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Effects of Stirrups Spacing on the Flexural Strength of Reinforced Concrete Beams

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Abstract

The work investigated reinforced concrete beam with stirrup spacing at close and wide range intervals of 150 mm, 200 mm, 300 mm, 400 mm, 600 mm and 1200 mm respectively. The 12 mm beam is tied in place with 8 mm stirrup bar and subjected to flexural strength (Modulus of Rupture) test. Metal formwork was prepared using 2mm metal plate and 5 mm metal angle bar. The formwork was fabricated to assume an internal dimension of 1200 mm (length) X 225 mm (depth) X 150 mm (width) with a concrete cover of 25 mm all round to ensure adequate protection of the reinforcing bars from corrosion caused by environmental effect. The average characteristic yield strength of 12 mm and 8 mm reinforcing bars used were determined to be 406 N/mm2 and 382 N/mm2 respectively. Concrete mixed in accordance with BS5328 specification with a mix ratio of 1:2:4 and grade M15 was poured inside the formwork housing the steel reinforcements with adequate vibration at calculated intervals. Thereafter the reinforced concrete beam was allowed to cure for 7, 14, 21 and 28 days before being subjected to flexural test in laboratory. The results showed flexural strength gain, increase in carrying capacity of the beam, decrease in cracking as the stirrup spacing decreases vice versa.

Keywords: Reinforced, concrete, flexural, characteristic, yield and strength

1.1 Introduction

A beam is a structural member which spans horizontally between supports and carries loads which act at right angles to the length of the beam. They are small in cross-section compared with their span (Sutharsan, 2015). Historically, beams were squared timbers but are also metal, stone, or combinations of wood and metal such as a flitch beam.

Beams generally are vertical gravitational forces but can also be used to carry horizontal loads (e.g., loads due to an earthquake or wind or in tension to resist rafter thrust as a tie beam or (usually) compression as a collar beam. The loads carried by a beam are transferred to columns, walls, or girders, which then transfer the force to adjacent structural compression members. In light frame, construction joists may rest on beams. In carpentry, a beam is called a plate as in a sill plate or wall plate, beam as in a summer beam or dragon beam (Wikipedia.org, 2021).

Experimental results has demonstrated that, as stirrup spacing decreases, there is an ultimate strength gain on the beam such as increase in carrying capacity of the beam, increase in the flexural strength, decrease in deformations etc. The beneficial aspect of using closer stirrup leg spacing than the maximum permitted by codes is not found in the available national building codes for structural concrete (Murty, and PapaRao, 2013). However, experiment has proven that closer stirrup legs provide a better strength to the structural elements in use.

Concrete, which is the most used building material in the world, has many advantages and disadvantages. Low tensile strength and moment bearing capacity are some of them. Researchers have done many studies to increase the tensile and flexural strengths of concrete. In order to increase the tensile strength of concrete, various reinforcing sequence were adopted, and specimens were tested to obtain the desired strength values (Ünal, Cengiz and Kamanlı, 2021).

The System of Columns and Beams have been used in Construction since Ancient Egypt. In modern day construction, Column-Beam-Slab System is been used in all superstructures with new technology and construction materials. Generally, the load of the slab is transferred to the columns or walls through the beams, down to the foundation, and then to the supporting soil beneath (Sutharsan, 2015).

The mechanical and physical properties of reinforcing steel bars obtained from Nigerian steel manufacturing companies were investigated and the results have shown Nigerian manufactured steel to possess low mechanical and physical qualities. At present there is inadequate information on the actual behaviour of these reinforcing steel bars which are already in use in structural concrete for the construction of all types of buildings, bridges, hydraulic structures, etc., yet they are classified as high yield steel in design specifications (Ozioko, 2016). The need to ensure adequate ultimate strength to a structure being constructed in Nigeria is inevitable.

Reinforced concrete structures have been known as the major construction facilities globally and it has shown great performance when the right reinforcement is used. Through effective bonding between concrete and reinforcement, stresses can be transferred from concrete to steel. The dangers of maximizing profit at the expense of quality was exposed by previous research work on the physical characteristics, chemical characteristics and strength characteristics of steel reinforcing materials. This situation pose a major threat to the structural durability, strength and reliability of buildings and civil structures (Ozioko, 2021). Basically beams are reinforced cement concrete (RCC). RCC is concrete that contains steel bars, called reinforcement bars, or rebars. Rebar (reinforcing bar) is an important component of reinforced concrete. It is usually formed from ridged carbon steel. The ridges give frictional adhesion to the concrete. Rebar is used because concrete is very strong in compression and virtually without strength in tension. However, these rebar are held in position by stirrups (basement.org.uk, 2016).

Stirrup in English is a loop, ring, or other contrivance of metal, wood, leather, etc., suspended from the saddle of a horse to support the rider's foot (studymode.com, 2014). In civil engineering stirrups mean the rings that are used to tie the top and bottom reinforcements in a beam. Stirrups help us to hold the top and bottom reinforcement in a beam in position before concreting and later provide resistance to shear after the concrete beam is set. Stirrups also provide critical anti-burst buckling restraint to highly loaded compression reinforcement at the sides of the beam. This would be usually at the bottom next to the support or at the top in mid span for a cantilever. This is why often "links" are required additionally to restrain highly loaded compression bars which are not on the sides of the beam. Stirrups are vertical (and sometimes diagonal) to resist shear because shear failure in a beam causes diagonal cracks.

Apart from stirrups, binding wires play a significant role in holding the rebars during construction. Rebar (short for reinforcing bar), collectively known as reinforcing steel and reinforcement steel, is a steel bar or mesh of steel wires used as a tension device in reinforced concrete and reinforced masonry structures to strengthen and hold the concrete in tension. Rebar's surface is often patterned to form a better bond with the concrete (Veerapandu and Ramakrishna, 2018). Binding wires are used for tying rebars to hold the structure intact. The primary and secondary reinforcement are tied together with binding wire made of mild steel. Binding wires, although a very small and seemingly insignificant component of a building, is very essential. It is majorly used to hold the rebar firm at a particular joint. It is a product of mild steel inker from a process called thermal annealing. It is also known as annealed wire.

Stirrups connections in reinforced concrete beam structure are very important elements in transferring load in the beams. Improper stirrups spacing could result to failure. Failure occurs in a structural member when it cannot keep up with further increase in load without deformation. Reinforced concrete beams can fail in various ways such as;

Flexural Mode: In flexural mode failure type, plastic hinges will form at points where the ultimate bending capacity is achieved.

Combined Flexure-Shear Mode: The combined flexure share mode occurs when the flexure cracks and tension cracks forms an inclination within its shear span.

Shear Compression Mode: The shear compression mode occurs when load is transferred to the supports in direct compression and the diagonal tension cracking reduces the element (Sayyad and Patankar, 2013).

With recurring incidence of collapsed buildings in Nigeria, there is urgent need to investigate the cause of these failures. Amongst the factors that lead to structural failure are;

Construction by unqualified personnel, Inappropriate foundation, Weak concrete mixture, Under or over reinforcing of a structure, Long interval stirrup spacing in RCC Columns, Long interval stirrup spacing in RCC Beams.This study provides an insight on the stirrups spacing intervals in reinforced concrete beam that will be most appropriate for construction works. Also the outcome of this research work will go a long way in providing data that will convince the engineers on the danger posed by careless and long interval stirrup spacing in structural work. Figure 1 shows a cross-section of encased beam.

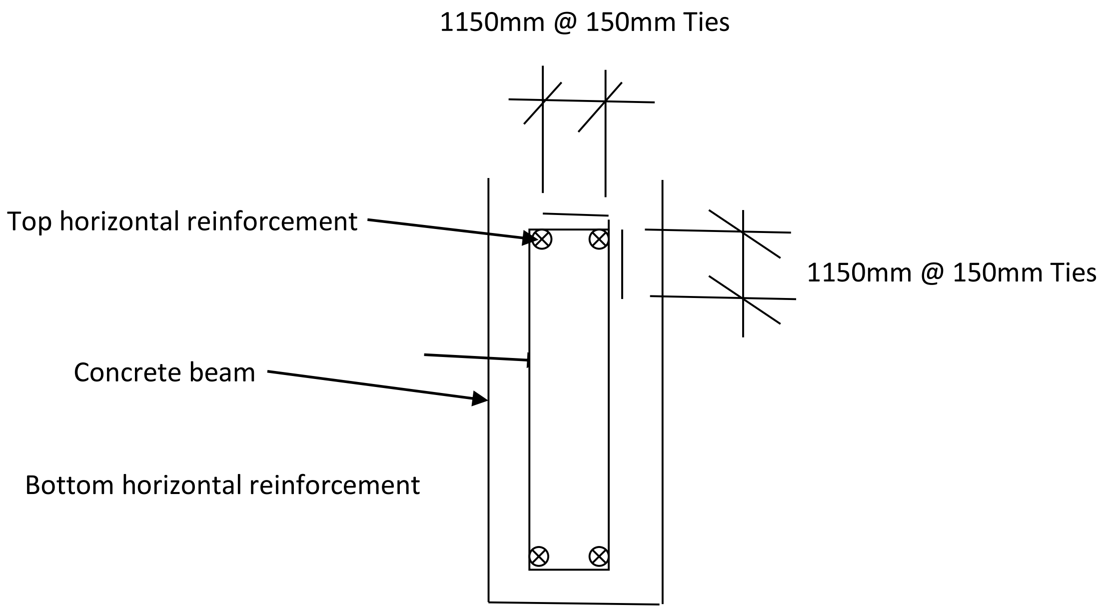

Figure 1: A cross-section of encased steel beam

Figure 1 shows the cross-section of the reinforced concrete beam with 12 mm steel used as main bars while 8 mm steel was used as the stirrup bars

2.1 Materials

Sharp sand (fine aggregate): It was sourced from Imo River which is the closest proximity of river sand to the laboratory. This river sand was chosen to ensure compliance with specifications given in BS 1377: part 2, 1990.

Gravel (coarse aggregate): Coarse aggregate of size 15 mm - 20 mm were obtained from Ishiagu in Ebonyi State. Ishiagu stone was chosen because, it is free from deleterious materials. Ishiagu stone has been proven by several researchers to meet the standard recommended in BS 1377: part 2, 1990.

Water: Tap water with PH 7 and fit for drinking were gotten from Civil Engineering laboratory, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria. This tap water was chosen because, experiment have shown that it complies with WHO standard for domestic household water.

Cement: Dangote cement was purchased at timber market Ahiaeke, Umuahia, Abia State, Nigeria. Dangote cement was chosen because of it quality and wild usability by construction workers in Nigeria.

Steel: Wrought iron steel of 12 mm diameter with average yield strength of 406 N/mm^2 were used as main steel while 8 mm diameter steel with average yield strength of 382 N/mm^2 were used as stirrup bars/shear reinforcements.

2.2 Method

2.2.1. Sieve analysis

i. Apparatus

Stacks of Sieves including pan and cover, Weighing Balance, Rubber pestle and Mortar, Mechanical sieve shaker, Oven, Various pans, Scoop, Brass wire brush, Bristle brush and Pan.

ii. Procedure

The samples were oven dried and made free from deleterious materials. After which the standard procedure as explained in BS410 1986 were followed to achieve the particle grain size distribution.

2.2.2 Slump Test

i. Apparatus

Figure 2 shows the Metallic mould (in the form of frustum of a cone having internal diameter of 200mm bottom, 100 mm top and 300 mm high, A steel tamping (rod of 16mm diameter. 0.6 m long with bullet end) and measuring rod/ruler.

ii. Procedure

The test was accomplished by following the step by step procedure listed in BS EN12350 part 2. The results is always classified in three forms, collapsed, shear and true slump as shown in figure 3. The Slump test results is as shown in Figure 4.

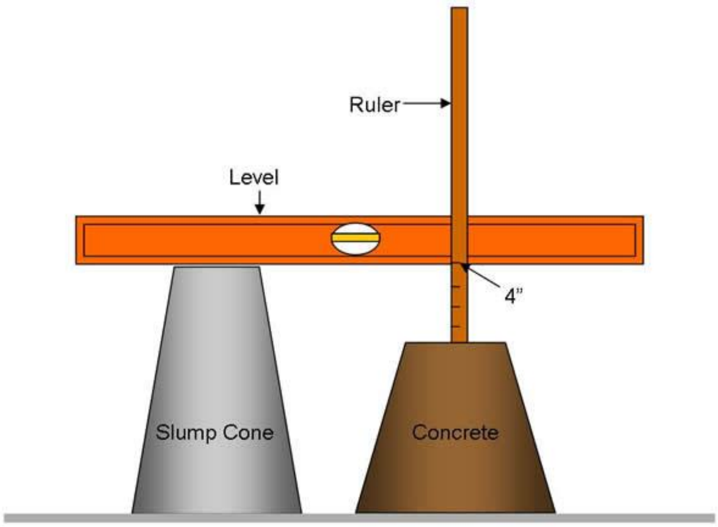

Figure 2: Apparatus for slump experiment

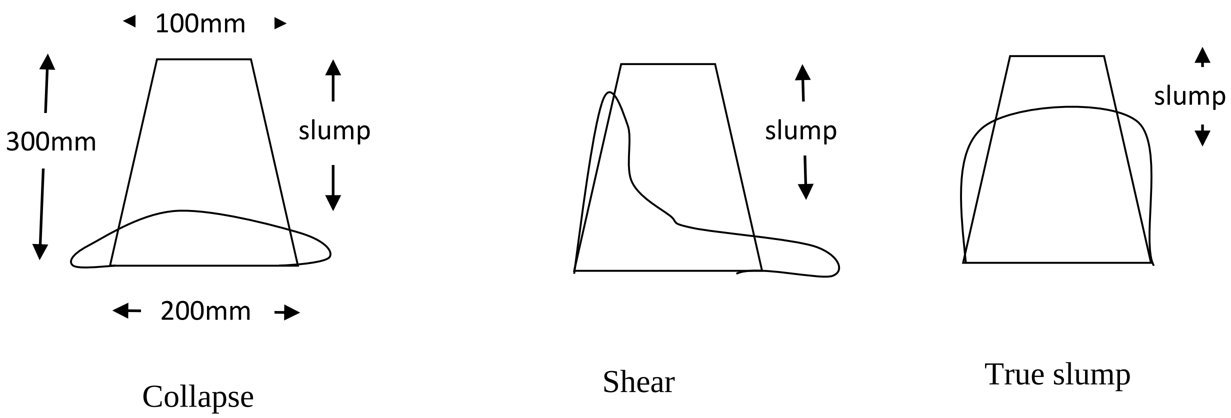

Figure 3: Types of slump

2.3 Specific Gravity of Fine and Coarse Aggregate

i. Apparatus

Riffle box**,** 30ml density bottle (Pycnometer) with stopper**,** Constant water bath **v**acuum desiccators**,** Dry oven maintaining temperature. 105°C-110°C, Test sieve 2 mm and 10 mm**,** Balance readable to 0.01 g**,** Wire mesh basket**,** Cry absorbent cloths**,** Shallow tray**,** Water free of impurities and Glass rod.

ii. Procedure for Fine Aggregate Test:

The procedure listed in BS 1377: part2: (1990) was duly followed to determine the density of the fine aggregate with the help of equation (1) as shown.

$$P = \frac{M_2 - M_1}{(M_4 - M_1)(M_3 - M_2)} \times 100 \qquad 1$$

iii. Procedure for Coarse Aggregate Test:

The procedure for coarse aggregate test which were written in BS 1377 part 2: (1990), were adopted and the following Equations (2, 3 & 4) employed as stated by the code.

$$\text{Specific gravity} = \frac{C}{B-A} \qquad 2$$

$$\text{Water absorption} = 100\,\frac{B-C}{C} \qquad 3$$

$$A = A_1 - A_2 \qquad 4$$

2.4 Flexural Test

The objective here is to determine the Flexural strength (Modulus of Rupture) of concrete beams reinforced with 12 mm steel bars with 8 mm stirrup spacing at intervals of 150 mm, 200 mm, 300 mm, 400 mm, 600 mm and 1200 mm.

Plate 1: Reinforcement Bars

Plate 1 is the pictorial view of already prepared reinforcement specimen that is ready to receive concrete

ii. Apparatus

Formwork: Metal formwork was prepared using 2 mm metal plate and 5 mm metal angle bar. The formwork was fabricated to assume an internal dimension of 1200 mm (length) X 225 mm (depth) X 150 mm (width).

Trowel: This is a Mason's hand tool which is used to spread mortar on the blocks during block laying and also spread concrete mix in concrete dressing. It has varying types and sizes for specific works.

Spade: The spade is used in the construction site for moving portions of materials such as earth and mortar from one place to another over a short distance. It can be used for digging. They are also used to carry or spread concrete mix evenly.

Head Pan: Head pans are used in the site for measuring of fine and coarse aggregation in volume.

Porker Vibrator: The is a machine that compacts concrete during its operation by the removal of air bubbles

Wheel Barrow: This is a manually operated vehicle which is used for transporting blocks, concrete mix and materials to places where they are needed on the site.

Universal Testing Machine: This is a combination of computerized electronics/electrical hardware and mechanically operated force application device. It automatically measures and store maximum force applied and displays it in a digital display screen.

Concrete Mix Design

All concrete produced with ingredient (Cement, fine aggregate, coarse aggregate, and water) for the purpose of this experiment were done with 1:2:4 mix ratio.

iii. Beams Preparation Procedure

All beam reinforcement specimens were of length 1150mm and cross-section of 175mm (depth) X 100 mm (width). The prepared concrete mix was poured into the steel mold housing the reinforcement as three layers of equal thickness and compacted until the mix became homogenous. The beams produced were cured in the laboratory for a period of 7, 14, 21 and 28 days after casting, in atmospheric temperature of 25^{o}C. Seventy two specimens were tested in order to investigate the effect of proposed positions of stirrup design for short deep beams. Picture of specimens' stirrups spacing are given in Plate 1. The thickness of concrete cover was selected as 25 mm to prevent splitting failure of concrete.

Test Procedure

Flexural tests of moist-cured specimens were made 24 hours after removal from the moist storage chamber. The specimens were surface dried to reduce the measured modulus of rupture. The procedure described in ASTM C293-02 were adopted. The flexural strengths were then calculated by applying Equation (5) as posited in the code.

$$R = 3\,PL/2bd^2 \qquad 5$$

Plate 2: Universal Testing Machine

Plate 2 is the picture of the universal testing machine used to test for the flexural strength of the concrete specimen.

3.1 Results and Discussions

3.1.1 Specific Gravity Test Results

The specific gravity for both fine and coarse aggregate are as shown on Table 1. The test is performed to measure the strength and quality of the materials. It is the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water. Aggregates that have low specific gravity are generally weaker than aggregates that have higher specific gravity values. The above statement is the reason why specific gravity of aggregates are very important to construction engineers. According to the code BS812, part 2, the specific gravity of a good construction aggregate should fall within the range 2.5 to 3.0 with an average of about 2.68. From Table 1, it is obvious that the specific gravity of both fine and coarse aggregate are 2.73 and 2.81. These values are above average, within the range and in conformity with the code.

Table 1: Specific gravity results

S/No	Materials	Specific Gravity
1	Fine aggregate	2.73
2	Coarse Aggregate	2.81

3.1.2 Sieve Analysis Results for Fine and Coarse Aggregate

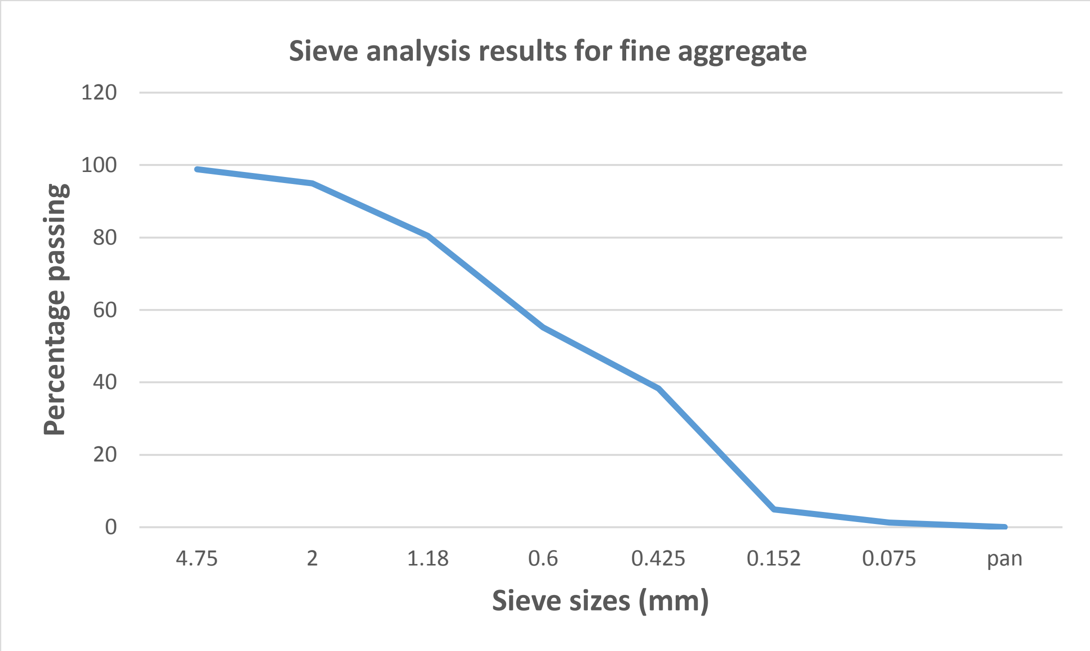

Figure 1: Graph for Particle Size Distribution of fine aggregate

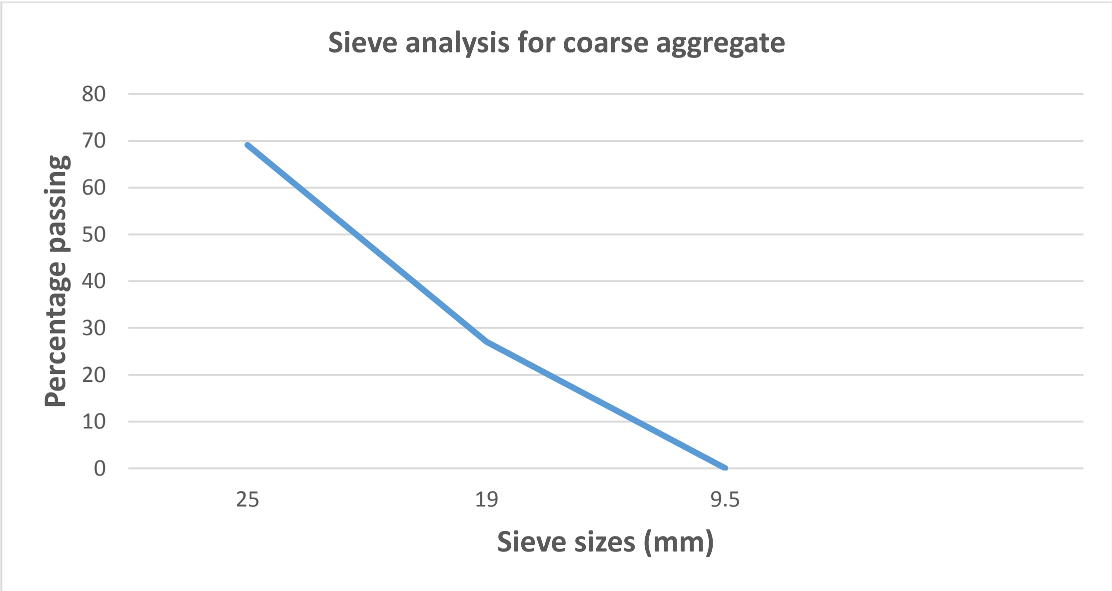

Figure 2: Graph for Particle Size Distribution of coarse aggregate

3.1.3 Slump Test Results

Figure 3 was used to determine the workability of the concrete by measuring the slump height of the concrete poured into a conical cylinder. Low slump confirms high level of workability and low strength because of the high level of water cement ratio. However, to ensure that the concrete flow and compact very well, an average workability must be achieved. The slump height of 101mm, 120mm, 158mm and 160mm are very good for obtaining the minimum required strength for a concrete. At these height, the concrete water cement ratio is good and will demonstrate a good workability. From figure 3, it is observed that workability decreases as the aggregate sizes increase vice versa. The above statement implies that lesser aggregate sizes yields higher strength concrete due to easy compaction and lesser air void.

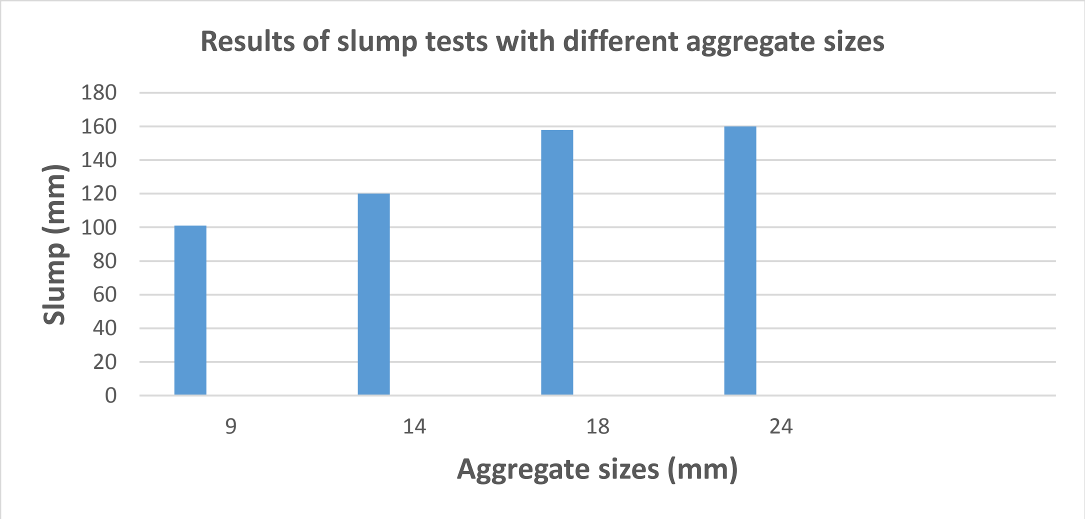

Figure 3: Slump test results for different aggregate sizes with the same water cement ratio and mix proportion

3.4 Flexural Strength Results

A total of seventy two specimens were casted and tested. All the specimens had dimensions of 150mm x 225mm x 1200mm. The beams were provided with same longitudinal reinforcement of 2 numbers of 12 mm diameter bars at tension region (below) and 2 hanger bars of 12 mm diameter at top (compression region) with 8mm stirrup spacing at intervals of 150mm, 200mm, 300mm, 400mm, 600mm and 1200mm. The flexural strength of the specimens was inferred from its failure load.

3.4.1 Flexural Strength Bar Charts For 7, 14, 21 and 28 Days

Figure 4 shows the flexural strength of the 12 mm steel bars tied with 8 mm stirrup spacing steel bars at different ages ranging from 7days, 14days, 21days and 28days. A closer observation indicate that the lesser the stirrup spacing the higher the strength of the concrete beam vice versa. Also the older the concrete beam the higher the flexural strength. That is why concrete at age 28 days possesses higher flexural strengths in all the ranges of stirrup spacing considered than when compared with other ages of the same spacing. Investigations have shown that most construction engineers do not pay attention to the stirrup spacing recommended by design calculations. They leave this huge responsibility to the hands of skilled reinforcement labourers (iron fitter) to carry out as he chooses. However, the practice is wrong and need to be corrected. Hence, it is recommended that stirrup spacing specifications obtain in design should be followed strictly in construction.

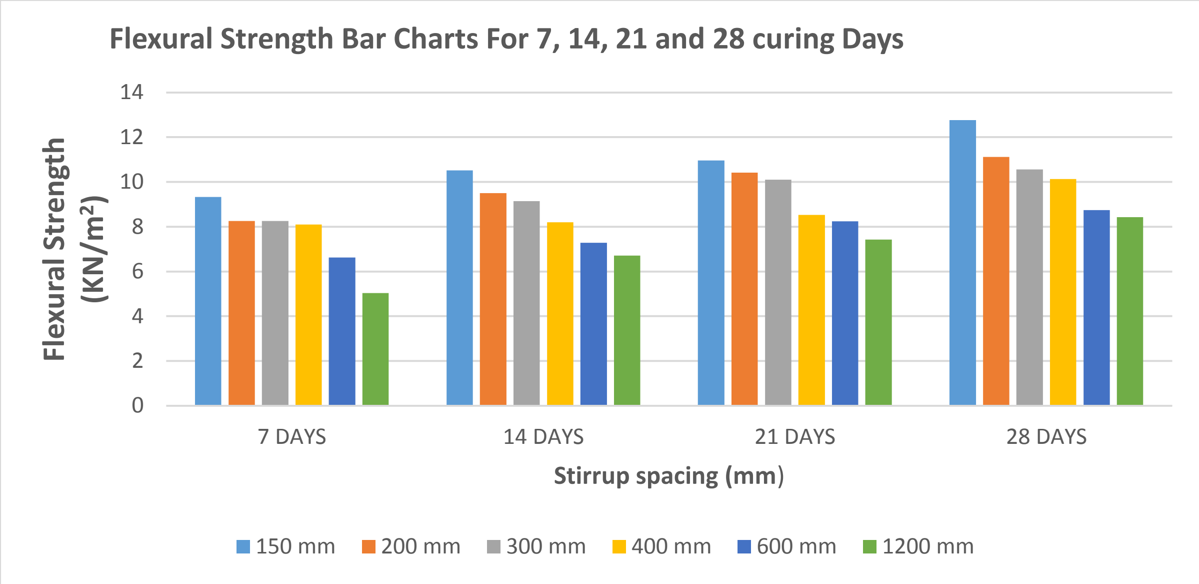

Figure 4: Flexural strength bar chart for 7, 14, 21 and 28 curing days

4.1 Conclusions

From the experimental study on effects of stirrups spacing on the strength of a concrete beam it can be concluded as follows, Increase in ultimate failure load was observed in Reinforced concrete beams with 150mm stirrups.

The change in the spacing of the stirrups had much effect on the ultimate failure load and flexural strength of the beams.

The beams with close stirrups spacing of 150 mm, 200 mm and 300 mm had greater values of flexural strength and hence will resists greater shear and diagonal tension stresses in a concrete structural member than the beams with very wide stirrups spacing.

Flexural strength decreases with increase in the stirrup bar spacing, however excessive quantities of stirrup bar increases the rate of cracking in the beam when subjected to external load.

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