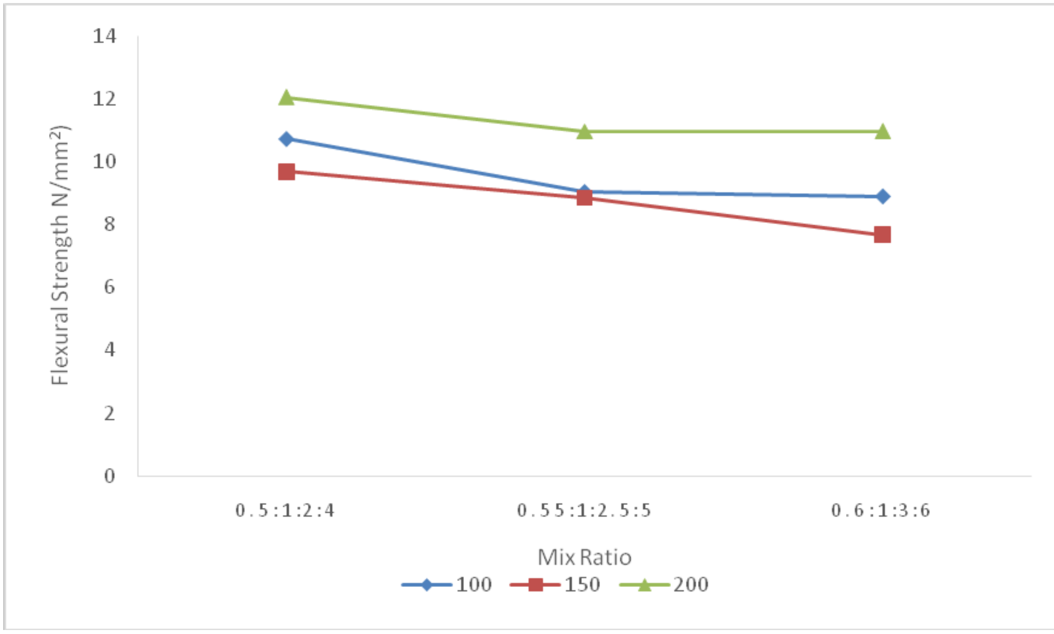


Figure 4.8 Mix ratio against flexural strength of conventional reinforced beam for different spacing

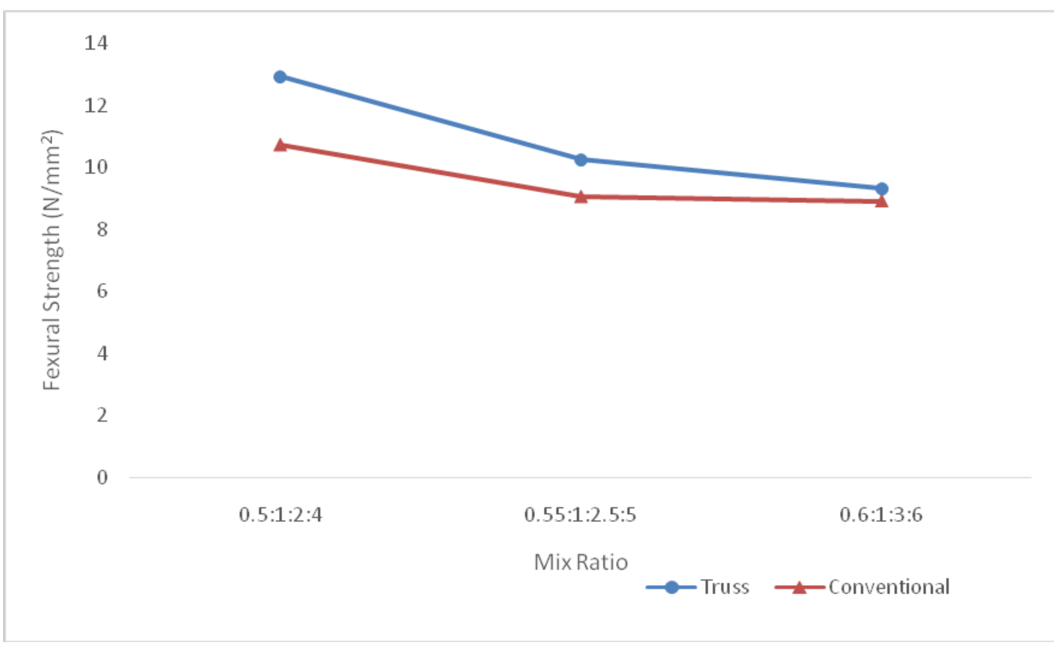


Figure 4.9Mix ratio against flexural strength of truss and conventional reinforced beam for 100mm spacing

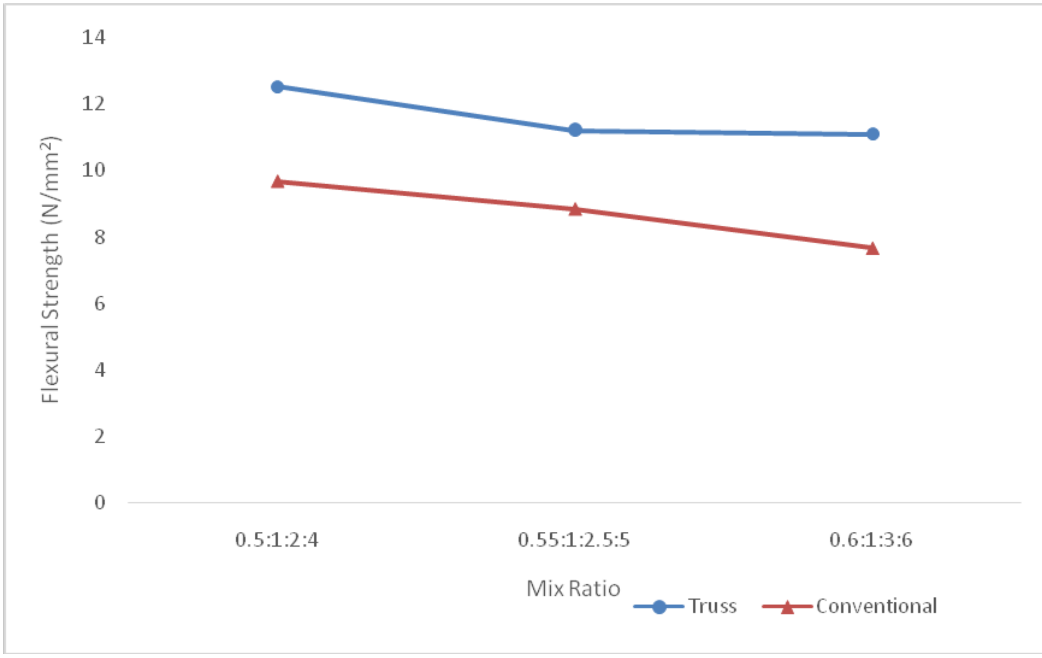


Figure 4.10Mix ratio against flexural strength of truss and conventional reinforced beam for 150mm spacing

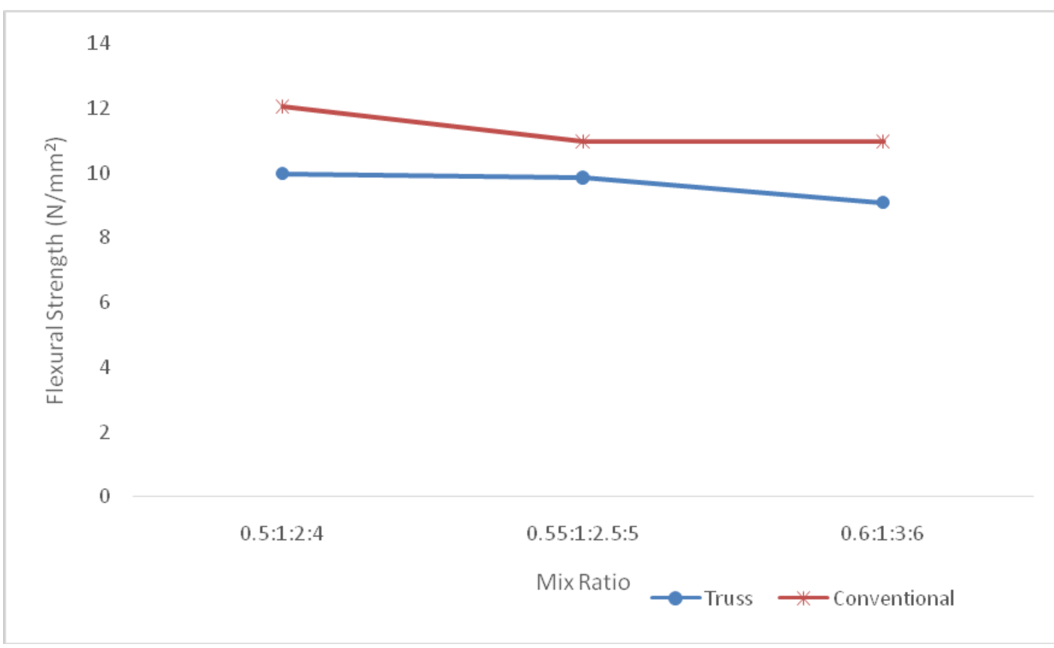


Figure 4.11Mix ratio against flexural strength of truss and conventional reinforced beam for 200mm spacing

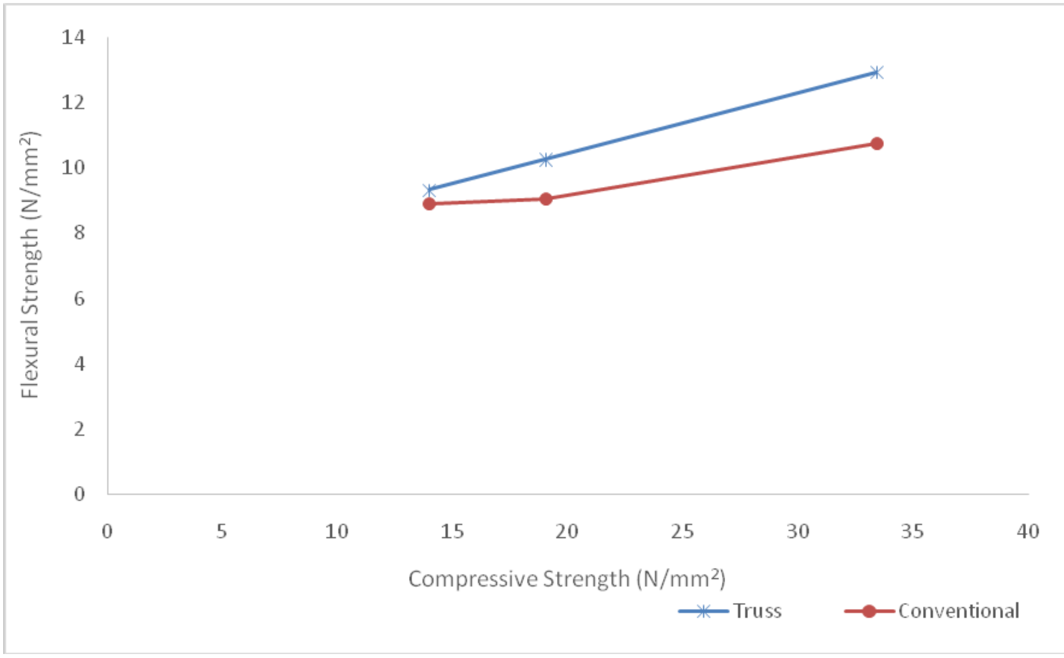


Figure 4.12Compressive strength against flexural strength of truss and conventional reinforced beam for 100mm spacing

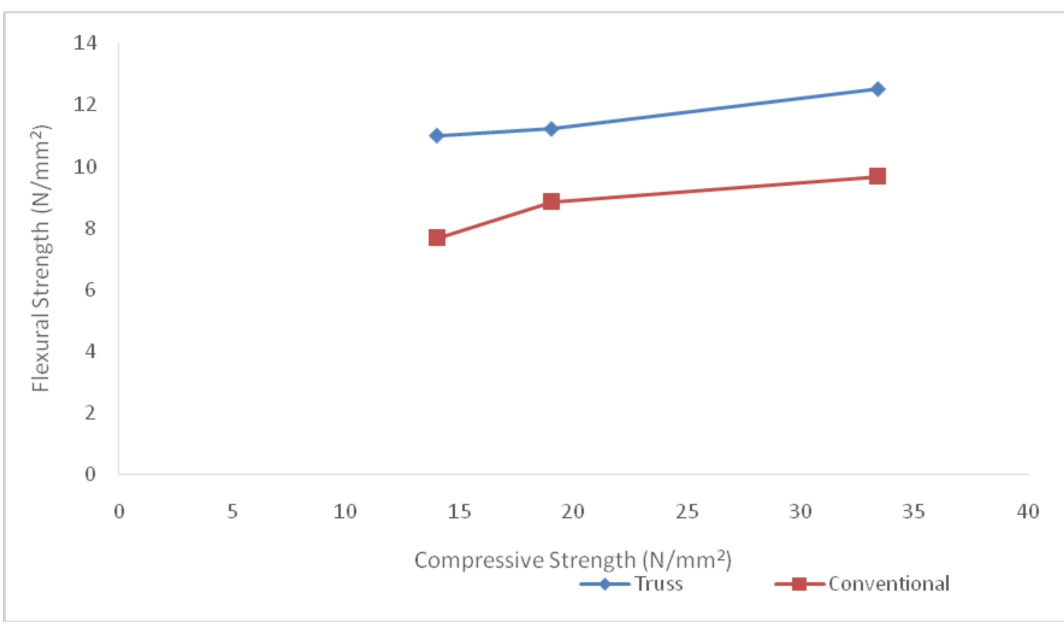


Figure 4.13Compressive strength against flexural strength of truss and conventional reinforced beam for 150mm spacing

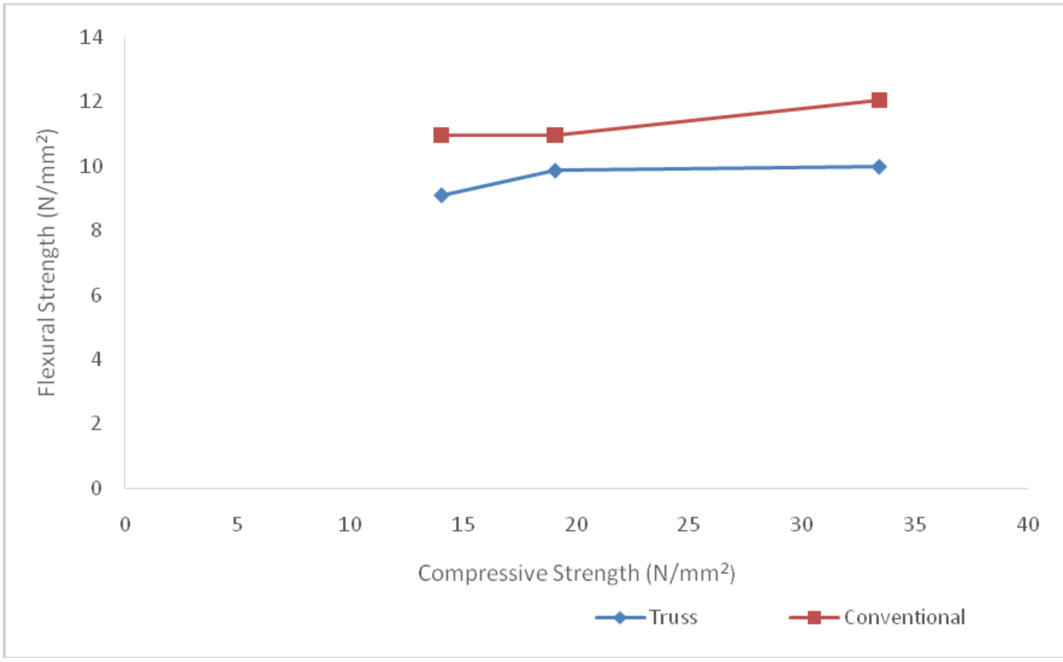


Figure 4.14Compressive strength against flexural strength of truss and conventional reinforced beam for 200mm spacing

4.3 Discussion of Results

4.3.1 Compressive Strength

Table 4.11 shows the various masses, loads, average loads, compressive strengths and average compressive strengths of cubes after 28 days strength. It can be seen that test no 1 and 4 with mix ratio of 0.5:1:2:4 for water-cement ratio, cement, sand and granite respectively, gave the highest compressive strength while those with mix ratio of 0.6:1:3:6 gave the lowest compressive strength. This shows that the more the cement content in the mix the higher the compressive strength of the concrete.

4.3.2 Flexural Strength

The Tables indicate that the conventional reinforced beams have higher self-weight than the truss reinforced beam. The beams from truss system of reinforcement were crushed at a greater load as shown in Tables 4.13 and 4.14. But in Table 4.15 (200mm spacing) the failure loads becomes greater in the conventional reinforcement in all the mix ratios than its corresponding beams from truss reinforcement. This implies that higher spacing of the stirrup favors the conventional reinforcement than the truss system of reinforcement in beam.

Tables 4.16 and 4.17 show that the flexural strength of truss reinforced beam at spacing of 100mm and 150mm are higher than its corresponding flexural strength in conventional reinforced beam. This simply shows that the closer the triangles in truss system of reinforcement the higher the flexural strength of the beam. Also in Table 4.18 the conventional beam reinforcement gave a higher flexural strength in all the mix ratios than its corresponding mix ratios in truss reinforced beams which implies that the conventional reinforced beam is better in flexural strength when the spacing in the truss triangles is not closer to each other.

The flexural strength of truss reinforced beam and that of conventional reinforced beam as compared in Tables 4.22, 4.23, and 4.24 for 100mm, 150mm, and 200mm spacing respectively show that higher flexural strength is achieved with 100mm and 150mm spacing in truss system. However, the conventional system gave higher flexural strength with 200mm spacing as can be seen in Table 4.24. Hence, higher flexural strength is obtained with a minimal spacing using truss system.

4.3.3 Graphs

Figure 4.3 shows that the compressive strength increases as the mix gets concentrated. In Figure 4.4, the flexural strength increased as the spacing gets closer in the truss system while spacing of 200mm gave high flexural strength in the conventional system. For 0.5:1:2:4 mix ratio, it can be observed that the truss system produced greater flexural strength with closer spacing of the shear reinforcements than the conventional system. The conventional system gave higher flexural strength at 200mm spacing as shown in Figures 4.5 and 4.6 while the reverse was the case in the truss system.

In Figure 4.7, the flexural strength increased as the mix gets concentrated while high flexural strength was achieved with 200mm spacing in the conventional system as shown in Figure 4.8. Also, it can be observed that the flexural strength increased as the mix ratios gets concentrated in all the spacing as shown in Figures 4.9, 4.10, and 4.11. The truss system gave higher flexural strength in 100mm and 150mm spacing except in 200mm spacing.

In the graphs of compressive strength against flexural strength for 100mm and 150mm spacing shown in Figures 4.12 and 4.13, the compressive strength increased along with the flexural strength for both truss and conventional system. The truss system produced higher flexural strength than the conventional system while the reverse is the case in Figure 4.14.

Table4.25 ManualTruss Analysis Result for100mm Spacing

Member	Force (KN)	Member	Force (KN)
AJ	19.78	SI	19.78
JK	9.29	SR	9.29
AK	16.51	IR	16.51
AB	17.04	IH	17.04
KB	16.51	RH	16.51
KL	24.80	RQ	24.80
BL	12.12	HQ	12.12
BC	30.48	HG	30.48
LC	12.12	QG	12.12
LM	36.18	QP	36.18
CM	7.73	GP	7.73
CD	39.80	GF	39.80
MD	7.73	PF	7.73
MN	43.44	PO	43.44
DN	3.34	FO	3.34
DE	45	FE	45
NE	3.34	OE	3.34
NO	46.58	ON	46.58

Table 4.26 Manual Truss Analysis Result for 150mm Spacing

Member	Force (KN)	Member	Force (KN)
AH	21.65	GM	21.65
AB	13.50	GF	13.50
HB	14.43	MF	14.43
HI	22.50	ML	22.50
BI	14.43	FL	14.43
BC	31.50	FE	31.50
IC	7.21	LE	7.21
IJ	36.00	LK	36.00
CJ	7.21	EK	7.21
CD	40.49	ED	40.49
JD	0.01	KD	0.01
JK	40.49	KJ	40.49

Table 4.27 Manual Truss Analysis Result for 200mm Spacing

Member	Force (KN)	Member	Force (KN)
AF	19.74	EI	19.74
AB	14.38	ED	14.38
FB	9.87	ID	9.87
FG	21.57	IH	21.57
BG	9.87	DH	9.87
BC	28.76	DC	28.76
GC	0	HC	0
GH	28.76	HG	28.76

Table 4.28 Computer Truss Analysis Result for 100mm Spacing

Member	**Force (KN)**	**Member**	**Force (KN)**
AJ	20.00	SI	20.00
JK	9.56	SR	9.56
AK	16.34	IR	16.34
AB	17.24	IH	17.24
KB	16.34	RH	16.34
KL	24.92	RQ	24.92
BL	12.35	HQ	12.35
BC	30.73	HG	30.73
LC	12.35	QG	12.35
LM	36.53	QP	36.53
CM	7.83	GP	7.83
CD	40.22	GF	40.22
MD	7.83	PF	7.83
MN	43.89	PO	43.89
DN	3.31	FO	3.31
DE	45.46	FE	45.46
NE	3.31	OE	3.31
NO	47.00	ON	47.00

Table 4.29 ComputerTruss Analysis Result for 150mm Spacing

Member	**Force (KN)**	**Member**	**Force (KN)**
AH	20.83	GM	20.83
AB	13.00	GF	13.00
HB	13.88	MF	13.88
HI	21.66	ML	21.66
BI	13.88	FL	13.88
BC	30.32	FE	30.32
IC	6.93	LE	6.93
IJ	34.65	LK	34.65
CJ	6.93	EK	6.93
CD	38.97	ED	38.97
JD	0.02	KD	0.02
JK	38.96	KJ	38.96

Table 4.30 ComputerTruss Analysis Result for 200mm Spacing

Member	**Force (KN)**	**Member**	**Force (KN)**
AF	20.05	EI	20.05
AB	14.61	ED	14.61
FB	10.02	ID	10.02
FG	21.92	IH	21.92
BG	10.02	DH	10.02
BC	29.22	DC	29.22
GC	0.01	HC	0.01
GH	29.22	HG	29.22

Table 4.31 Comparative Study of Computerand Manual Truss Analysis results for 100mm Spacing

	Computer	**Manual**	**% Difference**
Point Load (KN)	3.99	3.88	2.84
Angle (Degree)	61.96	61.99	0.05
Reactions at Support (KN)	17.94	17.46	2.75
No of Bays	9	9	0
Member Forces (KN)			
AJ	20.00	19.78	1.11
JK	9.56	9.29	2.91
AK	16.34	16.51	1.03
AB	17.24	17.04	1.17
KB	16.34	16.51	1.64
KL	24.92	24.80	0.48
BL	12.35	12.12	1.90
BC	30.73	30.48	0.82
LC	12.35	12.12	1.90
LM	36.53	36.18	0.97
CM	7.83	7.73	1.29
CD	40.22	39.80	1.06
MD	7.83	7.73	1.29
MN	43.89	43.44	1.04
DN	3.31	3.34	0.90
DE	45.46	45.00	1.02
NE	3.31	3.34	0.90
NO	47.00	46.58	0.90

Table 4.32 Comparative Study of Computerand Manual Truss Analysis results for 150mm Spacing

	Computer	**Manual**	**% Difference**
Point Load (KN)	5.43	5.64	3.72
Angle (Degree)	51.39	51.41	0.04
Reactions at Support (KN)	16.28	16.92	3.78
No of Bays	6	6	
Member Forces (KN)			
AH	20.83	21.65	3.79
AB	13.00	13.50	3.70
HB	13.88	14.43	3.81
HI	21.66	22.50	3.73
BI	13.88	14.43	3.81
BC	30.32	31.50	3.75
IC	6.93	7.21	3.88
IJ	34.65	36.00	3.75
CJ	6.93	7.21	3.88
CD	38.97	40.49	3.75
JD	0.02	0.01	100
JK	38.96	40.49	3.78

Table 4.33 Comparative Study of Computerand ManualTruss Analysis results for 200mm Spacing

	Computer	**Manual**	**% Difference**
Point Load (KN)	6.87	6.76	1.63
Angle (Degree)	43.21	43.23	0.05
Reactions at Support (KN)	13.73	13.52	1.55
No of Bays	4	4	0
Member Forces (KN)			
AF	20.05	19.74	1.57
AB	14.61	14.38	1.60
FB	10.02	9.87	1.52
FG	21.92	21.57	1.62
BG	10.02	9.87	1.52
BC	29.22	28.76	1.60
GC	0.01	0	0
GH	29.22	28.76	1.60

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the results obtained from this experimental research, the following conclusions can be made:

i. Truss reinforced concrete beam has greater strength than the conventional reinforced concrete beam.
ii. The higher the compressive strength the higher the flexural strength of a beam.
iii. Computer program can be used as an alternative to manual truss analysis.

5.2 Recommendations

The following recommendations were made:

i. Truss system of reinforcement should be used in concrete beam in civil engineering works.
ii. For better flexural strength, truss reinforcement should be used than conventional equivalent. Example at 100mm reinforcement spacing, the flexural strength of truss was 12932.80kN/m^2 against 10744.71kN/m^2 for conventional reinforcement.
iii. Computer program should be used as an alternative to manual truss analysis.
iv. Further research should be carried out on this using sandcrete and flat bars reinforcement.

5.3 Contribution to Knowledge

This research work has highlighted the fact that truss reinforced concrete beam can replace the conventional reinforced concrete beam to obtain greater flexural strength in civil engineering works.

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APPENDIX A

PLATES SHOWING VARIOUS STAGES OF WORK

Plate A.1 Fabricated Truss Reinforcement.

Plate A.2 Measuring and Fabrication of Conventional Reinforcement

Plate A.3 Fabrication of Conventional Reinforcement.

Plate A.4 Weighing of Water

Plate A.5 Weighing of Cement

Plate A.6 Weighing of Coarse Aggregate

Plate A.7 Mixing of Concrete

Plate A.8 Truss Reinforcement Beam well positioned inside Beam Mould

Plate A.9 Ramming of Concrete in beam mould containing truss reinforcement beam

Plate A.10 Ramming of concrete in cube mould

Plate A.11 Carrying of beam to an open curing tank

Plate A.12 Curing tank containing beams and cubes

Plate A.13 Beams ready for crushing after curing

Plate A.14 Cubes ready for crushing after curing

Plate A.15 Crushing of beam in Magnus frame

Plate A.16 Concrete compressive Testing Machine

Plate A.17 Universal Testing Machine

Plate A.18 Front View of Magnus Frame

APPENDIX B

MATERIAL BATCHING CALCULATIONS

B.1 For Mix Ratio 0.5: 1 : 2 : 4 – Beam

1 : 2 : 4 = 7

Density of concrete = mass/volume

Density of concrete = 2400kg/m^3

Volume of concrete = 0.15 x 0.15 x 1

= 0.0225m^3

Therefore, Mass = Density x Volume

= 2400 x 0.0225

= 54kg

Cement: 1/7 x 54 = 7.71 x 3 Beams

= 23.13kg

Sand: 2/7 x 54 = 15.43 x 3 Beams

= 46.29kg

Aggregate: 4/7 x 54 = 30.86 x 3 beams

= 92.58kg

Water Cement Ratio: W/C = 0.5

Therefore, W = 7.71 x 0.5 = 3.86kg

3.86 x 3 Beams = 11.58kg

B.2 For Mix Ratio 0.5: 1: 2: 4 – Cube

1 : 2 : 4 = 7

Density of concrete = mass/volume

Density of concrete = $2400kg/m^3$

Volume of concrete = 0.15 x 0.15 x 0.15

$= 3.38 \times 10^{-3} m^3$

Therefore, Mass = Density x Volume

$= 2400 \times 3.38 \times 10^{-3}$

= 8.1kg

Cement: 1/7 x 8.1 = 1.16 x 3 Cubes

= 3.48kg

Sand: 2/7 x 8.1 =2.31 x 3 Cubes

= 6.93kg

Aggregate: 4/7 x 8.1 = 4.6 x 3 Cubes

= 13.8kg

Water Cement Ratio: W/C = 0.5

Where C = 1.16

Therefore, W = 1.16 x 0.5 = 0.58kg

0.58 x 3 Cubes = 1.74kg

Adding the mass of the beams and the cubes together, we have

Cement = 23.13 + 3.48 = 26.61 x 2 = 53.22kg

Sand = 46.29 + 6.93 = 53.22 x 2 = 106.44kg

Aggregate = 92.58 + 13.80 = 106.38 x 2 = 212.76kg

Water = 11.58 + 1.74 = 13.32 x 2 = 26.64kg

B.3 For Mix Ratio 0.55 : 1 : 2.5 : 5 – Beam

1 + 2.5 + 5 = 8.5

Density of concrete = mass/volume

Density of concrete = 2400kg/m^3

Volume of concrete = 0.15 x 0.15 x 1

= 0.0225m^3

Therefore, Mass = Density x Volume

= 2400 x 0.0225

= 54kg

Cement: 1/8.5 x 54 = 6.35 x 3 Beams

= 19.05kg

Sand: 2.5/8.5 x 54 = 15.88 x 3 Beams

= 47.64kg

Aggregate: 5/8.5 x 54 = 31.76 x 3 beams

= 95.28kg

Water Cement Ratio: W/C = 0.55

Therefore, W = 6.35 x 0.55 = 3.49kg

3.49 x 3 Beams = 10.47kg

B.4 For Mix Ratio 0.55 : 1 : 2.5 : 5 – Cube

1 : 2.5 : 5 = 8.5

Density of concrete = mass/volume

Density of concrete = 2400kg/m^3

Volume of concrete = 0.15 x 0.15 x 0.15

= 3.38 x 10 -3m^3

Therefore, Mass = Density x Volume

= 2400 x 3.38 x 10^{-3}

= 8.1kg

Cement: 1/8.5 x 8.1 = 0.95 x 3 Cubes

= 2.85kg

Sand: 2.5/8.5 x 8.1 =2.38 x 3 Cubes

= 7.14kg

Aggregate: 5/8.5 x 8.1 = 4.76 x 3 Cubes

= 14.28kg

Water Cement Ratio: W/C = 0.55

Where C = 0.95

Therefore, W = 0.95 x 0.55 = 0.52kg

0.52 x 3 Cubes = 1.56kg

Adding the mass of the beams and the cubes together, we have

Cement = 19.05 + 2.85 = 21.90 x 2 = 43.80kg

Sand = 47.64 + 7.14 = 54.78 x 2 = 109.56kg

Aggregate = 95.28 + 14.28 = 109.56 x 2 = 219.12kg

Water = 10.47 + 1.56 = 12.03 + 0.8 can wt

= 12.83 x 2 = 25.66kg

B.5 For Mix Ratio 0.6 : 1 : 3 : 6 – Beam

1 + 3 + 6 = 10

Density of concrete = mass/volume

Density of concrete = 2400kg

Volume of concrete = 0.15 x 0.15 x 1

= 0.0225m3

Therefore, Mass = Density x Volume

= 2400 x 0.0225

= 54kg

Cement: 1/10 x 54 = 5.4 x 3 Beams

= 16.20kg

Sand: 3/10 x 54 = 16.20 x 3 Beams

= 48.60kg

Aggregate: 6/10 x 54 = 32.40 x 3 beams

= 97.20kg

Water Cement Ratio: W/C = 0.55

Therefore, W = 5.4 x 0.6 = 3.24kg

3.24 x 3 Beams = 9.72kg

B.6 For Mix Ratio 0.6: 1 : 3 : 6 – Cube

1 : 3 : 6 = 10

Density of concrete = mass/volume

Density of concrete = 2400kg

Volume of concrete = 0.15 x 0.15 x 0.15

= 3.38 x 10 -3m3

Therefore, Mass = Density x Volume

= 2400 x 3.38 x 10-3

= 8.1kg

Cement: 1/10 x 8.1 = 0.81 x 3 Cubes

= 2.43kg

Sand: 3/10 x 8.1 =2.43 x 3 Cubes

= 7.29kg

Aggregate: 6/10 x 8.1 = 4.86 x 3 Cubes

= 14.58kg

Water Cement Ratio: W/C = 0.6

Where C = 0.81

Therefore, W = 0.81 x 0.6 = 0.49kg

0.49 x 3 Cubes = 1.47kg

Adding the mass of the beams and the cubes together, we have

Cement = 16.20 + 2.43 = 18.63 x 2 = 37.26kg

Sand = 48.60 + 7.29 = 55.89 x 2 = 111.78kg

Aggregate = 97.20 + 14.58 = 111.78 x 2 = 223.56kg

Water = 9.72 + 1.47 = 11.19 + 0.8 can wt.

= 11.99 x 2 = 23.98kg

APPENDIX C

BEAM LOADINGCALCULATIONS

Using the average result obtained in Tables 4.16, 4.17 and 4.18

Geometrical properties:

$Dimension\ of\ plate - 150mm \times 150mm$

$effective\ diameter\ of\ cylinder, d_r = 110mm = 0.110m$

$Effective\ Area\ of\ cylinder, A_r = \pi {d_r}^2/4 = \pi 110^2/4 = 9504.55mm^2$

Modulus of Section, $Z = \frac{bh^2}{6}$

$Flexural\ Strength = \frac{M}{Z}$

$10\ bar = 1N/mm^2$

Where;

Uniformly distributed load, q(KN/m) = Self weight of beam, $W/Length\ (L + 2a)$

$Force, F = Applied\ Load \times Effective\ Area\ of\ cylinder, A_r$

C.1 100MM SPACING

TEST NO 1

$Using\ Total\ Maximum\ Moment, M_{max} = FL/4 + q/2(L^2/4 - a^2)$

$where\ F = 69.38, q = 0.51, a = 290mm = 0.29m, L = 0.42m$

$M_{max} = 69.38 \times 0.42/4 + 0.51/2(0.42^2/4 - 0.29^2)$

$= 7.2849 + 0.255\ (0.0441 - 0.0841)$

$7.2747 kNm$

TEST NO 2

$Using\ Total\ Maximum\ Moment, M_{max} = FL/4 + q/2(L^2/4 - a^2)$

$where\ F = 55.13, q = 0.44, a = 290mm = 0.29m, L = 0.42m$

$M_{max} = 55.13 \times 0.42/4 + 0.44/2(0.42^2/4 - 0.29^2)$

$= 5.7887 + 0.22\ (0.0441 - 0.0841)$

$= 5.7799 kNm$

TEST NO 3

$Using\ Total\ Maximum\ Moment, M_{max} = FL/4 + q/2(L^2/4 - a^2)$

$where\ F = 50.06, q = 0.47, a = 290mm = 0.29m, L = 0.42m$

$M_{max} = 50.06 \times 0.42/4 + 0.47/2(0.42^2/4 - 0.29^2)$

$= 5.2563 + 0.235\ (0.0441 - 0.0841)$

$= 5.2469 kNm$

TEST NO 4

$Using\ Total\ Maximum\ Moment, M_{max} = FL/4 + q/2(L^2/4 - a^2)$

$where\ F = 57.66, q = 0.52, a = 290mm = 0.29m, L = 0.42m$

$M_{max} = 7.66 \times 0.42/4 + 0.52/2\,(0.42^2/4 - 0.29^2)$

$= 6.0543 + 0.26\ (0.0441 - 0.0841)$

$= 6.0439kNm$

TEST NO 5

$Using\ Total\ Maximum\ Moment, M_{max} = FL/4 + q/2\,(L^2/4 - a^2)$

$where\ F - 48.59, q - 0.49, a - 290mm - 0.29m, L - 0.42m$

$M_{max} = 48.59 \times 0.42/4 + 0.49/2(0.42^2/4 - 0.29^2)$

$= 5.1020 + 0.245\ (0.0441 - 0.0841)$

$= 5.0922kNm$

TEST NO 6

$Using\ Total\ Maximum\ Moment, M_{max} = FL/4 + q/2\,(L^2/4 - a^2)$

$where\ F = 47.84, q = 0.52, a = 290mm = 0.29m, L = 0.42m$

$M_{max} = 47.84 \times 0.42/4 + 0.52/2(0.42^2/4 - 0.29^2)$

$= 5.0232 + 0.26\ (0.0441 - 0.0841)$

$= 5.0128kNm$

C.2 150MM SPACING

TEST NO 1

$Using\ Total\ Maximum\ Moment, M_{max} = FL/4 + \ q/2(L^2/4 - \ a^2)$

$where\ F = 67.16, q = 0.47, a = 290mm = 0.29m, L = 0.42m$

$M_{max} = \ 67.16 \ \times 0.42/4 + \ 0.47/2(0.42^2/4 - \ 0.29^2)$

$= 7.0518 + 0.235\ (0.0441 - 0.0841)$

$= 7.0424kNm$

TEST NO 2

$Using\ Total\ Maximum\ Moment, M_{max} = FL/4 + \ q/2(L^2/4 - \ a^2)$

$where\ F = 60.20, q = 0.47, a = 290mm = 0.29m, L = 0.42m$

$M_{max} = \ 60.20 \ \times 0.42/4 + \ 0.47/2(0.42^2/4 - \ 0.29^2)$

$= 6.321 + 0.235\ (0.0441 - 0.0841)$

$= 6.3116kNm$

TEST NO 3

$Using\ Total\ Maximum\ Moment, M_{max} = FL/4 + \ q/2(L^2/4 - \ a^2)$

$where\ F = 59.56, q = 0.48, a = 290mm = 0.29m, L = 0.42m$

$M_{max} = \ 59.56 \ \times 0.42/4 + \ 0.47/2(0.42^2/4 - \ 0.29^2)$

$= 6.2442 + 0.24\ (0.0441 - 0.0841)$

$= 6.2442kNm$

TEST NO 4

$Using\ Total\ Maximum\ Moment, M_{max} = FL/4 + \ q/2(L^2/4 - \ a^2)$

$where\ F = 51.96, q = 0.49, a = 290mm = 0.29m, L = 0.42m$

$M_{max} = \ 51.96 \times 0.42/4 + \ 0.49/2(0.42^2/4 - \ 0.29^2)$

$= 5.4558 + 0.245\ (0.0441 - 0.0841)$

$= 5.446kNm$

TEST NO 5

$Using\ Total\ Maximum\ Moment, M_{max} = FL/4 + \ q/2(L^2/4 - \ a^2)$

$where\ F = 47.52, q = 0.52, a = 290mm = 0.29m, L = 0.42m$

$M_{max} = \ 47.52 \times 0.42/4 + \ 0.52/2(0.42^2/4 - \ 0.29^2)$

$= 4.9896 + 0.26\ (0.0441 - 0.0841)$

$= 4.9792kNm$

TEST NO 6

$Using\ Total\ Maximum\ Moment, M_{max} = FL/4 + \ q/2(L^2/4 - \ a^2)$

$where\ F = 41.19, q = 0.49, a = 290mm = 0.29m, L = 0.42m$

$M_{max} = \ 41.19 \times 0.42/4 + \ 0.49/2(0.42^2/4 - \ 0.29^2)$

$= 4.3250 + 0.245\ (0.0441 - 0.0841)$

$= 4.3152kNm$

C.3 200MM SPACING

TEST NO 1

$Using\ Total\ Maximum\ Moment, M_{max} = FL/4 + \ q/2(L^2/4 - \ a^2)$

$where\ F = 53.54, q = 0.51, a = 290mm = 0.29m, L = 0.42m$

$M_{max} = \ 53.54 \times 0.42/4 + \ 0.51/2(0.42^2/4 - \ 0.29^2)$

$= 5.6217 + 0.255\ (0.0441 - 0.0841)$

$= 5.6115kNm$

TEST NO 2

$Using\ Total\ Maximum\ Moment, M_{max} = FL/4 + \ q/2(L^2/4 - \ a^2)$

$where\ F = 52.91, q = 0.46, a = 290mm = 0.29m, L = 0.42m$

$M_{max} = \ 52.91 \times 0.42/4 + \ 0.46/2(0.42^2/4 - \ 0.29^2)$

$= 5.5556 + 0.23\ (0.0441 - 0.0841)$

$= 5.5464kNm$

TEST NO 3

$Using\ Total\ Maximum\ Moment, M_{max} = FL/4 + \ q/2(L^2/4 - \ a^2)$

$where\ F = 48.79, q = 0.46, a = 290mm = 0.29m, L = 0.42m$

$M_{max} = \ 48.79 \ \times 0.42/4 + \ 0.46/2(0.42^2/4 - \ 0.29^2)$

$= 5.1230 + 0.23\ (0.0441 - 0.0841)$

$= 5.1138kNm$

TEST NO 4

$Using\ Total\ Maximum\ Moment, M_{max} = FL/4 + \ q/2(L^2/4 - \ a^2)$

$where\ F = 58.93, q = 0.53, a = 290mm = 0.29m, L = 0.42m$

$M_{max} = \ 58.93 \times 0.42/4 + \ 0.53/2(0.42^2/4 - \ 0.29^2)$

$= 6.1877 + 0.265\ (0.0441 - 0.0841)$

$= 6.1771kNm$

TEST NO 5

$Using\ Total\ Maximum\ Moment, M_{max} = FL/4 + \ q/2(L^2/4 - \ a^2)$

$where\ F = 64.63, q = 0.53, a = 290mm = 0.29m, L = 0.42m$

$M_{max} = \ 64.63 \times 0.42/4 + \ 0.53/2(0.42^2/4 - \ 0.29^2)$

$= 6.7862 + 0.265\ (0.0441 - 0.0841)$

$= 6.7756kNm$

TEST NO 6

$Using\ Total\ Maximum\ Moment, M_{max} = FL/4 + \ q/2(L^2/4 - \ a^2)$

$where\ F = 58.93, q = 0.55, a = 290mm = 0.29m, L = 0.42m$

$M_{max} = \ 58.93 \times 0.42/4 + \ 0.55/2(0.42^2/4 - \ 0.29^2)$

$= 6.1877 + 0.275\ (0.0441 - 0.0841)$

$= 6.1767kNm$

APPENDIX D

COMPRESSIVE AND FLEXURAL TEST RESULTSFOR DIFFERENT MIX RATIO AND SPACING

Tables D1 – D12 below show the tables used in plotting the graphs in Figures 4.3 – 4.14 respectively.

Table D1 Compressive strength for different mix ratio

Mix Ratio	Compressive Strength (N/mm^2)
0.5:1:2:4	33.40
0.55:1:2.5:5	19.04
0.6:1:3:6	14.00

Table D2 Flexural strength of truss and conventional reinforced concrete beam for different spacing for mix ratio 0.5:1:2:4

Spacing (mm)	Flexural Strength (N/mm^2)	
	Truss	Conventional
100	12.93	10.74

150	12.52	9.68
200	9.98	12.05

Table D3 Flexural strength of truss and conventional reinforced concrete beam for different spacing for mix ratio 0.55:1:2.5:5

Spacing (mm)	Flexural Strength (N/mm^2)	
	Truss	Conventional
100	10.28	9.05
150	11.22	8.85
200	9.86	10.98

Table D4 Flexural strength of truss and conventional reinforced concrete beam for different spacing for mix ratio 0.6:1:3:6

Spacing (mm)	Flexural Strength (N/mm^2)	
	Truss	Conventional
100	9.33	8.91
150	11.10	7.67
200	9.09	10.98

Table D5 Mix ratio and Flexural strength of truss reinforced concrete beam for different spacing

Mix Ratio	Flexural Strength (N/mm^2)		
	100mm	150mm	200mm
0.5:1:2:4	12.93	12.52	9.98
0.55:1:2.5:5	10.26	11.22	9.86

0.6:1:3:6	9.33	11.10	9.09

Table D6 Mix ratio and Flexural strength of conventional reinforced concrete beam for different spacing

Mix Ratio	Flexural Strength (N/mm^2)		
	100mm	150mm	200mm
0.5:1:2:4	10.74	9.68	12.05
0.55:1:2.5:5	9.05	8.85	10.98
0.6:1:3:6	8.91	7.67	10.98

Table D7 Mix ratio and Flexural strength of truss and conventional reinforced concrete beam for 100mm spacing.

Mix Ratio	Flexural Strength (N/mm^2)	
	Truss	Conventional
0.5:1:2:4	12.93	10.74
0.55:1:2.5:5	10.26	9.05
0.6:1:3:6	9.33	8.91

Table D8 Mix ratio and Flexural strength of truss and conventional reinforced concrete beam for 150mm spacing.

Mix Ratio	Flexural Strength (N/mm^2)	
	Truss	Conventional
0.5:1:2:4	12.52	9.68
0.55:1:2.5:5	11.22	8.85
0.6:1:3:6	11.10	7.67

Table D9 Mix ratio and Flexural strength of truss and conventional reinforced concrete beam for 200mm spacing.

Mix Ratio	Flexural Strength (N/mm^2)	
	Truss	Conventional
0.5:1:2:4	9.98	12.05
0.55:1:2.5:5	9.86	10.98
0.6:1:3:6	9.09	10.98

Table D10 Compressive strength and Flexural strength of truss and conventional reinforced concrete beam for 100mm spacing.

Compressive Strength (N/mm^2)	Flexural Strength (N/mm^2)	
	Truss	Conventional
33.40	12.93	10.74
19.04	10.26	9.05
14.00	9.33	8.91

Table D11 Compressive strength and Flexural strength of truss and conventional reinforced concrete beam for 150mm spacing.

Compressive Strength (N/mm^2)	Flexural Strength (N/mm^2)	
	Truss	Conventional
33.40	12.52	9.68
19.04	11.22	8.85
14.00	11.00	7.67

Table D12 Compressive strength and Flexural strength of truss and conventional reinforced concrete beam for 200mm spacing.

Compressive Strength (N/mm^2)	Flexural Strength (N/mm^2)	
	Truss	Conventional
33.40	9.98	12.05
19.04	9.86	10.98
14.00	9.09	10.98

APPENDIX E

BEAM MODE OF FAILURE

The beams were loaded to capacity and the beams failed by cracking at the bottom part. This is shown vividly in plate E.1. The steel yielded first before the concrete thus, the beams failed in tension due to failure of the reinforcements.

Plate E.1 Crack pattern of a loaded Beam