JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

STRUCTURAL ENGINEERING STREAM

Low Cyclic Load Behavior of Reinforced Concrete Beams

A research submitted to the school of graduate studies, Jimma Institute of Technology, Jimma University as a partial requirement for the Masters of Science Degree in Civil Engineering (Structural Engineering)

By

Abinet Alemseged

April, 2017

Jimma

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Advisor: - Dr Esayas G/ Youhannes (PhD)

Co-Advisor: - Engr. Elmer C. Agon

DECLARATION

I, The undersigned declare that this thesis entitled "**Low Cyclic Load Behavior of Reinforced Concrete Beams**" is my original work, and has not been presented by any other person for an award of a degree in this or any other university, and all sources of material used for these have been dually acknowledged.

Candidate:-

Abinet Alemseged

________________________ ________________________

Signature Date

As Masters research Advisors, we hereby certify that we have read and evaluate this MSc research prepared under our guidance, by Ms Abinet Alemseged entitled: Low Cyclic Load Behavior of Reinforced Concrete Beams

We recommended that it can be submitted as fulfilling the MSc thesis requirements.

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Signature Date

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ABSTRACT

In the present scenario, the design of concrete structure needs accurate knowledge on the behavior of concrete. Information is available on the static load behavioral condition of concrete but limited information on the cyclic loading of concrete. The objective of the study is to examine the cyclic loading behavior of reinforced concrete beams.

The present study has focused on investigating the effect of cyclic loading on the failure mode of reinforced concrete beam under bending. The cyclic loading of concrete was achieved by loading-unloading-reloading, for a short duration, in a specific stress range and for a few numbers of cycles.

The experimental investigation included testing of six reinforced concrete beams. All beams have equal dimensions and length. The only variable was the ratio of web reinforcement. Four of the specimens were tested under a cyclic loading, at the stress range of 0 to 92 % of the yield loading and ultimate load for few numbers of cycles then loaded till failure. The remaining specimen was tested under monotonic loading till failure.

The results of cyclic loading tests were compared with the beam tested under monotonically loaded. The mode of failure for Test Beam-1, which is loaded under cyclic loading in a single side, and Test Beam-4, which tested under cyclic loading and monotonically for reverse side was investigated. The shear cracks occurred before the yielding of longitudinal reinforcement. This is different from expected mode of failure which shows the cyclic loading change the mode of failure of the beam. While checking Test Beam-2 and Test Beam-3, the beams failure were due to yielding of longitudinal reinforcement followed by concrete crushing as expected. The result of this test shows that up to 15% of flexural to shear capacity ratio, the mode of failure of the beams in this experimental result were changed.

It was recommended that follow up study on high cyclic loading, and low cyclic loading for deep beam, pre-stressed beam and composite beam should be done to validate the overall results.

Key words*: RC beam, shear, yielding, cyclic load, monotonic loading*

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CHAPTER 1

INTRODUCTION

1.1 Background

The use of cementing material in all construction aspect starts in ancient years. The ancient Egyptians used calcite impure gypsum. The Greeks and the Romans used calcite limestone and later learned to add to lime and water, sand and crushed stone or brick and broken tiles. This might be the first concrete in history. These days, concrete and steel are the two most commonly used structural material. They sometimes complement one another, and sometimes compete with one another so that structures of a similar type and function can be built in either of these materials. And yet, the engineer often knows less about the concrete of which the structure is made than about the steel, it demands additional knowledge of its behavior under several types of loading and collapse issue.

Rational design of concrete structures requires an accurate knowledge of concrete properties under anticipated loading conditions. A large volume of information is available on behavior of concrete under static loading conditions. However, relatively limited information is available on behavior of concrete subjected to cyclic loadings.

In recent years, a profound interest has developed towards the cyclic behavior of concrete. Firstly because there is always concern about the effect of repeated loads on concrete structures, and secondly, even if repeated loads do not cause a fatigue failure, it may lead to inclined cracking in a beam at lower than expected loads, or may cause cracking in component materials of a member that alters the static load carrying characteristic.

Design codes are constantly being upgraded in many countries including Ethiopia as new loading requirement dictates for higher strength demands of structural members. In Ethiopia most of the existing buildings were designed based on the provisions of EBCS-1995 codes. Based on the research carried out at department of Geophysics, AAU the expected ground acceleration has increased and new design codes have been released as of 2015. Recently, the design code was revised for higher strengths demanded of structural members. In most areas or zones the bed rock acceleration has been increased to double in the recently design code. This reason made the researcher do this inquiry on cyclic loadings in RC beams.

Many researchers conducted experimental studies about cyclic loading such as: Sinha (1964), Karasan and Jirsa (1969), Sakai and Kawashima (2000) and Bangash (2001). The results of the previous experimental researches showed that repeated loading and unloading do not influence the behavior of concrete.

This research was undertaken to evaluate the behavior of reinforced concrete under cyclic loading for a few numbers of cycles, the report also provides extensive listing of references related to fatigue behavior of plain concrete, reinforced concrete, and reinforcing steel for reader interested in further in depth study of behavior of concrete subjected to fatigue loadings.

1.2 Statement of the Problem

In the present scenario, the design of concrete structure needs accurate knowledge on the behavior of concrete. Information is available on the static load behavioral condition of concrete but limited information on the cyclic loading of concrete. These researches evaluate the behavior reinforced concrete beam under cyclic loading for a few numbers of cycles, in a specific range of stress.

1.3 Objective

General Objectives

The general objective of this study is to examine the behavior of reinforced concrete under static cyclic loading for a few numbers of cycles.

Specific Objectives

To support the above general objectives, the following specific objective was sought:

- To check wither the cyclic load alter the mode of failure of reinforced concrete members, and to what ratio of shear to flexure load capacity of RC members do the failure mode changes under cyclic loading.

- To provide experimental data to validate finite element models being developed for another research project.

1.4 Significance of the study

The Ethiopian building code standard has been revised after two decades. The new design code has emerged with increased peak ground acceleration. And the existing structures are inadequate due to the increment in peak ground acceleration. So it is necessary to give good and effective solutions of rehabilitation for existing structures.

Cyclic load changes the mode of failure from flexural to shear type in the beams. Shear failure is a brittle mode of failure; and thus rehabilitation of existing structure is needed. Even if strengthening the existing structure is made we do not know what percentage of flexural to shear capacity ratio does strengthen the structure. This study checks that the cyclic loading alters the mode of failure of RC members from flexural to shear and percent difference between shear and flexure capacity.

1.5 Scope and Limitations

In this study an attempt is made to investigate the monotonic load and cyclic load resistance of reinforced concrete member. The tests are also intended to provide the percentage that the failure mode of RC member changed from pre designed mode of failure.

The current study does not cover:

- Only normal slender beams with internal force of flexure and shear were included in this research. Deep beams, beam-columns, pre-stressed beams
- Different types of cyclic load were not studied; a low cycle load has been applied.
- Size effect of specimens with different dimensions was not considered.
- One mix composition for each concrete type was tested, so the effects of different mix composition and different grade of concrete is not considered.

CHAPTER 2

LITERATURE REVIEW

In recent years, considerable interest has developed in the fatigue behavior of reinforced concrete members. There are several reasons for this interest. The widespread adoption of ultimate strength design procedures and the use of higher strength and more durable materials require that structural concrete members perform satisfactorily under high stress levels for a longer period of time. There is also a new recognition of the effects of repeated loading on a member, even if repeated loading does not cause a fatigue failure. Repeated loading may lead to internal cracking of a member that alters its stiffness and load-carrying characteristics ACI Committee 215(1974). There has been significant research conducted on the fatigue of reinforcing steel Helgason and Hanson (1974); Corely et. Al (1978).; Tilly (1982); Moss (1982), plain concrete Shah and Chandra (1970); Hordijk and Reinhardt (1992) and the bond between the steel and concrete Rehm and Eligehausen (1979); Balazs (1991). Verna and Stelson did some limited work on reinforced concrete beams in the 1960s.

2.1 Cyclic/Fatigue Loading of Structural Members

Quite a while ago, engineers discovered that if you repeatedly applied and then removed a nominal load to and from a metal part (known as cyclic load), the part would break after a certain number of load-unload cycles; even when the maximum cyclic stress level applied was much lower than the Ultimate Tensile Stress (UTS), and in fact, much lower than the Yield Stress (YS). They discovered as they reduced the magnitude of cyclic stress, the part would survive more before breaking. This behavior became known as “Fatigue” because it was originally thought that the metal got “tired”. In summary, when a ductile metal is loaded so that the load is gradually increased from zero to a max, final rupture of the material is produced by very large strains. However, if the same material is subjected to repeated loads, failure may occur as a result of stresses much lower than the elastic limit and there will be no plastic deformation in the region of the fractures. Most often, there is usually no prior indication of impending failure. Both tensile and compressive stresses can lead to fatigue damage. The process of fatigue consists of three (3) stages: a) Initial fatigue damage leading to crack nucleation and crack initiation. b) Progressive cyclic growth of a crack (crack propagation) until the remaining uncracked cross-section of the part becomes too weak to sustain the loads imposed. c) Final, sudden fracture of the remaining cross-section.

There are three (3) different types of fatigue loading/ cyclic loading:

1) Zero-to-max-to-zero: Where a part which is carrying no load is then subjected to a load, and later, the load is removed, so the first part goes back to no-load condition. Example: chain used to haul lugs behind a tractor.

2) Varying loads superimposed on a constant load: The suspension wires in a railroad bridge are an example of this type. The wires have a constant static tensile load from the weight of the bridge, and an additional tensile load when a train is on the bridge.

3) Fully-reversing load: Once cycle of this type of loading occurs when a tensile stress of some value is applied to an unloaded part and then released, then a compressive stress of the same value is applied and released. A rotating shaft with a bending load applied to it is a good example of fully reversing load.

2.2 Fatigue Behavior of Plain Concrete

Concrete does not have a fatigue limit, that is, a ratio of applied stress to static ultimate strength (stress-strength ratio) below which the concrete can withstand an infinite number of loading cycles. Therefore, the fatigue limit of concrete is taken as the maximum stress-strength ratio at which failure occurs only after a large number of cycles, usually 10^7. In normal strength concrete, the fatigue limit thus defined is approximately 55 % of its static ultimate strength. The fatigue strength of concrete is sensitive to several factors, most of which are associated with the details of the applied loading. The number of cycles of loading to failure depends on the level of cyclic stress applied to the specimen. As shown in **Figure 2.1**, as the stress-strength ratio is increased, the number of cycles to failure decreases. Also, the range of maximum to minimum cyclic stress has an effect. As the difference between the two stresses increases, the number of cycles to failure decreases. ASTM Standard (2006)

Hordijk and Reinhardt (1992) studied the fatigue behavior of plain concrete and concluded that the propagation of cracks leads to failure of concrete, although the exact mechanism is not clear.

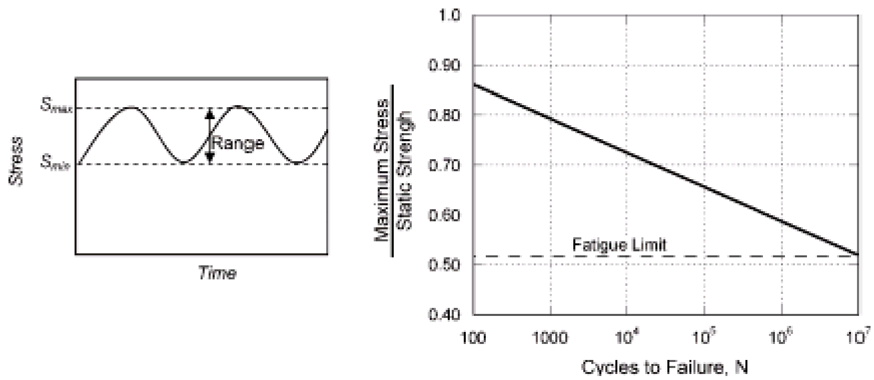


Figure2. 1 **Schematic of cyclic load history and fatigue strength curve of concrete**

2.3 Fatigue Behavior of Steel Reinforcement

Fatigue failure of reinforcing steel is caused by a microcrack that initiates at a stress concentration on the bar surface. The crack gradually propagates as the stress continues to cycle. Sudden fracture occurs when the crack reaches a critical length at which its propagation becomes unstable. Thus, the fatigue life of reinforcing steel is equal to the time or number of cycles to crack initiation plus the duration of crack growth. Crack initiation typically occurs at the location of the largest stress concentration, usually at the intersection of transverse lugs and longitudinal ribs. The fatigue strength of reinforcing bars depends on chemical composition, microstructure, inclusions, minimum stress, bar size, type of beam, geometry of deformations, yield, and tensile strength, etc ACI Committee 215 (1974). The lowest stress range known to have caused a fatigue failure of the bars in a concrete beam is 145 MPa Helgason and Hanson (1974). Additionally, the fatigue strength of reinforcing bars may be only one-half of the fatigue strength of coupons machined from samples of the bars Corley et. al.(1978). Since fatigue strength is significantly affected by physical characteristics (lug geometry, diameter of the bars, and the grade of the bar), the variables related to these physical characteristics are of great concern Corley et. al.(1978). Helgason and Hanson (1974) conducted a statistical analysis of test data from deformed bars tested axially in air. They concluded that the lowest average stress range on reinforcing steel that causes fatigue failure is 165 MPa and derived the following fatigue life relationship:

$$\text{Log}(N) = \frac{6.969}{0.00055Sr} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots... (1)$$

Where:

N = number of cycles to failure; and

sr = stress range applied to the steel in MPa.

Another analysis of experimental results, conducted by Moss (1982), derived the following fatigue life relationship for axially loaded reinforcing bars embedded in concrete:

Nsmr = K …………………………………………………………………… (2)

Where:

smr = stress range within tensile reinforcing steel in MPa;

N = number of cycles to failure;

m = inverse slope of log sr–log N curve = 8.7;

$K = 0.11 \times 1029$ for the mean line of the relationship; and $K = 0.59 \times 1027$ for the mean minus two standard deviations line.

As the concrete in a reinforced concrete beam cracks in the tension zone of the beam, high strain values and hence high stresses in the bar spanning the crack are developed. Since the maximum stress occurs at limited locations, it is less likely that these coincide with defects in the bar. This result in a longer fatigue life for reinforcing steel embedded in a concrete beam as compared with reinforcing steel subjected to the same stress range in air.

2.4 Fatigue Behavior of Reinforced Concrete

All the research cited above investigated the fatigue behavior of plain concrete and axially loaded reinforcing bars. However, the performance of a reinforced concrete beam also depends on the composite action between steel and concrete. Whereas an under reinforced member has its flexural fatigue performance dominated by the steel, a heavily reinforced member may fail in flexure or shear depending on whether the concrete or steel strength is critical. Research on reinforced concrete beams Liu Jin et al.(2016) concluded that shear fatigue failure could occur in beams with or without stirrups, the fatigue life of reinforcement being much the same whether it is longitudinal tensile reinforcement or transverse stirrups. As the fatigue loading of a beam progresses, and the subsequent cracks propagate, there is a redistribution of stress; thus, fatigue failure is not always by the same mechanism as static failure Corely et. al (1978).

The design of concrete structures is mainly depending on compression tests under uniaxial loading until failure occurs due to the crushing of concrete at ultimate strain. The typical shape of the stress-strain curve is closely associated with the mechanism of internal progressive micro-cracking, as shown in **Figure2.2**.

On the other side, many of engineering structures are subjected to the cyclic loading in service conditions. The cyclic loading is represented as a live load in the residential, industrial and hydraulic constructions. Many researchers offered experimental studies about cyclic loading such as: Sinha (1964), Karasan and Jirsa (1969), Sakai and Kawashima (2000) and Bangash (2001). The results of the previous experimental researches showed that repeated loading and unloading do not influence the behavior of concrete, so long as the value of stress does not exceed about 50 percent of the strength in compression, while a substantial decrease in strength as well as in stiffness is observed whenever stress exceeds about 85% of strength.

For each cycle of unloading and reloading, a hysteresis loop is formed, and the area of this loop decreases with each successive cycle, but eventually increases before fatigue failure. The stress-strain curve for monotonic loading serves as a reasonable envelope for the peak values of stress for concrete under cyclic loading, see **Figure2.2**.

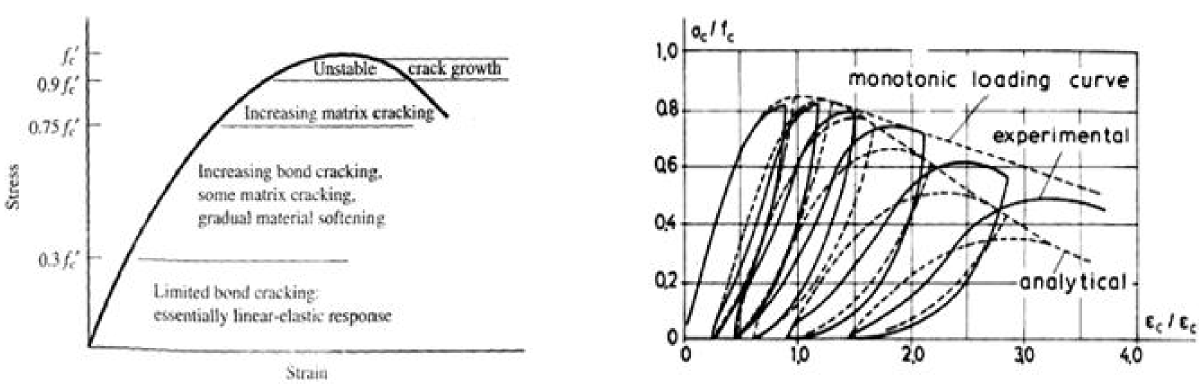


Figure2. 2 **Stress strain curve for monotonic and cyclic loading**

2.5 Loading-dependent Effects on Fatigue Behavior of Concrete

Fatigue loading usually falls into two categories, i.e. low-cycle and high-cycle loading. Low-cycle loading involves the application of a few load cycles at high stress levels. On the other hand, high-cycle loading is characterized by a large number of cycles at lower stress levels. M.K. Lee (2004) presented a wider range of fatigue load spectrum with the inclusion of super-high cycle loading. Table 2.1 summarizes the different classes of fatigue loading.

Table2. 1 Class of fatigue load; from M.K. Lee (2004)

Low-cycle fatigue			High-cycle fatigue				Super-high-cycle fatigue		
1	10^1	10^2	10^3	10^4	10^5	10^6	10^7	10^8	10^9
Structures subjected to earthquake			Airport pavements and bridges		Highway and railway bridges, highway pavements		Mass rapid transit structures	Sea structures	

The fatigue strength of concrete, defined as a fraction of the static strength that it can support repeatedly for a given number of cycles, is influenced by the range of loading, load history, the rate of loading, and rest periods.

The sequence of loading cycles is also significant. Miner's rule, which states that the effects of cyclic loads are cumulative, does not strictly apply to concrete Rather, the fatigue life, the number of cycles to failure, of a specimen is different if it is subjected first to high stress-strength ratios followed by low stress-strength ratios, than if subjected to the reverse sequence. Cycling below the fatigue limit increases both the fatigue strength and the static strength by 5–15 %. When the frequency of load application is low, the fatigue life is shortened compared with a higher frequency of load application. This is probably due to mechanisms of creep and crack propagation. Rest periods of up to 5 min during fatigue testing also increase the fatigue life; increasing the length of the rest period beyond 5 min has no additional beneficial effect ASTM Standard (2006).

CHAPTER 3

RESEARCH STRATEGY

3.1 Study Area

This chapter presents the experimental program of the current investigation. The experimental program consists of tests of six full scale reinforced concrete beams. RC beams were tested to evaluate their cyclic load behavior under cycling loading. Control beam were tested under monotonic loading. Also it presents material properties for reinforcement and concrete ingredient, construction process, loading application and instrumentation.

The study was conducted in Addis Abeba City, Addis Abeba Institute of Technology, Construction Material Laboratory.

3.2 Study Design

In the investigation reported here in, a total of six simply supported beams were tested under monotonic and cyclic loadings. The test aimed to investigate the behavior of reinforced concrete beam under cyclic loading. Each beam has six cubes (150mm x 150mm x 150mm) to determine compressive strength at 28 days and on the test day. Three cylinders with a dimension of 150mm diameter and 300mm height were casted to determine tensile strength of the concrete.

Initially the experimental program determines the engineering properties of reinforcement and concrete ingredient. The compressive and splitting tensile strength tests were carried out to clarify mechanical properties of reinforced concrete.

Entire reinforced concrete beams were subjected to loading. One beam was tested by reverse sided cyclic loading the rest are tested for zero to max to zero load condition (bending cyclic loading) and monotonic loading. The cyclic loading was carried out for a few numbers of cycles by loading unloading and reloading.

3.2.1 Test specimen

Six full- scale RC beams with rectangular shaped cross section and a total length of 1700mm were tested. The beam size used 200mm (b) by 250mm (D). All of the beams were simply supported over a length of 1300 mm center to center and subjected to central loads. This configuration creates two equal shear regions with lengths of 650 mm each. One beam were monotonically loaded to failure under load control and served as a control for all beams, because the expected yielding and ultimate load capacity for the beams under monotonic loading is the same. Three of those are test beams which tested by cyclic loading with single sided and two beam is tested by reveres side cyclic loading. In order to study the effect of cyclic loading the beams with (10%, 20% and 50% of flexural to shear load capacity ratio) were subjected to cyclic loads under load-control. Table 3- 1 gives distribution of web reinforcement for tested beams.

The expected mode of failure for all the tested beams is a yielding of longitudinal reinforcing bar. The configuration was designed to avoid bond failure and ensure flexural failure. The beams were reinforced with Grade 60 diameter 16mm deformed bar in the compressive and tensile zone. The clear concrete cover of 25 mm was kept constant for all the beams. One beam was without web reinforcement, however stirrups were provided outside the shear span to mount the longitudinal reinforcement and to prevent the anchorage failure. In order to avoid shear failure web reinforcement was provided, based on the flexural to shear load capacity ratio. A diagrammatical sketch of specimen's details is shown in **Figure 3.1** and **Figure 3.2**.

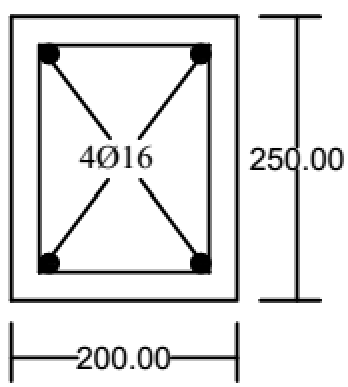
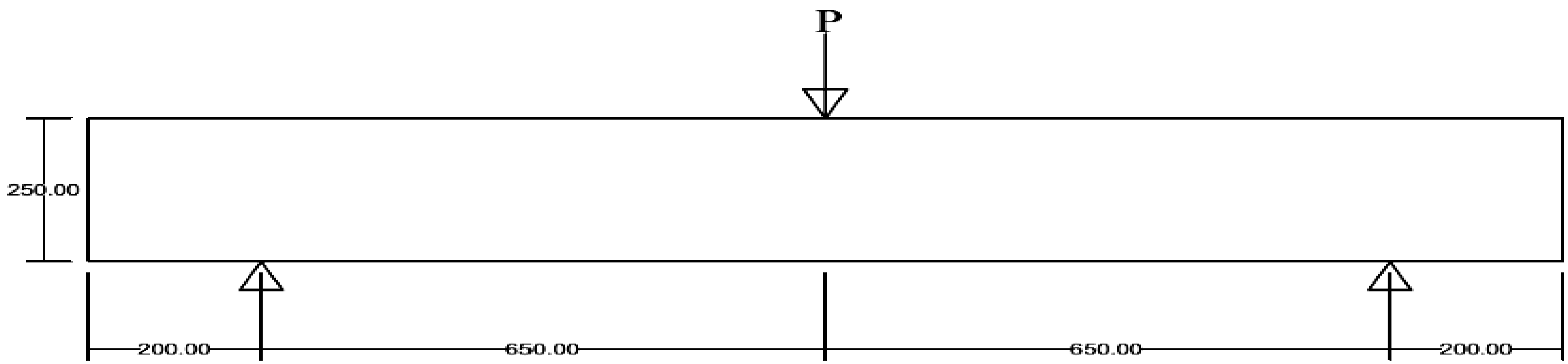
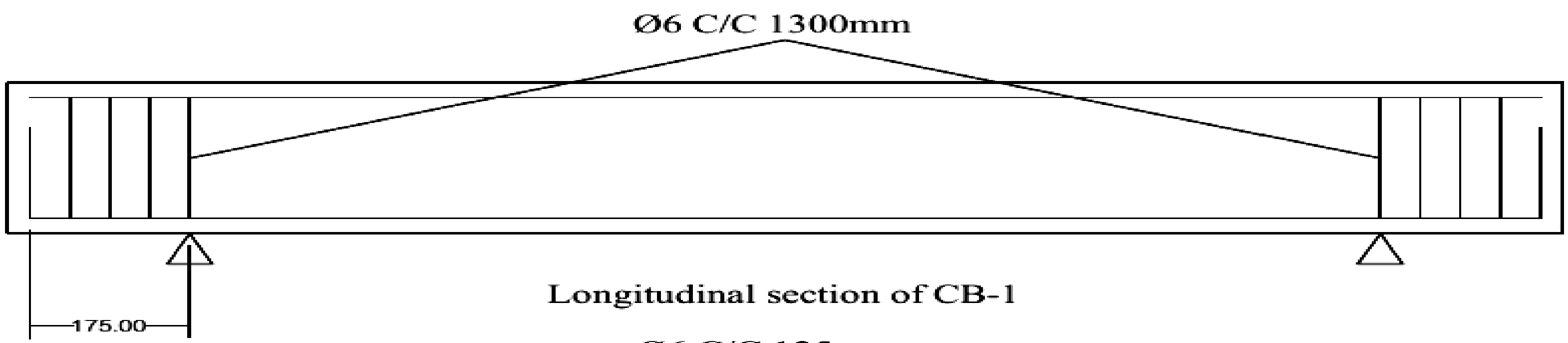


Figure3. 1 **Cross Section and Reinforcement Detail of Beams**

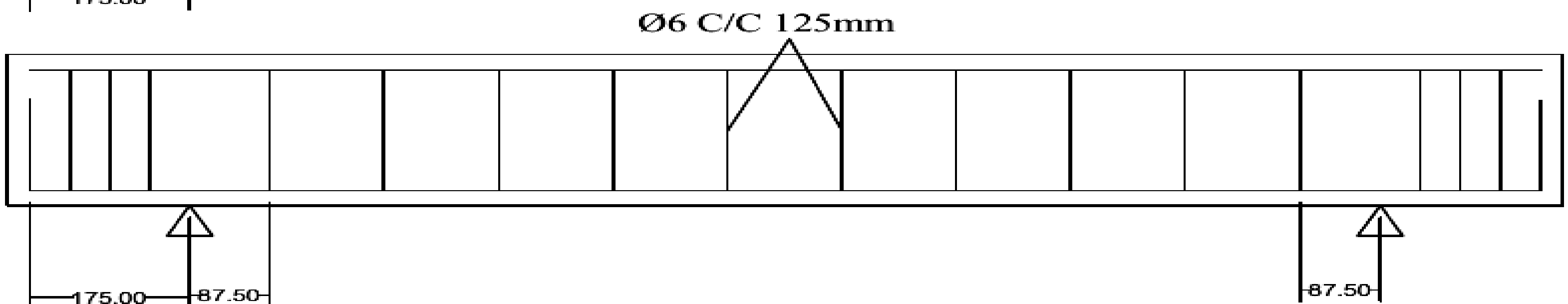
Note: All units are in mm



Longitudinal view



Longitudinal section of CB-1



Longitudinal section of CB-2 and TB-1

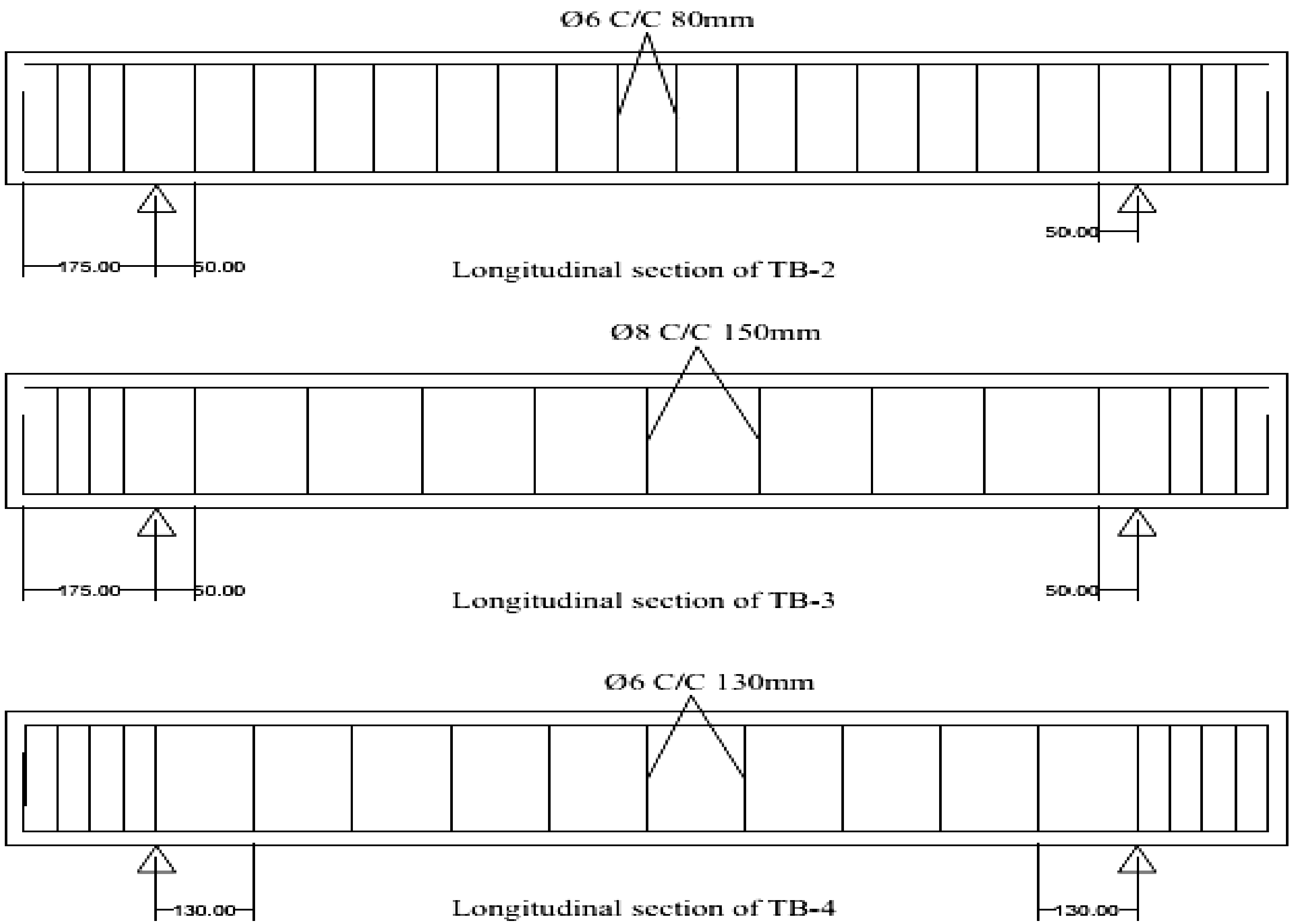


Figure3. 2 **Beam Types and Reinforcement Configuration**

Note: unless specified all units are in mm

Table3. 1Specimen detail

Beam Code	Beam Description	Stirrup Spacing (mm)	Load Intensity	Number of Sample
Control Beam-1	Design without web reinforcement	ϕ6 C/C 1300	Monotonic with Single Sided	1
Control Beam -2	Beam with the Ratio between Flexural to Shear capacity is 10%	ϕ6 C/C 125	Monotonic with Single Sided	1
Test Beam -1	Beam with the Ratio between Flexural to Shear capacity is 10%	ϕ6 C/C 125	Cyclic with Single Sided	1
Test Beam -2	Beam with the Ratio between Flexural to Shear capacity is 20%	ϕ6 C/C 80	Cyclic with Single Sided	1
Test Beam -3	Beam with the Ratio between Flexural to Shear capacity is 50%	ϕ8 C/C 150	Cyclic with Single Sided	1
Test Beam -4	Beam with the Ratio between Flexural to Shear capacity is 10%	ϕ6 C/C 130	Cyclic with Reverse Sided	1

3.3 Study variables

Dependent Variable: cyclic behavior of reinforced concrete.

Independent Variable:

- Reinforcement ratio
- Loading rate and type
- All the beams were constructed with a different distribution of web reinforcement to set the desired shear to flexural capacity ratio.

But the controlled variables of this experimental research were the quality of ingredients (cement, sand, aggregate and water), amount of water for curing, formwork type, compressive strength of concrete, water to cement ratio and dimension of beam.

3.4 Constituent Material

3.4.1 Concrete

Normal strength concrete of C 20/ 25MPa was used to cast rectangular beam. Ordinary Portland cement was used to prepare the concrete. The minimum design specification for each mix required a 28-day compressive strength of 25MPa, 80 - 100 mm slump, and a maximum aggregate size of 37.5 mm. The materials used in the concrete were coarse aggregate, fine aggregate, and cement etc. Fineness modulus, specific gravity, absorption capacity and moisture content for both fine aggregate and coarse aggregate are determined in the laboratory also compacted unit weight for coarse aggregate and specific gravity were determined.

After casting, the specimens are allowed to cure in laboratory temperature conditions for about 28 days. It helps the concrete to stabilize its own properties like compressive strength and modulus of elasticity. The strength of concrete under uniaxial compression is determined by loading standard test cubes (150mm) to failure in a compression testing.

a) Quartering of aggregate and sand b) Silt content of sand

Figure3. 3 **Material properties**

3.4.2 Reinforcements

In all test specimens except control beam 1 and test beam 3, plain reinforcement bar with a diameter of 6 mm is used. Control beam 1 is constructed without web reinforcement and 8mm diameter deformed bar was used as web reinforcement for test beam 3. The longitudinal bars used in all beams are 16mm diameter deformed bar, this are provided in the compression and tension zone of the beams. In this investigation before providing the reinforcement tests are conducted in the laboratory to determine the stress-strain characteristics.

Figure3. 4 **Reinforcement Testing Machine**

3.5 Test Specimen Fabrication

This section describes in brief the details of the specimen construction process. The test specimens were constructed at the Construction Materials Laboratory of AAiT. First the reinforcing steel cage was assembled in and placed the forms as shown in **Figure3.4 (a)**. Control cubes and cylinders were cast in plastic molds **Figure3.4 (b).** A vibrator was used to ensure good concrete compaction around the steel reinforcement. The concrete was allowed to set for one day until it stopped bleeding. The formwork was removed from the specimens. The RC beam, cubes and cylinders were cured in laboratory temperature and covered by plastic cover to prevent rapid water loss from exposed surface for 28 days. Following the water curing the specimens were stored at the same laboratory temperature condition to be tested.

a) Assembly of the specimen

b) casting of cubes

c) Casting and compaction of concrete

d) removal of formwork

e) Curing f) make ready the specimen for test

Figure3. 5 **Specimen Fabrication**

3.6 Test on Fresh Concrete

3.6.1 Slump Test

The slump test was determined in accordance with ASTM C143. The slump test is measure of relative fluidity and was performed to determine the consistency of the concrete. The test was run during the 3 minute-resting period of the mixing process.

Figure3. 6 **Slump test**

3.7 Test on hardened concrete

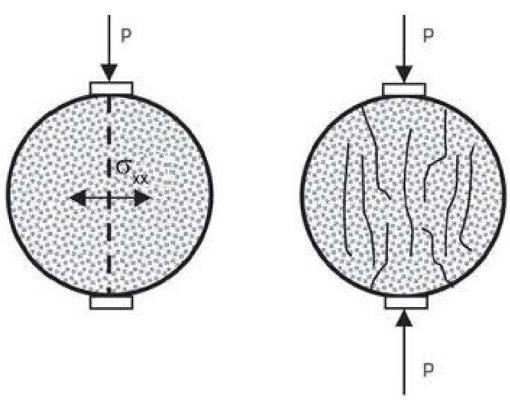
3.7.1 Compressive Strength Test

The concrete specimens were casted and tested in accordance with ASTM Standard. For each beams, a total of six cube specimens measuring with 150 × 150 × 150 mm. Three were casted and tested to determine compressive strength at 28 days. The rest three cubes were casted and tested to determine compressive strength on the test day.

Figure3. 7 **Concrete compressive test**

3.7.2 Splitting tensile strength test

Three cylinders 150 mm in diameter and 300 mm in height would utilized for the splitting tensile test. The setup and cracking patterns are shown in Figure below. The applied force rate was considered to be equal to 690-1380 kN/mm ^{2}/min.sec based on the ASTM C496.



Calculate the splitting tensile strength of the specimen as follows:

$$T = \frac{2P}{\pi l d} \qquad (1)$$

where:

T = splitting tensile strength, psi (kPa),

P = maximum applied load indicated by the testing machine, lbf (kN),

l = length, in. (m), and

d = diameter, in. (m).

Figure3. 8 **Concrete cylinder splitting tensile strength test**

3.7.3 Three point bending test

The 3 point bending test produces its peak stress at the specimen mid-point with reduced stress elsewhere. This stress localization was ideal for testing for specific isolation of stress on a component or material. For cyclical and fatigue testing, where specified force-displacement and force-time waveforms can be executed. This test method enables different strain rates to be induced onto a sample over a period of time, allowing analysis of cycles to failure as well as force-displacement and force-time characteristics to be determined.

3.8 Test setup

The beam was placed on steel plate supports for test; the beam has a roller connection with plates. These roller supports were installed on concrete members anchored to the strong floor. A concentrated load was applied using manual hydraulic jack, which have a maximum capacity of 320 kN. Zipper bags filled with gypsum was placed in between the roller support and beams to make a smooth contact surface and protected the beam from sliding. In this experiment the loading rate was ranged between 0.27-2.66 mm/min (0.25-2.4 kN/s). A frame which holds the deflection reading instrument was connected with the rods. This rod was anchored to a beam on both ends by drilling at the axis of rotation. The loading setup is shows in **Figure 3.8**.

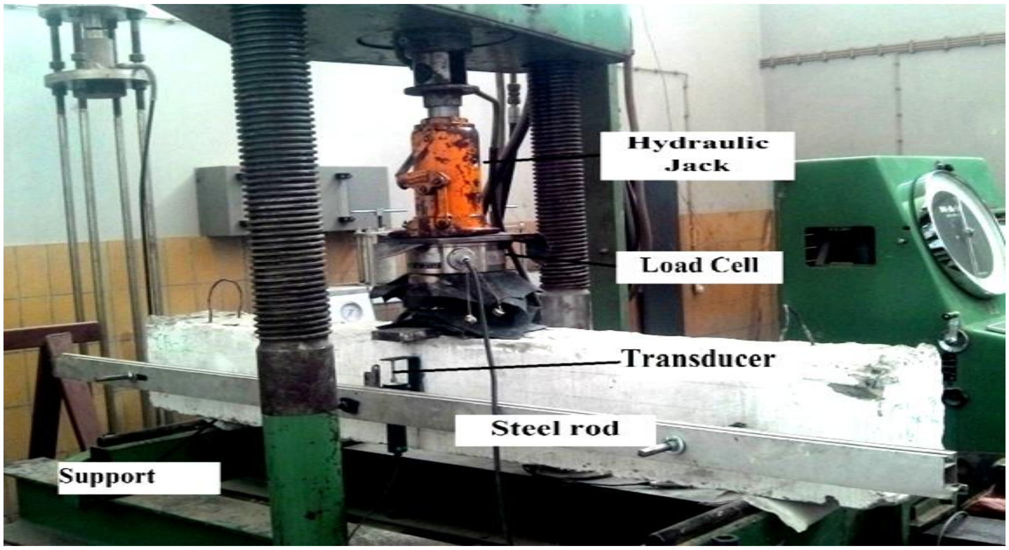


Figure3. 9 **Loading Setup**

3.9 Instrumentation

All beams were fully instrumented to measure the applied loads and deflections on the beams. The instrumentation consisted of a load cell which measures the applied load; two transducers are used to measure the mid span deflection. All of the instrumentations were connected to a data logger and the experimental data was directly obtained by a USB flash disk.

a) Displacement measuring tool **b) Load Cell**

c) Data Logger

d) Load applying hydraulic jack

e) Load system machine

Figure3. 10 **Instruments**

3.10 Loading History

TB-1, TB-2, TB-3 and TB-4 were subjected to cyclic bending load. In addition, those three beams (TB-1, TB-2 and TB-4) are subjected to constant cyclic load of 92% of yielding load for 40, 20 and 39 cycles respectively. The next cyclic load was applied equal to the monotonic failure load for 20 cycles. But TB-4, the test was stopped when the width of shear cracks are widen, this is because of the beam was test monotonically on the reverse side. Since the failure load of TB-3 much greater than the shear failure load, the beam was loaded simply for 92% of the ultimate flexural load for 20 cycles.

After the cyclic load was applied the beams are tested until failure. The specimens were displaced downward. Displacements at the mid-height of the beam were monitored on the transducers. The beams are tested under load controlled condition. For this reason the loads are taken as the reference point for the applied load Figure 3.10 depicts the cyclic loading history.

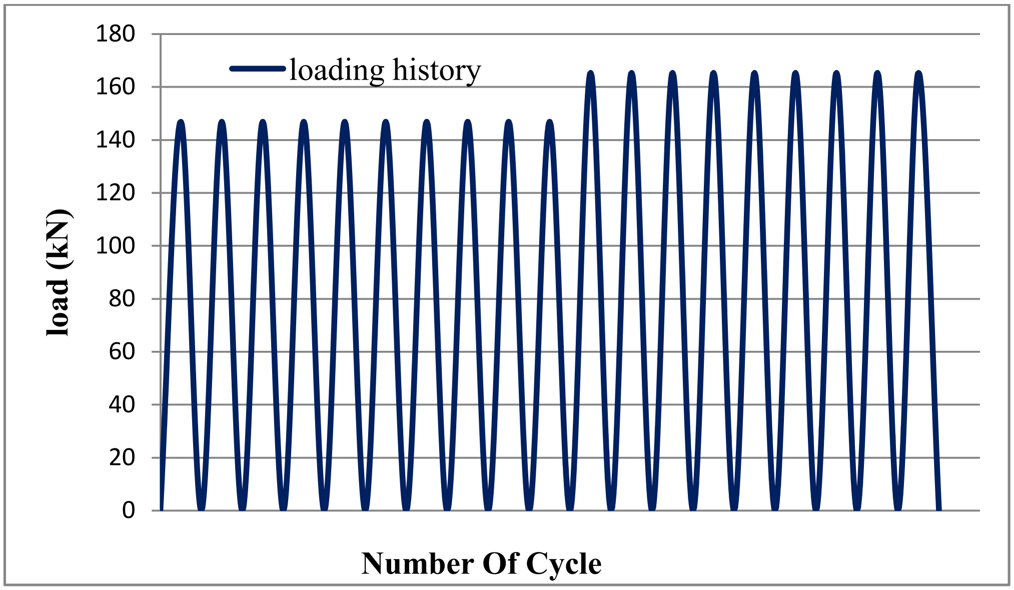


Figure3. 11 **Loading history for the specimen**

3.11 Data processing and analysis

The test results of the samples were compared with the respective control concrete Properties and the results were presented using tables, pictures and graphs. Conclusions and recommendations would finally forward base on the findings and observations.

CHAPTER 4

RESULTS AND DISCUSSION

Test results from the experimental program described in Chapter 3 are presented in this chapter for the constituent material tests, reinforcing steel test, monotonic concrete compression and split cylinder tests, the monotonic and cyclic loading beam tests.

The behavior and the results of beam that were tested monotonically and cyclically to failure were presented. The load deflection behavior, the mode of failure, the cracking load and the ultimate load of the beams are discussed.

4.1 Result for Constituent Materials

4.1.1 Mix design parameters

A summary of the properties of concrete ingredients used for the RC beams, for cubes and cylinders was given in Table 4.1. Reference data from ACI and ASTM were presented in Appendix for comparison purposes

Table4.1 Material Properties

Material Property	Coarse Aggregate	Fine Aggregate	Cement
Fineness Modulus	7.5	2.85	-
Compacted Unit Weight (kN/m^3)	1651.7	-	-
Specific Gravity	2.61	2.51	3.15
Absorption Capacity %	1.21	3.52	-
Moisture Content %	2.04	1.11	-
Water To Cement Ratio		0.62	

4.1.1.1 Mix proportion

All the RC beams are casted by normal weight concrete of C20/25MPa. The proportions of concrete mix are given in following table.

Table4. 2 Concrete Mix proportion

Materials	Quantity (Kg/m^3)	Ratio
Cement	287.65	1
Fine Aggregate	787.57	2.74
Coarse Aggregate	1191.46	4.14
Water	187.43	0.65

4.1.2 Monotonic Concrete Properties

4.1.2.1 Compressive Strength of Concrete

A summary of the compressive strengths of the concrete used for the RC beams is given in Table 4.3. For each concrete beam, the mean compressive strength f_c, was used in the theoretical calculations given in this chapter.

Table4. 3 Average Cylinder Compressive Strength at 28 and test days

Beam Code	Avg. Comp. Strength at 28 Days (MPa)	Testing Days (in days)	Avg. Comp. Strength at Test Days (MPa)
CB-1	22.39	80	27.66
CB-2	21.99	65	24.53
TB-1	21.83	75	29.19
TB-2	23.34	81	31.38
TB-3	23.51	82	30.51
TB-4	23.90	83	29.16

4.1.2.2 Direct Tensile Strength of Concrete

For the evaluation of the direct tensile strength of concrete, three cylinders are made and tested under tensile splitting test, mainly due to the complexity of the test equipment and execution of the experiments. The test results obtained cylindrical splitting test was compared by the result of control beams.

The correlation between the direct tensile strength and the equivalent cylindrical compressive strength is expressed. According to EC 2 and Model Code 2010 the direct tensile strength f_{ct} can be derived from the characteristic compressive strength f_{ck} according to Eqs. 1

$$\boldsymbol{ft}\, splitting = \mathbf{0.3} \times (\boldsymbol{fc'})^{\frac{2}{3}} \quad \text{.........................(1)}$$

$$\boldsymbol{ft}\, tensile = \mathbf{0.9} \times \mathbf{0.3} \times (\boldsymbol{fc'})^{\frac{2}{3}}$$

Table4. 4 Average tensile Strength at 28 and test days

Beam Code	Avg. Tensile Strength at 28 Days (MPa)	Testing Days (in days)	Avg. Tensile Strength at Test Days (MPa)
CB-1	2.04	80	2.35
CB-2	2.02	65	2.17
TB-1	2.01	75	2.44
TB-2	2.10	81	2.56
TB-3	2.11	82	2.51
TB-4	2.13	83	2.43

4.1.3 Reinforcing Steel Monotonic Properties

The uni-axial tensile stress-strain relationship for the reinforcing steel is summarized in Table 4.5 and Table 4.6 for each of the steel batches used for the construction of the concrete beams. All the main steel specimens exceeded the nominal 600 MPa yield strength, specified for Grade 60 reinforcing steel. All specimens demonstrated initial linear-elastic behavior up to the yielding of the steel. This was followed by plastic behavior and subsequent strain hardening, until the ultimate strength for the specimen was attained.

Table4. 5 Tensile strength of longitudinal reinforcement

Specimen Code	Diameter(mm)	Yield Load (kN)	Yield Stress (MPa)	Failure Load (kN)	Failure Stress (MPa)	Original Length (cm)	Final Length (cm)	Elongation (%)
I	15.33	111.93	638.32	132.90	757.47	20.00	22.93	14.67
II	15.06	114.23	641.29	134.70	756.18	20.00	22.90	14.50
III	15.41	112.65	621.8	133.75	734.6	20.00	22.75	13.75
IV	15.18	115.07	635.79	136.60	754.77	20.00	22.27	11.33
V	15.01	110.43	623.82	133.50	754.11	20.00	22.10	10.50

Figure4. 1 **Testing of longitudinal reinforcement**

Table4. 6 Tensile strength of web reinforcement

Specimen Code	Diameter(mm)	Yield Load (kN)	Yield Stress (MPa)	Failure Load (kN)	Failure Stress (MPa)	Original Length (cm)	Final Length (cm)	Elongation (%)
I	6.73	29.07	816.29	32.93	924.88	20.00	21.90	9.50
II	5.30	6.90	312.76	9.83	445.72	20.00	23.53	17.67

Figure4. 2 **web reinforcement testing**

4.2 Test Results for Reinforced Concrete Beams

For each beam, the results of the tests are presented. Along with the test details; the recorded data, crack patterns, and mode of failure are discussed. The predicted behavior of each beam is compared to the experimental results of the control beam.

The results of the monotonic bending load tests for CB-2 which is reinforced concrete beams are presented. These tests are used to determine the yielding load and failure mode at ultimate capacity. The results of the cyclic bending load tests are given for TB-1, TB-2, TB-3 and TB-4. These data are used to examine the mode of failure for the beams subjected to cyclic loading.

4.3 Beam Tested Under Monotonic loading

4.3.1 Mode of Failure for Monotonic Loading

The specimen tested under monotonic load was CB-2 beam which served as a control beam for the beams. Its load versus deflection curve is shown in **Figure 4.3**. The concrete cracked at a load of 26.76 kN. However, the expected cracking load was 26.73 kN. The beam appeared to have linear behavior until the cracking moment was reached. After this point, the linear behavior continued, but the stiffness was reduced. At this point, the slope of the load deflection curve decreased indicating that flexural stiffness of the beam had decreased.

The first hairline cracks appeared in the form of flexural cracks in the maximum moment region. Two cracks occurred at the same time, near to the center of the beam and the other two vertical cracks are occurred in the critical shear region.

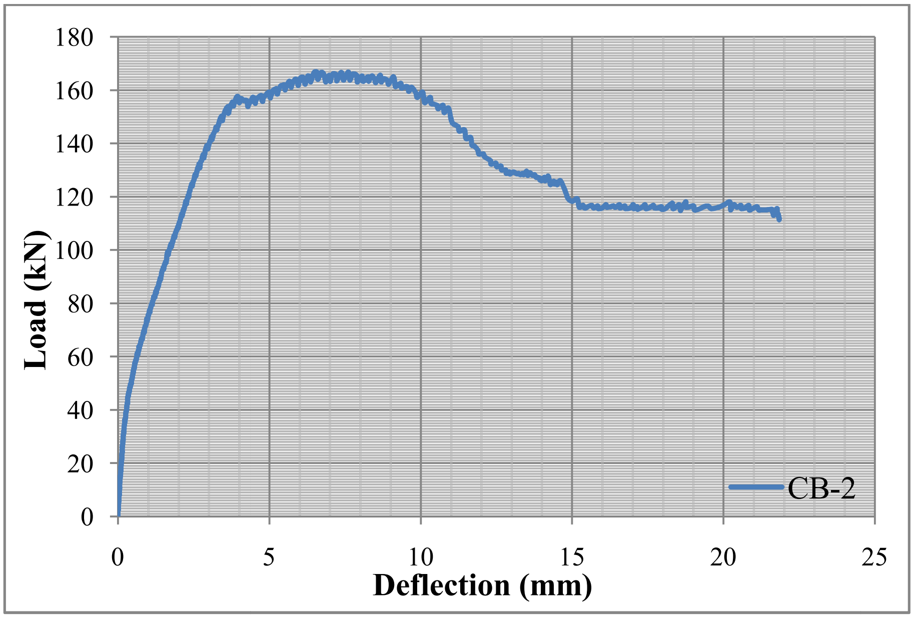


Figure4. 3 **Load deflection curve for beam under static loading**

As the load increased, more those two flexural cracks which appeared in the shear spans of the beam, converted in to diagonal cracks. And also the cracks in the maximum moment region grew vertically as the load increased as shown in **Figure 4.4**. When the load reached 166.8 kN, which was slightly equal to the expected ultimate capacity 167.4 kN, the beam fails in flexural- shear failure mode. As shown in the **Figure 4.5**.

Figure4. 4 **Cracks propagation for CB-2**

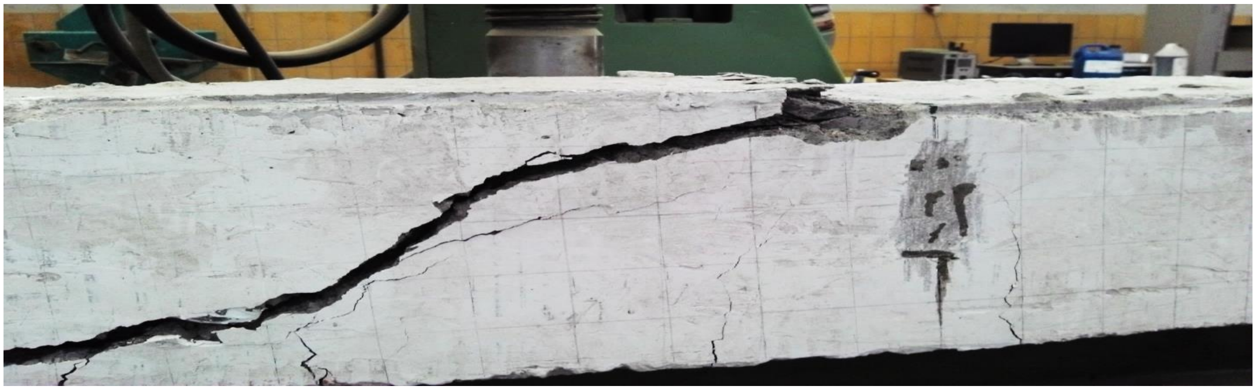


Figure4. 5 **Mode of failure for CB-2**

Table4. 7 Monotonic load predicted and test results for CB-2 beams

Beam Code			Control Beam -2
Theoretical Calculated	Ultimate capacity	Cracking (kN)	26.73
		Yielding (kN)	150.12
		Flexural (kN)	174.41
		Shear (kN)	167.4
Expected Failure		Load (kN)	167.4
		Mode	Yielding
Experimental Result		Cracking (kN)	26.76
		Yielding (kN)	159.31
		Failure Load (kN)	166.82
		Coincidence	Yielding
		Failure Mode	Flexural shear failure

As seen by the table, the load at ultimate shear and at maximum flexural capacity for test beam is reasonably predicted by the theoretical calculation. The largest percent difference between the load of first steel yielding of the test beam and the theoretical calculation is 6%. However, the yielding load does not correspond to the theoretical predictions. The mode of failure of the beam was as predicted the longitudinal reinforcement's yields before the shear failure.

4.4 Beams Tested Under Cyclic Loading

Four beams were tested under cyclic loading. The load range varied from 0% (0.0 kN) to 92% (145.56kN) of the yielding static capacity of the beam (159.31kN). At the outset of the test, all of the beams were loaded to the maximum load (145.56kN) and then back to the minimum load manually. While loading to the maximum load, flexural cracks were observed on the center and on the shear span for all beams. During cycling, flexural cracks propagated and grew vertically and a longitudinal crack initiated on bottom face at the midspan of the beam.

4.4.1 Mode of Failure for Cyclic Loading

Test beam-1 is tested at 146.81kN for 40 cycles. Its load versus deflection curve is shown in **Figure 4.6.**

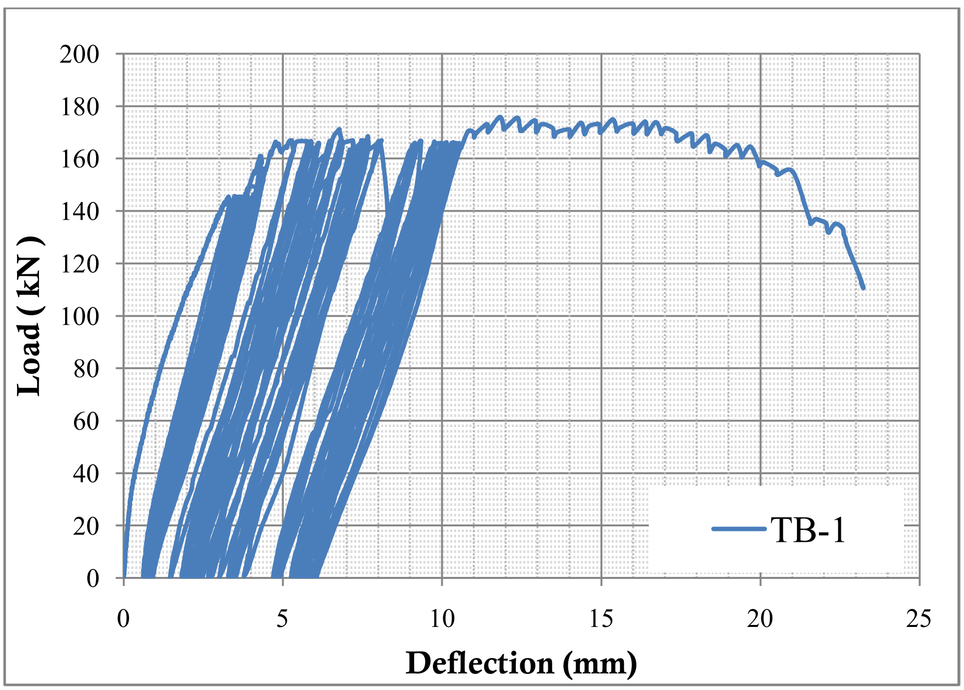


Figure4. 6 **Load deflection curve for TB-1 under cyclic loading**

Flexural cracks were observed on the center and on the shear span of the beams and shear cracks are visible on the 7th cycle. During cycling, flexural cracks propagated and grew vertically as well as the diagonal cracks propagated from the core to the outside of the beam as shown in **Figure 4.7**.

Figure4. 7 **Cracks propagation for TB-1**

The load is increased from 146.81 kN to 165.32 kN for the remaining 27 cycles after that the beam is loaded until failure. As the load increases the flexural cracks are propagated upward and the width of the diagonal cracks increased when the load reached 175.82kN, which was slightly equal to the expected ultimate capacity 174.2 kN the beam fall by shear as shown in **Figure 4.8**.

Figure4. 8 **Mode of failure for TB-1**

Test beam-2 tested at 147.37kN for 20 cycles. Its load versus deflection curve is shown in **Figure 4.9**.

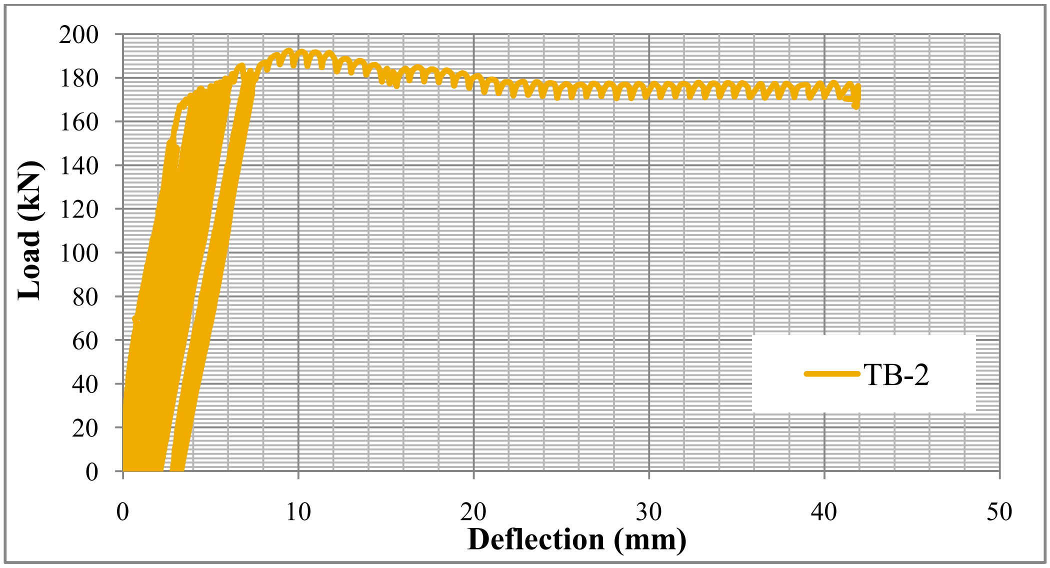


Figure4. 9 **Load deflection curve for TB-2 under cyclic loading**

Flexural cracks were observed on the center. During cycling, flexural cracks propagated and grew vertically as shown in **Figure 4.10**. The load is increased from 147.37kN to 92% of the ultimate static capacity of the beams (176.56 kN) for the remaining 20 cycles. The diagonal cracks visible and the concrete starts to crush at 27th cycle.

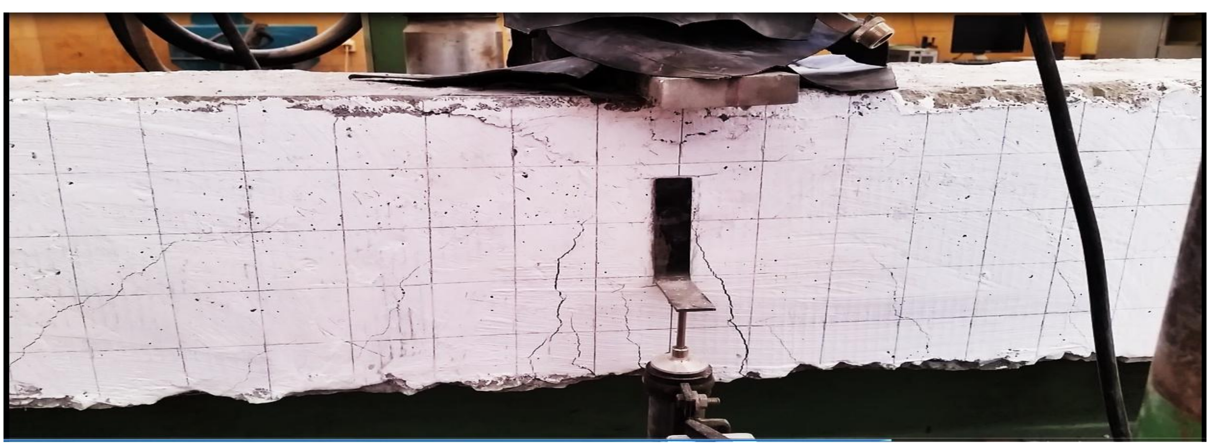


Figure4. 10 **Cracks propagation for TB-2**

At 41 cycles the beam is loaded until failure. As the load increases the diagonal cracks are propagated and the flexural cracks become enlarge and the concrete crushed, when the load reached 192.33 kN, which was slightly increased from the expected ultimate capacity 185.2 kN this is because of stiffness finally the beam fall by flexure as shown in **Figure 4.11**.

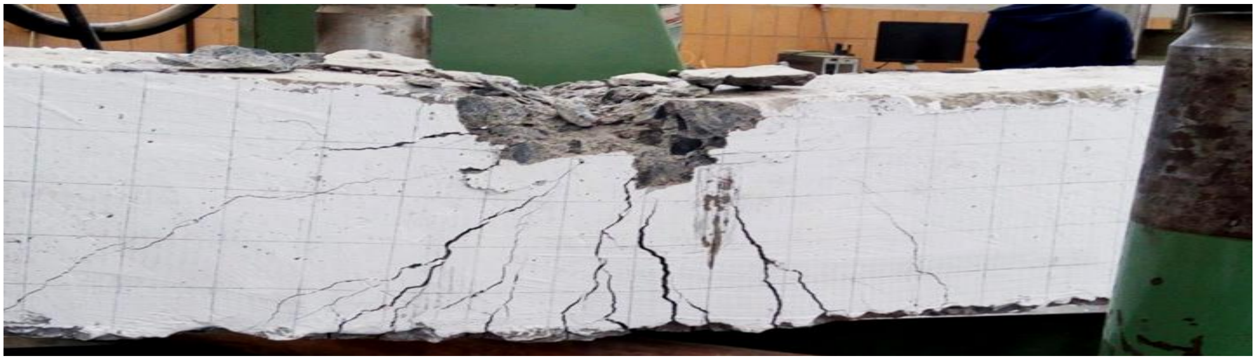


Figure4. 11 **Mode of failure for TB-2**

Test beam-3 tested at 168.32 kN for 20 cycles. Its load versus deflection curve is shown in **Figure 4.12**.

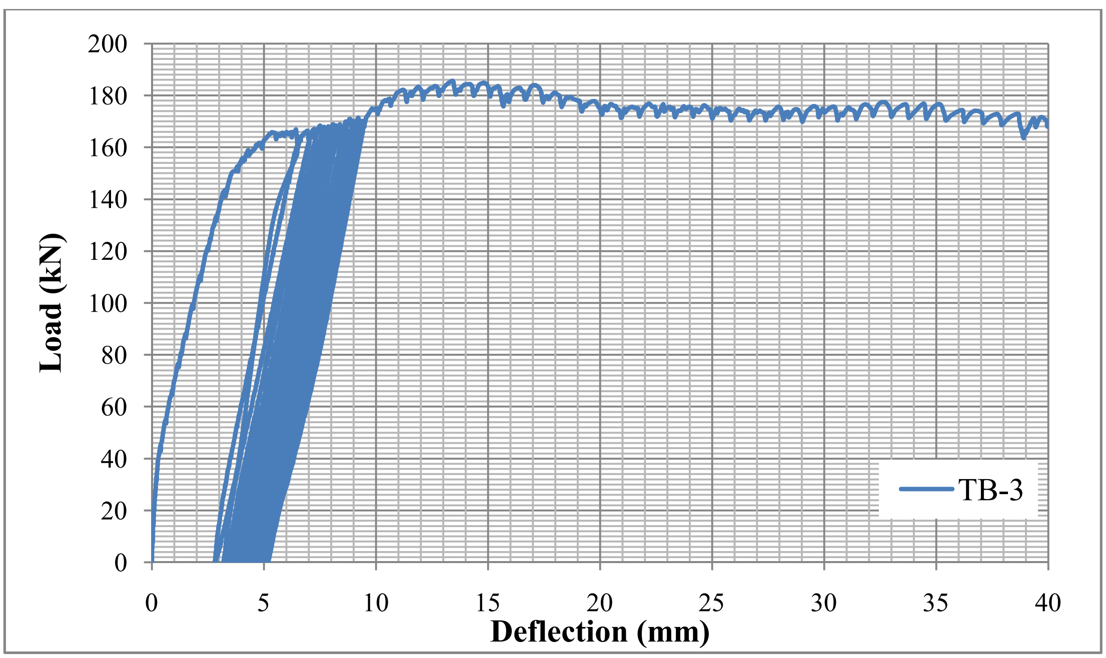


Figure4. 12 **Load deflection curve for TB-3 under cyclic loading**

Flexural cracks were observed on the center. During cycling, flexural cracks propagated and grew vertically as shown in **Figure 4.13**. The hair line shear cracks became visible and the concrete starts to crush at 5th cycle.

Figure4. 13 **Cracks propagation for TB-3**

At 21 cycles the beam is loaded until failure. As the load increases the flexural cracks propagated vertically, the crack width is increased and the concrete crushed, when the load reached 184.82kN, which was slightly equal from the expected ultimate load 181.37 kN finally the beam fall by yielding of longitudinal reinforcement followed by concrete crushing as shown in **Figure 4.14.**

Figure4. 14 **Mode of failure for TB-3**

Test beam-4 tested at 147.16 kN for 39 cycles. Its load versus deflection curve is shown in **Figure 4.15**

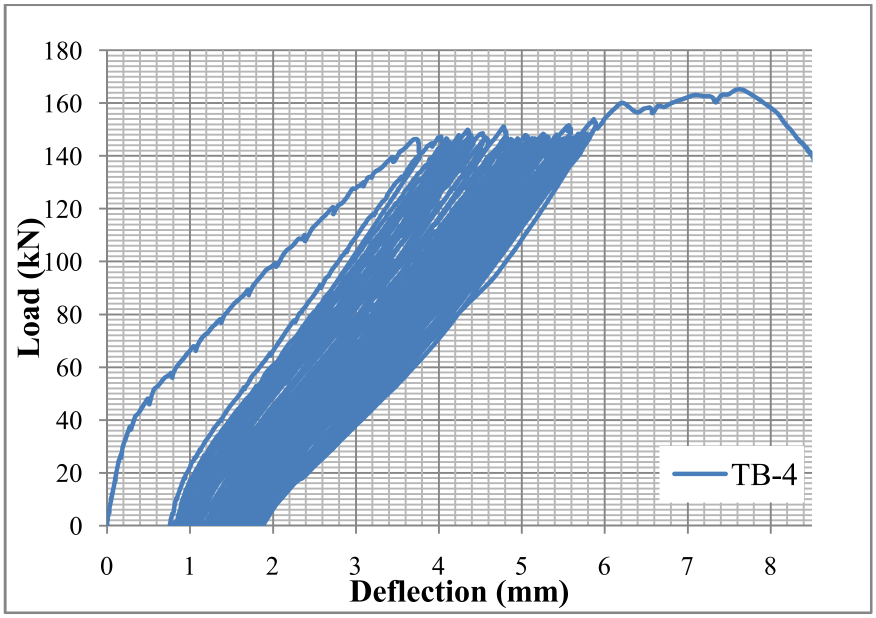


Figure4. 15 **Load deflection curve for TB-4 under cyclic loading**

Flexural cracks were observed on the center and on the shear span of the beams and shear cracks are visible on the 3rd cycle. During cycling, flexural cracks propagated and grew vertically as well as the diagonal cracks propagated from the core to the outside of the beam. This diagonal crack occur one side of the shear span as shown in **Figure 4.16**.

The load is increased from 147.16 kN to 165.05kN. As the load reached 165.05 kN the diagonal cracks are become enlarge at that time loading was stopped. This is because the beam was tested for reverse side for monotonic loading to determine the damage effect of cyclic loading.

Figure4. 16 **Failure mode for TB-4 under cyclic loading**

The beam was reversed to the other side and tested under monotonic loading condition. During reverse side loading the first diagonal crack occurred on the uncracked shear span of the beam after a while the diagonal crack was created on the other shear critical span. As the load increasing the diagonal crack make wider and the flexural cracks are converted in to diagonal crack. When the load reached 161.81 kN, which was slightly less than the expected ultimate capacity 177.7 kN. This was occurring due to the applied cyclic load affect the internal bond in the concrete. Finally the beam was fall by shear as shown in **Figure 4. 18.**

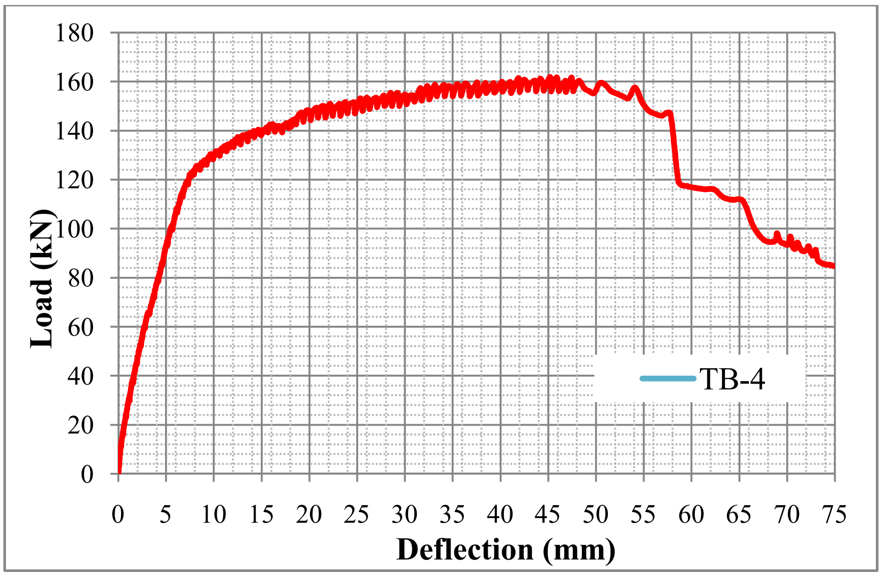


Figure4. 17 **Load deflection curve for TB- 4 reverse side under monotonic loading**

Figure4. 18 **Mode of failure for TB-4 under reverse side monotonic loading**

4.4.2 Cyclic load Results summary

Table 4- 8 gives a summary of the cyclic load for all the tested beams together with the expected failure load calculated from the test result of the reinforcement and concrete data presented in this chapter.

Table4. 8 cyclic load test results for all beams

Beam Code		Test Beam -1	Test Beam -2	Test Beam -3	Test Beam -4
at 92% yield load	cycle	40	20	-	39
	load (kN)	146.81	147.37	-	147.16
	Δ (mm)	4.023	2.85	-	5.10
at 92% ultimate load	cycle	27	20	20	1
	load (kN)	165.32	176.56	168.32	165.07
	Δ (mm)	8.2	5.78	8.3	7.66
Expected failure	load (kN)	174.16	185.21	181.37	177.77
	mode	yielding	yielding	yielding	yielding
Experimental failure	cycle	67	40	20	40
	load (kN)	175.82	192.33	184.82	161.81
	coincidence	Diagonal crack before yielding	yielding	yielding	Diagonal crack before yielding
	mode	shear	FC	FC	shear

Note Failure mode: - F= yielding of longitudinal reinforcement C = crushing of concrete,
Δ = average deflection for all cycle at peak load

As described in the above table, table4.8 cyclic loading for a few numbers of cycles in specific stress range does not influence the ultimate failure load of the specimens. But in the case of TB-4 the beam was tested under reverse side loading the failure load was decreased from expected, this is because of the applied cyclic loading affects the bond between the aggregate and surrounding pasts and the confinement effect which is created by stirrup spacing's.

4.4.3 Deflection behavior of cyclically loaded beams

Figure 4- 19 shows typical curves of beam deflections over the cyclic life of three specimens. Two of the specimens are tested for 92% of the yield loading for 40 cycles. Test beam 1 tested again for 92% of the ultimate load this load is equal to the control beam failure for the remaining 27 cycles and after that the beam is loaded until failure. Test beam 2 tested once more for 92% of the ultimate load for 20 cycles then loaded to failure. Test beam 3 tested for 92% of the ultimate load for 20 cycles then loaded to failure. As was expected three stages are observed in the deflection behavior of all of the beams tested under cyclic loading. In the first stage, the deflection increases rapidly for about 15-20% of the cyclic life of the specimens. In the second stage that lasted for about 80% of the cyclic life, there is a steady slow increase in deflection. In the final stage, the beams showed a rapid increase in deflection.

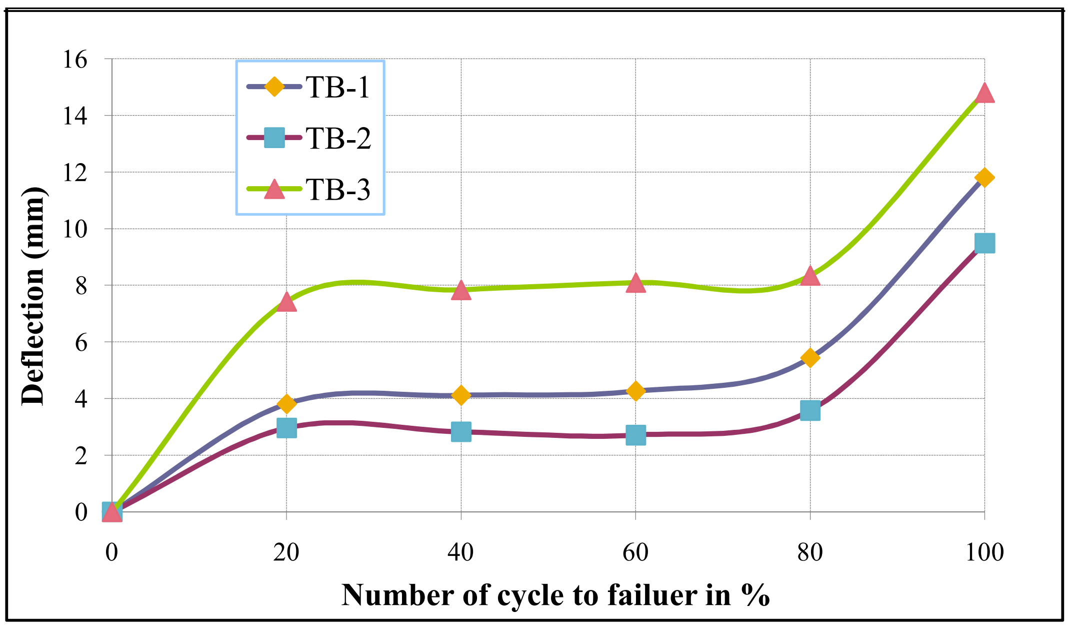


Figure4. 19 **Deflection verses percentage number of cycles to failure**

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

An attempt has been made to obtain the effect of controlled cyclic loading on reinforced concrete beams. This research states that the specific conclusions are base upon the test result carried out in the present experimental investigation.

The test result of the selected engineering properties of material in mixing concrete conforms to the requirement stated in the ACI and ASTM standards.

The mode of failure of the control reinforced concrete beam under monotonic loading was due to the yielding of longitudinal reinforcement and the section above the flexural cracks are subjected to shear stress due to this the flexural cracks converted in to shear cracks and finally the beam failure was in flexural shear failure mode. This result is due to the shear capacity of the specimen is between the yielding and ultimate flexural capacity of the specimen.

The mode of failure for TB-1and TB-4 tested under cyclic loading is due to shear. The shear cracks occurred before the yielding of longitudinal reinforcement and this is different from expected mode of failure which shows that the cyclic loading changes the mode of failure of the beam from flexure to shear. While checking TB-2 and TB-3 the beams fall as expected, by yielding of longitudinal reinforcement followed by concrete crushing as expected.

In this paper, experimental work the application of cyclic loading for a few numbers of cycles in specific stress range does not influence the ultimate failure load of the specimens. But in the case of TB-4 the beam which was tested under reverse side loading, the failure load was decreased from expected. This is because of the applied cyclic loading affects the bond between the aggregate and surrounding paste and the confinement effect which is created by stirrup spacing.

The average ultimate deflection under cyclic loading conditions is the same as the ultimate deflection under static loading conditions. The results of this study indicate that the minimum allowable stress range for reinforcing steel embedded in a concrete subject to cyclic loading of 145 MPa recommended by Helgason and Hanson, is appropriate and suitably conservative for reinforced concrete beams.

5.2 Recommendation

The low cycle load, which was the case in this study, corresponds to a real environmental condition when a concrete element is exposed to an earthquake load. It would be valuable to carry out an experimental and numerical investigation under a high cycle load, which simulates other types of cyclic loads.

Since this study focused on slender beams with critical shear span length by effective depth ratio 3.08, for future if it would conduct with different critical shear span length by effective depth ratios for slender and deep beams. Although if studies are conducted for different shape and grades of concrete. Also studies should have been conducted for beam-column joint, pre-stress beams and composite beams.

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APPENDIX

Appendix A: - Procedures of concrete mixed design

For compressive strength =25MPa (C-25)

- Materials parameters are described as follow.

Cement; type 1; specific gravity= 3.15

Bulk specific gravity C.A=2.614

Compacted unit weight C.A=1651.735 KN/m^3

Bulk specific gravity F.A =2.515

Fines modulus F.A=2.851

Surface moisture contents coarse aggregate =2.04

Surface moisture contents fine aggregate =1.11

Absorption coarse aggregate =1.21

Absorption fine aggregate =3.52

❖ Ranges in physical properties for normal weight aggregate used in a concrete according to ACI E-701

Property		Typical ranges
Fineness modulus of fine aggregate (defined in the following)		2.0 to 3.3
Nominal maximum size of coarse aggregate		9.5 to 37.5 mm (3/8 to 1-1/2 in.)
Absorption		0.5 to 4%
Bulk specific gravity (relative density)		2.30 to 2.90
Dry-rodded bulk density* of coarse aggregate		1280 to 1920 kg/m^3 (80 to 120 lb/ft^3)
Surface moisture content	Coarse aggregate	0 to 2%
	Fine aggregate	0 to 10%

*Previously dry-rodded unit weight.

➢ The mix design procedures are as follows:-

1. choice of slump

Table 1 Recommended slumps for various types of construction.

Types of construction	Maximum Slump (cm)	Minimum Slump (cm)
Reinforced foundation walls and footings	8	2
Plain footings, caissons, and substructure walls	8	2
Beams and reinforced walls	10	2
Building columns	10	2
Pavements and slabs	8	2
Mass concrete	8	2

Since the type construction is beam so from table 1, maximum slump= 10cm and minimum slump= 2cm.

2. maximum size of aggregates is 37.5 mm
3. Estimation of mixing water and air content
    ➢ Assume the concrete is non air entrained

Table 2 Approximate Mixing Water Requirements for Different Slumps and Maximum Sizes of Aggregates

NON-AIR-ENTRAINED CONCRETE								
Slump (mm)	**10 mm**	**12.5 mm**	**20 mm**	**25 mm**	**40 mm**	**50+ mm**	**70+ mm**	**150+ mm**
3 to 5	205	200	185	180	160	155	145	125
8 to 10	225	215	200	195	175	170	160	140
15 to 18	240	230	210	205	185	180	170	-
Air entrapped (%)	3.0	2.5	2.0	1.5	1.0	0.5	0.3	0.2

For non-air entrained and slump of 8-10cm, the water in 1m³ of concrete is 178.333Kg.

4. Water to cement ratio selection table 3

Table 2 Relationship between water-cement compressive strength of concrete

Compressive strength at 28 days (MPa)	**Water-cement ratio by weight (Non-air-entrained concrete)**
45	0.38
40	0.43
35	0.48
30	0.55
25	0.62
20	0.70
15	0.80

For C-25 and non-air entrained concrete water to cement ratio is 0.62.

5. Cement content calculation

For slump =8-10cm

Water content=178.33Kg/m³

Water/cement=0.62

$$cementcontent = watercontent/(\frac{w}{c})$$

$$= \frac{178.333}{0.62}$$

$$\underline{\underline{= 287.634\ Kg/m^3}}$$

6. Estimation of course aggregates quantity

Table 4 Volume of dry-rodded coarse aggregate per unit volume of concrete for different fineness module of sand

Nominal maximum size of aggregate (mm)	**2.40**	**2.60**	**2.80**	**3.00**
10	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
20	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
40	0.76	0.74	0.72	0.70
50	0.78	0.76	0.74	0.72
70	0.81	0.79	0.77	0.75
150	0.87	0.85	0.83	0.81

The sand has 2.851 fines modules and the maximum size of aggregate is 37.5mm

The volume of dry rodded course aggregate per unit volume of concrete is 0.7066

Unit weight of C.A =1651.735kg/m^3 from laboratory

$$requereddrymassofC.Ain\ 1\ m^3 = 0.7066 \times 1651.735$$

$$\underline{\underline{= 1167.06\ kg/m^3}}$$

7. Estimation of fine aggregates content

First estimate the unit weight of fresh concretes.

Table 5 First estimate of concrete weight (kg/m3)

Nominal maximum size of aggregate (mm)	Non-air-entrained concrete
10	2280
12.5	2315
20	2355
25	2375
40	2420
50	2445
70	2465
150	2505

The unit weight of fresh concrete for max. Aggregate size of 37.5mm and non- air entrained is **2412.5 kg/m^3**

Form the above

- Cement content =287.634 kg/m^3
- Water content = 178.333 kg/m^3
- Coarse aggregate content = 1167.06 kg/m^3
- Fresh concrete content = 2412.5 kg/m^3

Fine aggregates are qualified in to two ways

- ✓ weight method or
- ✓ absolute volume method

Weight method is used in this paper

- **Content of fine aggregate (F.A) = unit weight of concrete – (C.A + cement + water)**

Fine aggregate content = [2412.5 – (1167.06+287.634+178.333)] **=779.47 kg/m^3**

Ingredients	Quantity In Kg/m^3
Cement content	287.634
Fine aggregate content	779.47
coarse aggregate content	1167.06
Water content	178.333
Total content	2412.5

8. Moisture adjustment

Absorbed water does not become part of the mixing water and it must be removed from the mixing water, if moisture content is greater than absorption capacity. But, if absorption capacity is greater than moisture content of aggregate, we need to add water up to its moisture capacity. Therefore, in this case since the moisture content of the aggregates is greater than their absorption capacity, water should be deducted from the mixing water.

Coarse aggregates:

- ✓ absorption capacity= 1.214 %
- ✓ moisture content= 2.04 %

Fine aggregate (sand)

- ✓ absorption capacity= 3.519 %
- ✓ moisture content=1.11%

Adjusted fine aggregate =779.47 × 1.011=788.12 kg/m^3

Adjusted coarse aggregate =1167.06 × 1.0204=1190.87 kg/m^3

Adjusted water = 178.33-[1167.06*(0.0204-0.01214) +779.47(0.0111-0.03519)] =187.43 kg/m^3

Ingredients	Quantity In Kg/m^3
Cement content	287.634
Fine aggregate content	788.12
coarse aggregate content	1167.06
Water content	187.43
Total content	2454.05

In this experimental program for one beam there are 6 cubes casted and for 3 cylinders.

- Volume of a Beam Concrete = $1.7 \times 0.2 \times 0.25$ = 0.085m^3
- Cubes =$6 \times 0.15 \times 0.15 \times 0.15$=0.02025 m^3
- Cylinder = $3 \times \pi \times 0.0752 \times 0.3$ = 0.0159 m^3

Total volume (wastage and shrinkage is 20 %) = 0.14538m^3

❖ Ingredients for one beam and 6 cubes and 3 cylinders

Ingredients	Weight in (kg)
Cement	41.819
Fine aggregate	114.501
coarse aggregate	173.22
Water	27.25

➢ **Total ingredient for the six beam samples** total amount of concrete = 0.8723m^3

Ingredients	Weight (kg)
Cement	250.913
Fine aggregate	686.994
coarse aggregate	1039.309
Water	163.498

Appendix B: - Theoretical calculation

I) Beam Design

Dimension of beam and other specifications

- Total beam length = 1.7m
- Clear span of beam =1.3m
- Depth of beam= 250mm
- Width of beam = 200mm
- Concrete cover = 25mm
- Stirrups diameter = 6mm
- Longitudinal bar in one row (bottom) = 16mm (two number of bars)
- Longitudinal bar in one row (top) = 16mm (two number of bars)

Initial data's and Material strength

$$d' = cc + Øs + ØL2 = 25 + 6 + \frac{16}{2} = 39mm$$

$$d = D - d' = 250 - 39 = 211mm$$

$$d2 = cc + Øs + ØL2 = 25 + 6 + \frac{16}{2} = 39mm$$

Ratio of shear span to effective depth

$$\left(\frac{av}{d}\right) = \frac{0.650}{0.211}$$

$$= 3.08$$ →The beam is a slender beam

- Design procedure for control beam

Actual **As** (longitudinal tension bars) =369.15 mm^2 (2ø16)

Actual **As2** (longitudinal compression bars) = 369.15 mm^2 (2ø16)

Concrete	Reinforcement
C-25/20 f'_{cm}=28 MPa	$fy_{long.\ tension} = 638.32\ MPa$ $fy_{long.\ compression} = 520\ MPa$

- ✓ Shear section capacity of the beam

$Vc = 0.25 \times fct \times k1 \times k2 \times b \times d$

Where:

- $K2\ = 1.6 - d = 1.6 - 0.211 = 1.389$, $K1 = 1 + 50 * \rho = 1.437$
- from labratory result of spliting test $fct\ = 2.02\ MPa$

$Vc = 0.25 \times 2.02 \times 1.437 \times 1.389 \times 200 \times 211$

$Vc = 42.55kN$

$P = 2 \times Vc = 85.1kN$

- ✓ Maximum moment capacity of the beam

$Mu,s = 0.85 \times b \times d^2 \times fc \times \rho m(1 - 0.4 \times \rho m)$

$Mu,s = 45.45\ kNm \rightarrow P = 4 \times \frac{M}{l} \rightarrow P = 139.85\ kN$

- ✓ Check the section for singly reinforced section

$$\gamma u,s = \frac{Mu,s}{fc \times b \times d^2}$$

- *Kx, max = 0.8(δ-0.44),* *Where δ=1 for 0% moment redistribution.*
- $\gamma su^* = 0.295$

$$\gamma u,s = \frac{Mu,s}{fc \times b \times d^2} = 0.262 < 0.295$$

If $\gamma_{su,} < \gamma_{su}^*$, then the section is singly reinforced

Since $As_{,prov.} = 369.15\ mm^2$

$$Kx = (As) \times \left(\frac{M}{bd}\right) = 0.348 < 0.488\ ok\ reinforcment\ at\ bottom\ first\ yield$$

✓ Shear reinforcement design

$A_{s\ shear}$ =22.06 mm^2 Av= 2× $A_{s\ shear}$ = 44.12mm^2 spacing= 125 mm

$$Vs = Av \times d \times \frac{fy}{S} = 44.12 \times 211 \times \frac{445.72}{125} = 33.2\ kN$$

$$Vc = 42.55\ kN\ Vs = 33.2\ kN\ \ Vds = 75.75\ kN, \rightarrow P = 151.49kN$$

✓ Flexural to shear load ratio

$$= \frac{139.85}{151.49} \times 100 = 92.6\% \rightarrow longitudnal\ reinforcement\ first\ yeilds$$

➢ Calculation of anchorage length

✓ Bond strength according to the new Ethiopian building code

$$fbd = 2.25 \times \mu1 \times \mu2 \times fct$$

- From laboratory result from splitting test fct at 28 days= 2.01
- $\mu1 = 1\ , \mu2 = 1$

$$fbd = 2.25 \times 1 \times 1 \times 2.01 = 4.52\ MPa$$

✓ Basic anchorage length

$$lb,req = \left(\frac{\emptyset}{4}\right) \times \left(\frac{\sigma sd}{fbd}\right)$$

- From laboratory result for reinforcing steel f_y = 641.64MPa
- $\emptyset = 16$

$$lb,req = \left(\frac{16}{4}\right) * \left(\frac{641.64}{4.52}\right) \rightarrow lb,req = 567.82mm$$

✓ Design anchorage length

$$lbd = \alpha1 \times \alpha2 \times \alpha3 \times \alpha4 \times \alpha5 \times lb,req$$

- $\alpha1 = 1, \alpha2 = 0.916, \alpha3 = 0.925, \alpha4 = 0.7, \alpha5 = 1$

$$lbd = 1 \times 0.916 \times 0.925 \times 0.7 \times 1 \times 567.82 \rightarrow lbd = 336.74mm$$

❖ During casting the concrete cross- section increase.

II) Capacity Calculation

i) $Mcr = \frac{(frIg)}{yt}$

Where

Mcr=cracking moment

fr = modulus of rupture, $fr = 0.63\sqrt{fc'}$

Ig= Gross section moment of inertia

yt = Distance from the extreme top fiber to the centroid of the gross section

ii) $M = 0.85 \times fc \times b \times d \times x\left[1 - 0.4\frac{x}{d}\right]$

Where

b = width of the beam

d= effective depth

fc = Cylindrical compressive strength of concrete

x=depth of natural axis, $x = \rho md, \rightarrow \rho = \frac{As}{bd}$,

$m = \frac{fs}{0.8fc}$ $\rightarrow fs = fy\ for$ yield moment calculation

$\rightarrow fs = fu\ for\ ultimate\ moment\ calculation$

iii) $Vn = Vc + Vs$

Where

Vs = shear resisted by the stirrup, $Vs = Av \times d \times \frac{fy}{s}$

Vc = concrete section capacity, $Vc = 0.25 \times fct \times k1 \times k2 \times b \times d$

iv) Load calculation:

- Load due to moment, $P = \frac{4M}{le} \quad \rightarrow le = 1.3m$
- Load due to shear, $P = 2Vn$

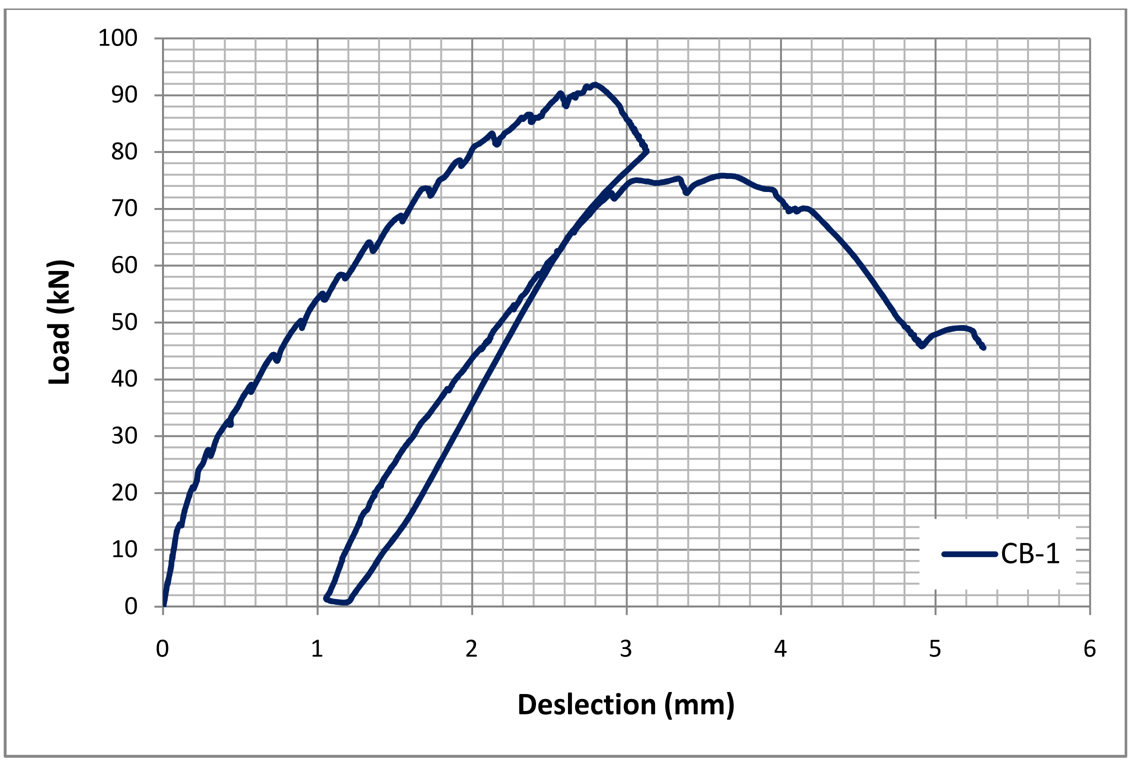
Summary of cracking, yielding, ultimate and shear loads resisted by each RC beams

Beam Code	Cracking Moment kNm	Yield Moment kNm	Ultimate Moment kNm	Shear Capacity kN	Cracking Moment kN	Yield capacity kN	Ultimate capacity kN	Shear capacity kN
CB-2	8.69	48.75	56.64	83.74	26.73	150.00	174.28	167.47
TB-1	8.78	49.32	57.44	87.08	27.00	151.77	176.74	174.16
TB-2	9.59	51.42	60.19	111.41	29.50	158.20	185.21	222.83
TB-3	9.76	50.58	58.94	143.00	30.04	155.63	181.37	286.01
TB-4	9.71	50.13	58.77	88.88	29.86	154.24	180.84	177.77

Note all the values are calculated based on actual compressive and tensile strength of concrete, yield and ultimate strength of reinforcement and beam size.

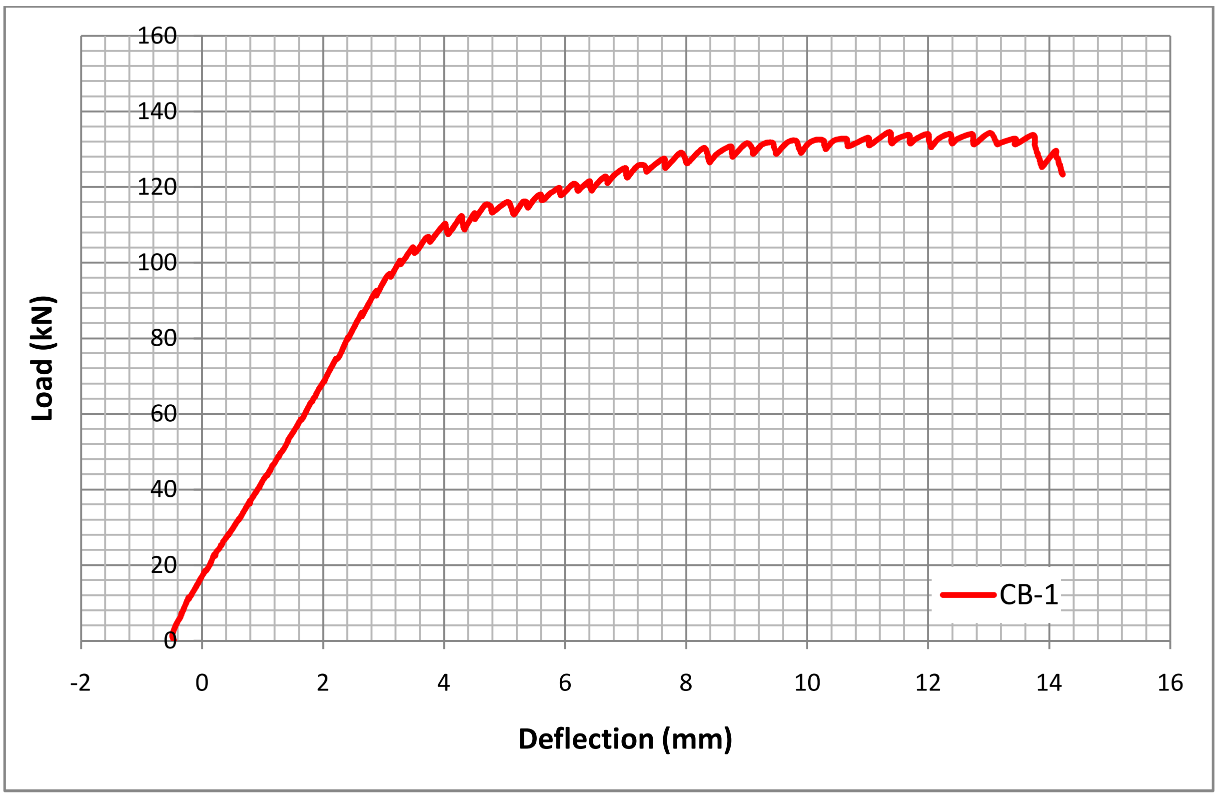
Appendix C: - Discussion for CB-1

The specimen tested under monotonic load was CB-1 beam which served as a control beam for the beams. But these beam first casted to check cylindrical splitting tensile strength test. CB-1 a beam without internal web reinforcement since TB-1 failures by shear the tensile strength of concrete section was checked by it. This beam was testes under cyclic loading of 92% of the failure load of 99.42 kN which is 91.5 kN load as we can see load deflection curve 1the beam fails by two cycles without reaching the ultimate load of the spacemen. From this cyclic load affects its ultimate section capacity. After the shear crack becomes wide the beam is reversed to the other side and tested. From load deflection curve 2 the beam sustains 132.55 kN load, as we can see from this sometimes damages are good those internal cracks from the first loading case dissipate energy in the section.



Load deflection curve 1

Final failure mode



Load deflection curve 2 on the reverse side