COMPARISON OF DYNAMIC RESPONSE OF SELF-COMPACTING CONCRETE (SCC) AND CONVENTIONAL VIBRATED CONCRETE (CVC)

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CERTIFICATION OF APPROVAL

Comparison of Dynamic Response of Self-compacting Concrete (SCC) and Conventional Vibrated Concrete (CVC)

by

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Approved by,

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(Mr. M. Mubarak Abdul Wahab)

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

SHAH HAEQAL BIN SHAH AMRI

ABSTRACT

This report is a brief discussion on the preliminary research conducted and basic understanding of the chosen topic, which is **Comparison of Dynamic Response of Self Compacting Concrete with Normal Concrete**. The objective of the project was to study and compare the response in terms of flexure between conventional vibrated concrete (CVC) and self compacting concrete (SCC) after subjected to dynamic loadings. Lab testing were conducted to evaluate the properties of fresh concrete but more focus was on the hardened concrete. The fresh concrete was tested for its workability, viscosity and resistance to segregation. 3 pairs of SCC and CVC beams were subjected to 3 different dynamic load ranges. The performance of all beams was evaluated based on the results of crack pattern, deflection rates and strain ratios. The strength of SCC beams were found to be higher than CVC beams, but the strain ratios of SCC beams were higher than CVC beams which suggested that SCC beams recorded more elongation.

ACKNOWLEDGEMENT

First and foremost, I am forever thankful to Allah, the God Almighty for His love and blessings that enabled me to complete this project. I would like to express my greatest gratitude to my supervisor, Mr. Mohamed Mubarak bin Abdul Wahab, whose patience, dedication and inspiration were evident throughout this entire process. He has provided me with assistance and advice in numerous ways which were essential for the completion of this project. I am also grateful to Mr. Agus Kurniawan, postgraduate student from the Civil Engineering Department of Universiti Teknologi Petronas, for his tireless guidance and advices regarding this project. And this project would not be completed if it were not for Mr Johan Ariff bin Mohamed and Mr. Muhammad Hafiz bin Baharun, the concrete laboratory technologists who were very professional in doing their jobs.

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LIST OF ABBREVIATIONS

SCC – Self Compacting Concrete
CVC – Conventional Vibrated Concrete
NC – Normal Concrete
OPC – Ordinary Portland Cement
HSE – Health, Safety and Environment
LVDT – Linear Variable Displacement Transducer

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Self compacting concrete (SCC), also known as self consolidating concrete was developed in Japan in 1988. It is a kind of concrete that can flow through and fill reinforcement gaps and corners of formworks without the need for vibration and compaction during the pouring process. SCC can be applied in precast applications or for in situ concreting. (Domone 2006)

SCC has three key fresh properties as listed below (Brouwers and Radix 2005):

1) Filling ability – the ability of concrete to flow freely under its own weight, both horizontally and vertically upwards if necessary, and to completely fill formwork of any shape including the voids.
2) Passing ability – the ability of concrete to flow freely in and around reinforcements such as steel bars incorporated inside a beam, without any obstructions.
3) Resistance to segregation – homogeneity is an important aspect of SCC, which means that there should not be any aggregate separation from paste or solids from water; and no tendency for coarse aggregates to sink downwards through the fresh concrete mass under gravity

The main reasons for the employment of SCC can be summarized as follows:

1) to accelerate construction works
2) to reduce the need to use labor (as shown in Figure 1.1)
3) to make sure that all designated areas in the formwork are covered with concrete
4) to eliminate noise due to vibration, essential especially at sensitive areas such as nearby hospitals

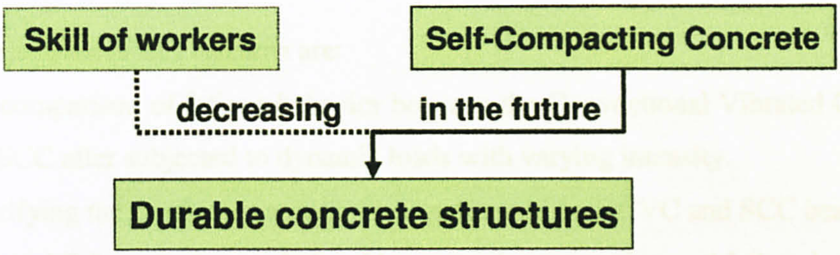


Fig. 1.1: Importance of Self-Compacting Concrete

1.2 Problem Statement

Various researches had been done to produce concrete which have the characteristics of high flowability and workability during its fresh (plastic) state, but very strong and durable once it has hardened. The present data implies that high-strength concrete is made with a low water-to-binder ratio, thus it requires a large amount of cement in the mixing process. This may cause severe creep and drying shrinkage (Felekog˘lu et al. 2006). The strength of concrete derives from the coarse aggregates, but in SCC the aggregates contents need to be minimized in order to achieve higher workability. There have been little discussion regarding of hardened properties as compared to fresh properties of SCC but still, the strength of hardened SCC is considered to be as equal as conventional vibrated concrete (CVC). However, the application of SCC is expected to improve the flexural behavior and increase the bond between concrete and reinforcement (Rozie`re et al. 2007). Therefore, this study aims to prove the aforementioned statement.

1.3 Objectives

The main objectives of this research are:

- The comparison of fatigue behavior between the Conventional Vibrated Concrete (CVC) and SCC after subjected to dynamic loads with varying intensity.
- Identifying the crack propagation trend/pattern on both CVC and SCC beams.
- The establishment of any relationship on crack propogation and failure load on both types of concrete beams.

1.4 Scope of Study

The scope of work for this project is to investigate the dynamic responses of SCC in the form of reinforced concrete beam specimens. The data will be compared later with the dynamic responses of normal reinforced concrete beam. Flexural test will be implemented for this comparative study. But before the hardened concrete tests are conducted, fresh concrete tests on SCC specimens must be done to ensure that they are valid to be considered as SCC. The rheological properties for fresh concrete such as flowability and workability must be investigated to determine optimum parameters for the self-compactability of the mixtures (Felekog˘lu et al. 2006).

This study also needs an optimum mix design of SCC to be used in preparing the specimens. Several variables such as the quantities of water, cement and super plasticizer will be manipulated. To do that, the approaches listed below were considered:

- Evaluate the water demand and at the same time optimize the stability and flow of the paste
- Determine the proportion of fine aggregates (sand) and the admixture amount to be included for optimum workability
- Addition of the right amount of coarse aggregates
- Proper testing on all the varied SCC mixes, especially for hardened state

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Concrete is a type of construction material that consists of cement, water, aggregates, admixtures, and additives. The admixtures and additives are used accordingly and selectively depending on the type of structure design. The word concrete is derived from the Latin word "concretus", which means "hardened" or "hard". Concrete solidifies and hardens after mixing with water and placement due to a chemical process known as hydration. The water reacts with the cement, which bonds the other components together, eventually creating a stone-like material (Neville 2006).

For this project, the focus will be on a specific type of concrete which is called self compacting concrete (SCC).

2.2 Self Compacting Concrete

Self compacting concrete (SCC), also known as self consolidating concrete, is a highly flowable, non-segregating concrete that can flow freely into place, fill the formwork and cover the reinforcement without any mechanical consolidation (vibration). It was developed in Japan in the 1980s. Two important properties specific to SCC in its plastic state are its flowability and stability. There is no need for vibrators to compact the concrete and this will result in its placement being easier. SCC also has no bleed water, or aggregate segregation in its composition (Ouchi et al. 2003).

The characteristics of SCC mentioned in the previous paragraph were proven possible by the development of admixtures such as super plasticizers (also known as highly effective water reducing agents). SCC mixtures typically have a higher paste volume, less coarse aggregate and higher sand-coarse aggregate ratio than typical concrete mixtures.

The basic ingredients used in SCC mixes are basically the same with those of normal concrete mixes. The only major differences are both are mixed in different proportions and SCC needs the addition of special admixtures to meet its specifications. The hardened properties of SCC are expected to be similar to those of normal concrete (Domone 2006).

Up until 2005, SCC made up 10-15% of concrete sales in several European countries. SCC represents over 75% of concrete production in the United States precast concrete industry (Brouwers and Radix 2005).

2.3 Super Plasticizer (High Range Water Reducer)

Super plasticizer is a type of chemical admixture that is used in concrete mixtures to enhance the workability. It is a vital element in ensuring a workable concrete that uses less water. This is because the concrete strength depends on the amount of water added. Adding more water into the mixture will result in an unworkable concrete. Therefore, adding super plasticizer into the mixture can ensure workable concrete without having to add more water.

1-2% of super plasticizer added per unit weight of cement is normally adequate. But since the readily available super plasticizers are water dissolved, the extra water added has to be included in mix proportioning. The amount of super plasticizer added in the concrete is directly proportional to the segregation of concrete; therefore excess addition is not an option. The inclusion of too much super plasticizer will result in a retarding effect, as proved by (Felekog˘lu et al. 2006).

Plasticizers are usually produced from lignosulfonates, a by-product from the paper industry. High Range Super plasticizers have generally been manufactured from sulfonated naphthalene condensate or sulfonated melamine formaldehyde, although new-generation products based on polycarboxylic ethers are now available.

2.4 Dynamic Load (Cyclic Load)

Dynamic load or cyclic load is a type of load which, once in each period or stress cycle, fluctuates with respect to zero in one of the following ways which are alternating load, repeated load or pulsating load. By applying this load onto a structure over and over, it can cause a type of crack known as fatigue crack. The load amplitude and the mean load level have the highest influence on the fatigue capacity (the number of load cycles to failure). Cyclic load also is influenced by the deformation rate (Jacobs 1968).

The work done by Hassan et al. (2007) was to explain the behavior of full scale self consolidating concrete beams under shear conditions. A total of 20 flexurally reinforced concrete beams, with no shear reinforcement, were tested under mid-span concentrated load until shear failure occurred. The experimental test parameters included concrete type/coarse aggregate content, beam depth and the longitudinal reinforcing steel ratio. The performance of both SCC and conventional concrete beams was evaluated based on the results of crack pattern, crack widths, loads at the first flexure/diagonal cracking, ultimate shear resistance, and failure modes. The ultimate shear strength of SCC beams was found to be slightly lower than that of conventional concrete beams and the difference was more evident with the reduction of longitudinal steel reinforcement and with the increase of beam depth.

Li Bing et al. (2000) conducted an experiment on the behavior of short reinforced high-strength concrete columns under dynamic loading. After the maximum load was reached, a large inclined crack formed on the specimens that led to a very explosive type of failure. The experiment proved that normal strength concrete normally undergoes a more gentle failure. As the strain rate increased, the compressive strength and modulus of elasticity increased. The maximum strain at flexure also decreases while the strain at maximum stress might decrease or increase, depending on the rate of straining.

The study conducted by Thun et al. (2008) was to identify the tensile fatigue capacity of concrete. The results and analyses were presented from cyclic uniaxial tensile tests on plain cylindrical concrete cores. The deformation rate was studied and it showed that a certain fatigue limit exists below which a clearly greater number of load cycles is required for failure. From this research the exact limit cannot be predicted, but for tests with a mean load level of 40% of the ultimate load, a very low deformation rate has been obtained.

Lappa (2007) carried out a research on the static and dynamic behavior in bending of high strength fiber reinforced concrete (HSFRC). The main testing method was the four point bending test on un-notched beam specimens of dimension 125 x 125 x 1000mm. A series of static bending tests were performed, followed by a number of fatigue bending tests under different values of the upper load level. The fatigue tests were necessary in order to evaluate the fatigue bending behaviour and to provide S-N curves, which are commonly used in fatigue design verifications of structures. The HSFRC mixture, which was the mixture with the best workability, had the lowest scatter in the static and fatigue behavior compared with normal concrete. A general conclusion derived from the fatigue tests of the mixtures in this study, is that the fatigue regulations, as used for normal strength concrete, remain suitable for a safe fatigue design with high and ultra high strength concretes.

Mohd. Sam and Swamy (2005) studied the flexural behavior of concrete beams reinforced with glass fiber reinforced polymer (GFRP) bars. The specimens used were concrete beams of 150 x 255 x 2400mm in size and reinforced with GFRP and stainless steel bars. Analysis was done to identify their load carrying capacity, load-deflection, load-concrete strain, cracking and failure modes. From the experiment, it was concluded that beams reinforced with GFRP bars have lower ultimate load, lower stiffness and larger deflection at the same load level compared with normal concrete beams.

2.5 FRACTURE BEHAVIOUR

Fracture can be defined as the act of breaking or state of being broken. Fracture behaviour very much deals with the tensile and compressive strengths, ductility and durability of SCC. Fracture in concrete is caused by mechanical interaction between the coarse aggregates and the cement-based matrix (Wittmann 2002). Fracture energy can be influenced by several factors such as maximum aggregate size (Wittmann 2002), heat curing and also paste volume i. e. water, aggregates and admixture contents (Roziere et al. 2007).

2.6 GENERAL CRACK PROPAGATION

In general, SCC beams generate slightly less number of cracks as compared to CVC beams. The number of diagonal shear cracks is also lower in SCC as compared to CVC beams. Larger size of SCC/CVC beams have more cracks and develop higher diagonal crack widths at failure irrespective of reinforcement ratio (1% or 2%). The larger sizes of SCC/CVC beams also appeared to experienced sudden failure (A.A.A. Hassan et al. 2008).

As stated by A.A.A Hassan et al. (2008) in their paper, for both SCC and CVC beams, the cracks extended up to 50% and 70% of the failure load, respectively. The angle for the early diagonal dominant cracks was around 55° (to the beam longitudinal axis) while that for the failure diagonal crack was 35°.

CHAPTER 3

METHODOLOGY

3.1 Project Identification

The general sequence of methodology is as shown as below:

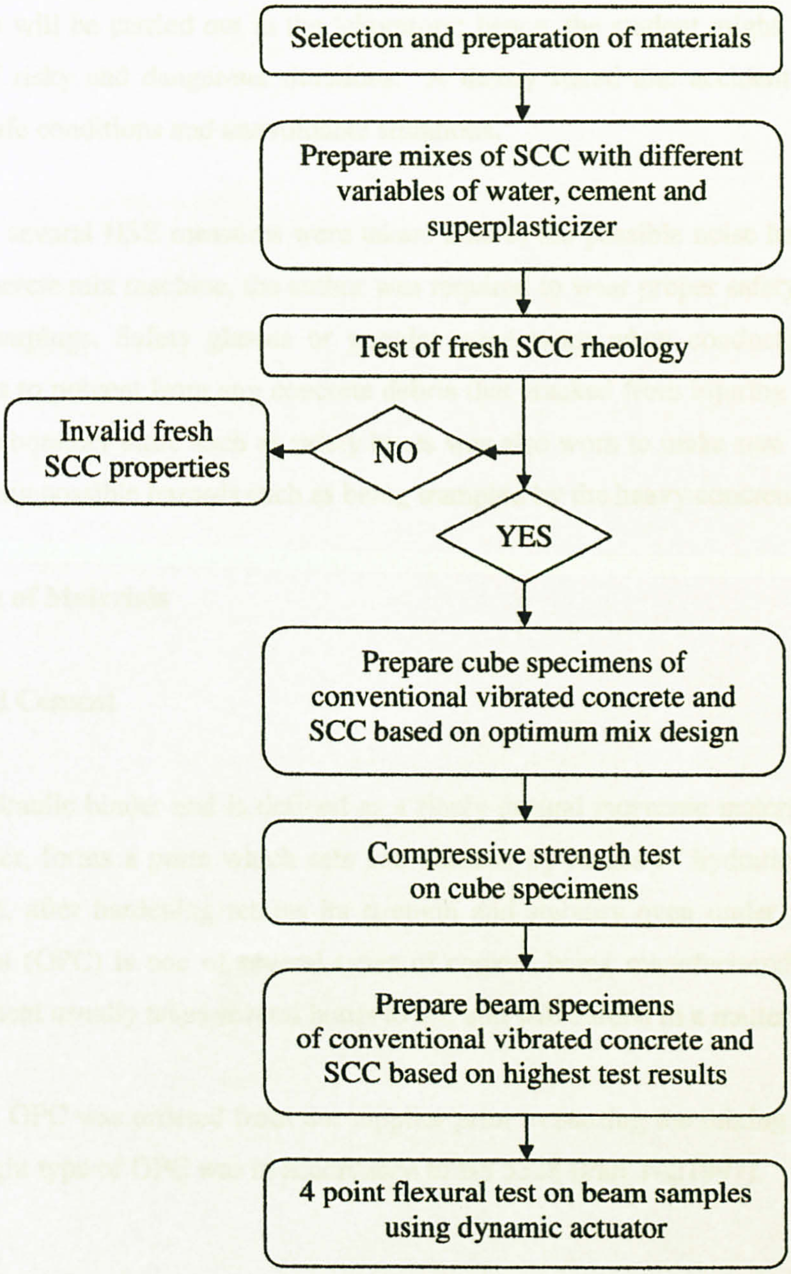


Figure 3.1: Project flowchart

3.1 Health, Safety and Environment (HSE) Awareness

According to history, the industrial accident rates increase each year not only limited in Malaysia but around the world. FYP students who will be working in the laboratory, roadside or any other places that invite risk and danger will always be exposed to the dangerous situation. For this project, the tests will be carried out in the laboratory; hence, the student might be dealing with several kinds of risky and dangerous situations. A theory stated that accident can caused by unsafe acts, unsafe conditions and unavoidable situations.

For this project, several HSE measures were taken. Due to the possible noise hazard during the operating of concrete mix machine, the author was required to wear proper safety ear protection; e.g. earmuffs, earplugs. Safety glasses or goggles were worn when conducting the flexural testing. This was to prevent from any concrete debris that cracked from injuring the eyes during testing. Proper laboratory attire such as safety boots was also worn to make sure that the feet are protected from any possible hazards such as being trampled by the heavy concrete beams.

3.2 Preparation of Materials

3.2.1 Portland Cement

Cement is a hydraulic binder and is defined as a finely ground inorganic material which, when mixed with water, forms a paste which sets and hardens by means of hydration reactions and processes which, after hardening retains its strength and stability even under water. Ordinary Portland Cement (OPC) is one of several types of cement being manufactured throughout the world. OPC cement usually takes several hours to set, and will harden in a matter of weeks.

For this project, OPC was ordered from the supplier prior to starting the mixing of the concrete. Choosing the right type of OPC was in accordance to BS 5328 (Part 1-2:1997).

3.2.2 Aggregates (Coarse and Fine)

For this project, both coarse and fine aggregates were used. The coarse aggregates were used in 2 different sizes; 20-8 and 8-4 mm. The aggregates were gathered and washed to eliminate any unwanted materials such as dirt and grass, which could affect the concrete mix. The selection of aggregate sizes was done by referring to BS 5328 (Part 1-2:1997).

3.2.3 Beam Specimen Preparation

The formwork for casting beams was fabricated at the laboratory and casted with the dimension of 150mm x 250mm x 1900mm. The type of material used for preparing the formwork is plywood, which is readily available in the laboratory (as shown in Figure 3.2). Only one formwork was prepared for this project.

Two types of reinforced bars were used, as listed below:

- 12mm Y-bar (460 MPa)
- 6mm R-bar (250 MPa)

Figure 3.2: Plywood being constructed into formwork parts

Figure 3.3: The author preparing reinforcement bars for beam specimen

3.3 Mix Design Proportion

The best mix design proportion must be obtained so that when beam specimens are cast, only the optimum concrete mix will be used. The mix should be an excellent balance of paste with super plasticizer that will result in a good concrete flow but at the same time can maintain its strength. This was an important part of the project which will be a big influence on the performance of the beam specimens later on. A safety factor of 1.1 is used for the mixed design. This is to provide a design margin over the theoretical design capacity to allow for uncertainty in the design process. In this study, the uncertainty is influence of dynamic loading on the beams.

Table 3.1: Mix design proportion per 1m^3 of concrete

Mix	Mix No.	Cement	Coarse Agg. (20-8)	Coarse Agg. (8-4)	Fine Agg.	Water/ Cement	Water	Super Plasticizer	Total Weight
SCC	1	500	325	610	815	0.30	150	15	2400
	2	500	310	600	815	0.35	175	15	2400
	3	500	295	590	815	0.40	200	15	2400
	4	500	280	585	810	0.45	225	15	2400
	5	500	265	575	810	0.50	250	15	2400
Control	Normal	500	265	575	810	0.50	250	0	2400

*All units are in kg

3.4 Concrete Mixing

The steps of concrete mixing should be followed accordingly to ensure a good mix. This should be in accordance to BS 1881 (Part 125:1986). Listed below is the procedure of concrete mix incorporating super plasticizer:

1) Pour all coarse and fine aggregates into the mixer and mix for 25 seconds to ensure uniform distribution between both materials.
2) Pour half of the water and mix for 1 minute.
3) Leave the mixes for 8 minutes to let both coarse and fine aggregates absorb water.
4) Pour all Portland cement into the mixer and mix for 1 minute.
5) Pour another half of the water and add super plasticizer and mix for 3 minutes.
6) Perform hand mixing until the mix is uniform.

Figure 3.4: The author conducting concrete mixing

3.5 Concrete Casting

Fresh concrete was then casted into cubes and beams. This is to prepare specimens for further hardened concrete tests.

Sizes of the cubes and beams are as follows:

- Cube: 100mm x 100mm x 100mm
- Beam: 1900mm x 250mm x 150mm

For cube specimens, the fresh concrete was poured into the concrete moulds that were available at the laboratory. 3 cubes were made for each; SCC and conventional vibrated concrete mixes, so there is a total of 18 cubes to be tested.

For beam specimens, fresh concrete was poured into the formwork prepared earlier. Grease was used to prevent the concrete mix from sticking to the formwork by brushing the grease onto the formwork's inside surface. The fresh concrete was poured into the formwork by three layers.

A concrete vibrator was only used for the conventional vibrated concrete beam casting. Vibrating increases compressive strength and bond between concrete and rebar and decreases concrete permeability. It also decreases excessive entrapped air and segregation. The vibrator is not needed in SCC beam casting as this will contradict the SCC's flowing and non-segregating abilities.

After a day of casting, the beam was ready for the curing process.

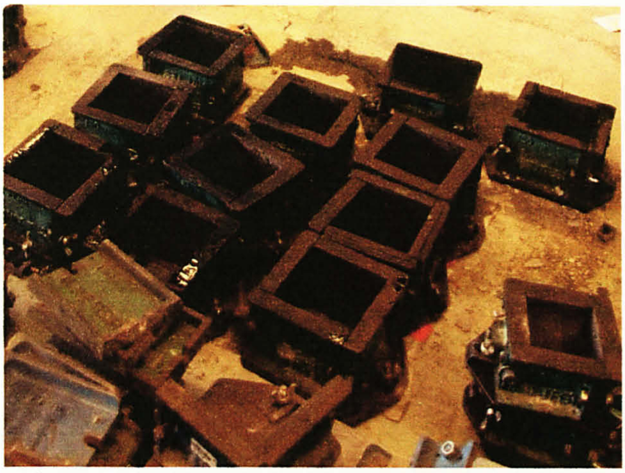


Figure 3.5: Concrete cube mould used for casting

Figure 3.6: Formwork for beam casting

Figure 3.7: Vibrating normal concrete in formwork

3.6 Concrete Curing

Curing is for avoiding shrinkage cracking due to fluctuation in temperature and it will also provide maximum strength for the concrete.

After removal of mould on the second day of casting, the cube specimens were placed inside the curing tank as shown in Figure 3.8 until the scheduled day for testing.

For beam specimens, curing was done by wrapping the specimens with damp gunny sacks and covering them with plastic canvas for a week.

Figure 3.8: Concrete cube curing

3.7 Fresh Concrete Tests

Few tests were conducted to study the main characteristics of SCC.

3.8.1 Slump Flow Test

This test provides information on filling ability (flowability) and passing ability (for a stable mix, high flowability tracks with passing ability). During this test, SCC will flow by the influence of gravity. In general, the slump flow test is very similar to the standard slump test. The slump flow is the diameter of the resulting concrete "patty" obtained from the average of measuring the greatest diameter and diameter perpendicular to this direction. Large differences between the two diameters indicate a non-level surface, which must be corrected. SCC generally has slump flow of 560 to 760 mm (De Schutter 2005)

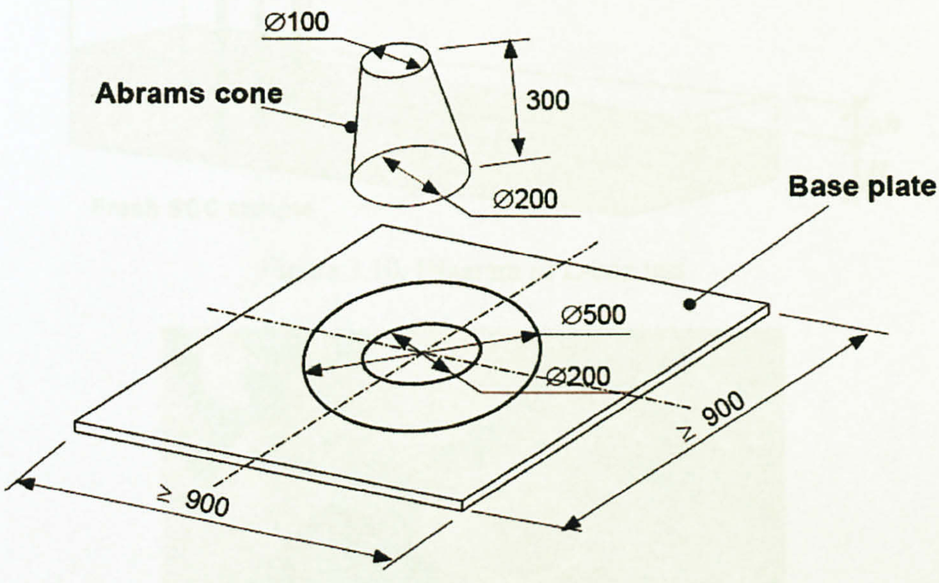


Figure 3.9: Diagram of slump flow test

3.8.2 L-Box Test

This test is for determining SCC with higher possibility of segregation between coarse aggregate and cement matrix. The L-box measures the filling ability, passing ability and placeability of SCC. In this method a closed vertical chamber is filled with the concrete to be tested so that a hydrostatic pressure head is produced. After a slide is opened the concrete has to level out through horizontal (L-box) flow obstacles. Passing ability is indicated by visual inspection of the area around the rebar – with an even distribution of aggregate indicating good passing ability. (De Schutter 2005)

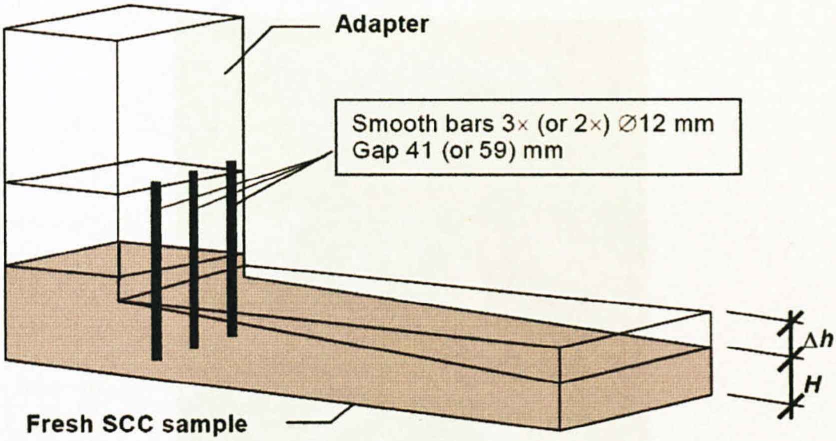


Figure 3.10: Diagram of L-box test

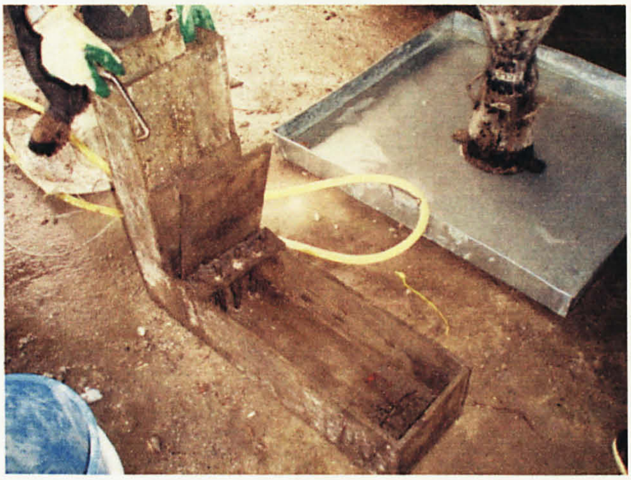


Figure 3.11: L-box test performed on SCC mixes

3.8.3 V-Funnel Test

V-Funnel test was used to determine the segregation potential. The funnel is filled with concrete and time taken for the concrete to leave the funnel is measured. Then, the funnel is refilled with the same concrete and allowed to settle for 5 minutes. The new time required for the concrete to leave the funnel is measured. The difference in time is a measure of segregation resistance of the concrete mix or better known as viscosity. A longer funnel flow time represents higher viscosity of the SCC mixture, which translates into better resistance to segregation. (De Schutter 2005)

Figure 3.12: V-funnel testing on SCC mixes

3.8 Hardened Concrete Tests

The tests conducted on hardened concrete will directly result in fracture behavior. This is because fracture can only be identified during the hardened state of SCC where it involves mechanical properties such as tensile and compressive strengths, ductility and durability.

3.9.1 Compressive Strength Test

One of the most important properties of concrete is its strength in compression. The strength in compression has a definite relationship with all other properties of concrete. The other properties are improved with the improvement of compressive strength.

The compressive strength is taken as the maximum compressive load it can carry per unit area. Compressive strength tests for concrete with maximum size of aggregate up to 20mm are usually conducted on 100mm cubes. (UTP Concrete Technology Laboratory Manual)

SCC compressive strengths are comparable to those of normal concrete made with similar mix designs and water/cement ratio. Test of cubes for compressive strength at 1, 3,7,14 and 28 days.

Figure 3.13: Cube compressive testing

Figure 3.14: Concrete cubes after testing

3.9.2 Flexural Test

Flexural test measures bend or fracture strength, modulus of rupture, yield strength, modulus of elasticity in bending, flexural stress and strain.

Six beams were casted for this study, three for conventional vibrated concrete and three for SCC. Four 12mm Y-bars were selected as flexural reinforcement. Twelve 6mm R-bars were placed in the beam as shear reinforcement at spacing of 200 mm evenly along the span. A clear cover of 30mm was provided on all sides.

The beam specimens were tested as simply supported beams under four-point loading condition with constant moment region of 600mm. The test setup included the use of a hydraulic jack and a 500kN dynamic actuator that applied load on the mid-span of beam specimens until failure. One linear variable displacement transducer (LVDT) was placed directly under the mid-span of each beam to measure central deflection. In order to monitor the strain, two electrical strain gauges were installed directly under the loading point at mid-span (as shown in Figure 3.17). A computer aided data acquisition system automatically monitored load, displacements and strains at pre-selected time intervals throughout the testing session (as shown in Figure 3.18).

Fatigue tests were performed at three different load ranges which are 40%, 60% and 85% for upper load and 10% for lower load. The load applied between upper load and lower load level was at a frequency of 5 Hz. In this project, the maximum numbers of cyclic load were applied was 150000 cycles. Thus, beams were analyzed based on 150000 load cycles.

The tests also provided information on the overall behavior of beams including development of cracks, crack patterns, load transfer mechanisms and failure modes.

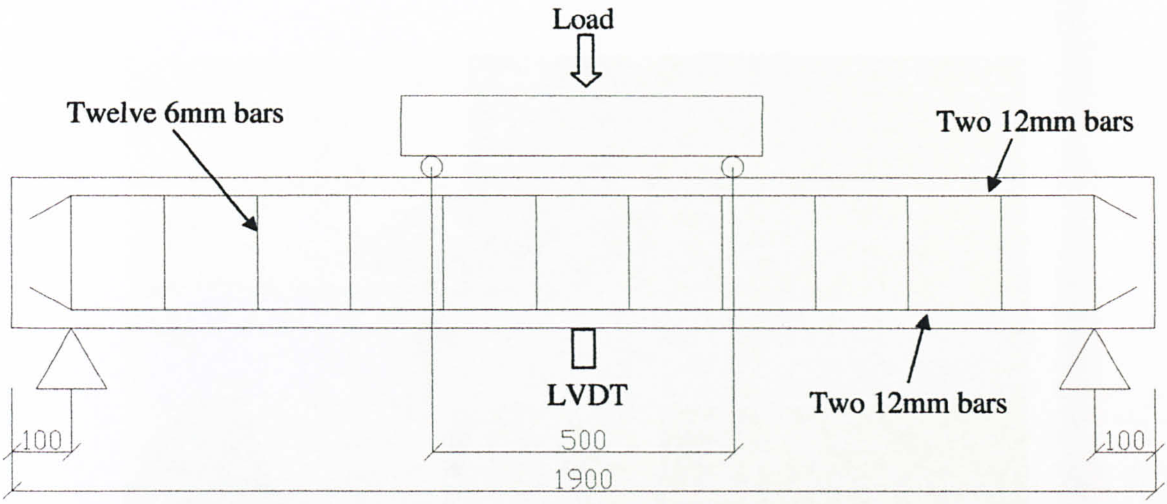


Figure 3.15: 4-point flexural test setup

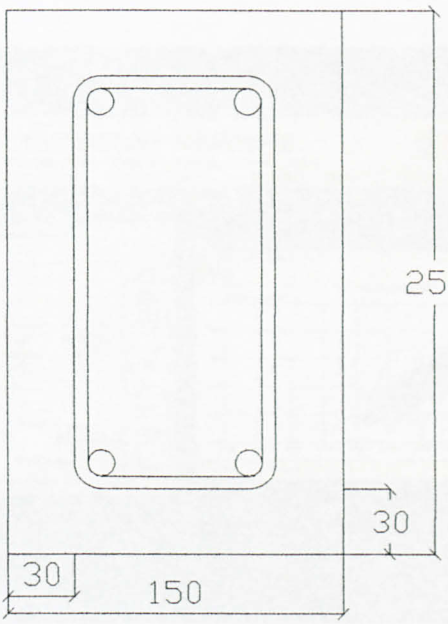


Figure 3.16: Cross section of beam specimen

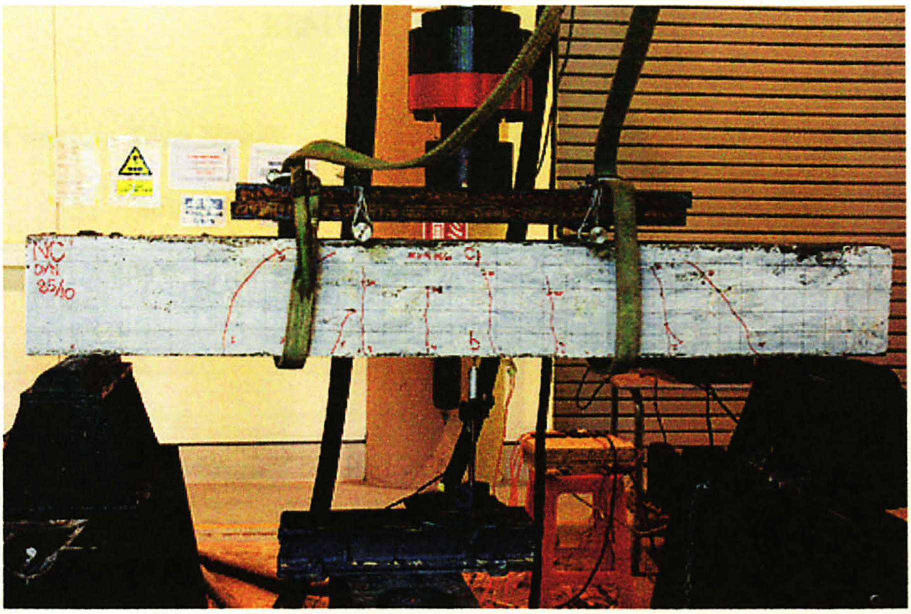


Figure 3.17: Actual arrangement of beam flexural testing

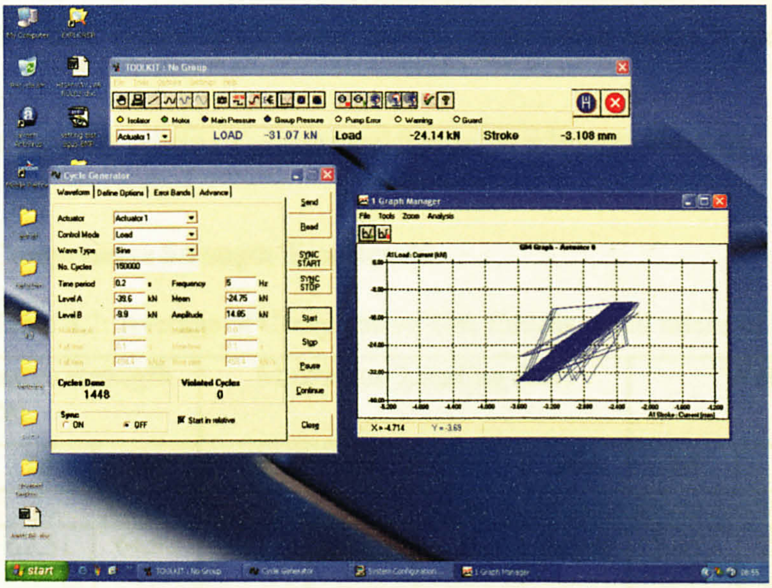


Figure 3.18: Software used in the beam flexural testing

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Fresh Concrete Tests Result

Table 4.1: Fresh Concrete Tests Results on all mixes of SCC

Mix No	V- Funnel (sec)	Slump Flow (mm)		L-Box (mm)		T_{50} (sec)
		0°	90°	H_{max}	H	
1	*Test of fresh concrete failed. Results were invalid.*					
2	9	550	590	210	90	5
3	15	770	690	130	90	2
4	2	790	850	100	90	2
5	2	820	910	100	100	2

Discussion:

- Mix 1 was too dry and cannot be considered as SCC. This is due to improper designation of mix design which results in an unsuitable passing ability of concrete mixture.
- Mix 3 has the longest time for V-Funnel Test (15 seconds), thus it is the most viscous among all 5 SCC mixes. But it has a low T_{50} value which makes it too watery and not workable.
- Mix 2 has the most suitable T_{50} value and it also has adequate viscosity

4.2 Average of Compressive Strength Test Results

Table 4.2: Average of Compressive Test Results on all mixes of SCC

Mix No.	Stress/ Compressive strength (MPa)				Maximum Loading (kN)				Weight of cube (kg)			
	1d	3d	7d	28d	1d	3d	7d	28d	1d	3d	7d	28d
1	*No test conducted due to failure in fresh concrete test*											
2	32.92	47.71	62.51	64.90	329.2	477.1	625.1	649.0	2.457	2.482	2.579	2.506
3	16.71	28.49	52.05	59.75	167.1	284.9	520.5	597.5	2.264	2.407	2.462	2.573
4	25.77	38.45	42.66	53.57	257.7	384.5	426.6	535.7	2.414	2.432	2.427	2.454
5	25.40	38.48	44.75	59.79	254.0	384.8	447.5	597.9	2.406	2.419	2.503	2.407

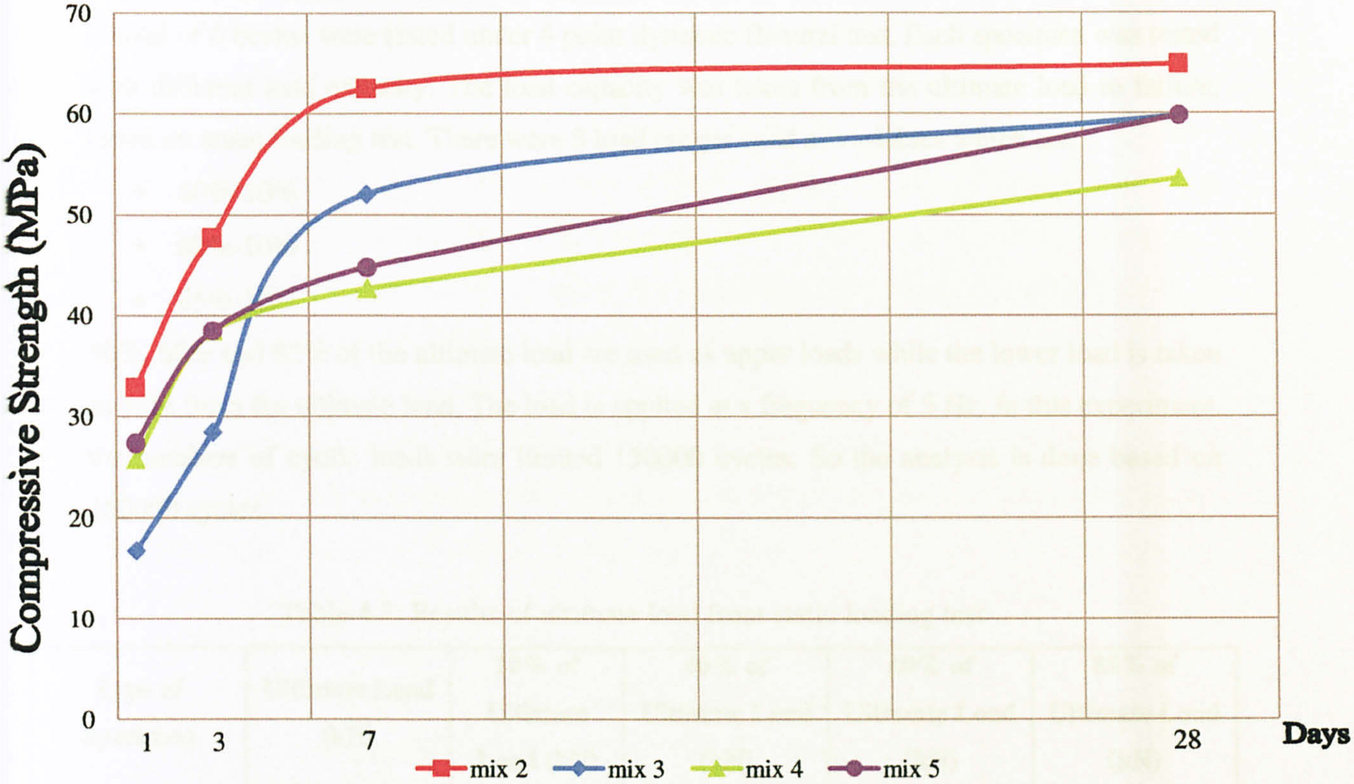


Figure 4.1: Cube Compressive Strength vs Days

Discussion:

- The average compressive strength of 3 cube samples from all 5 mixes was measured. The strength varies from 1 day, 3 days, 7 days and 28 days.
- The data is then plotted onto a graph, which will be used to determine the optimum mix design for SCC beam.
- From the graph, it shows that Mix 2 has the highest compressive strength compared to the other mixes; hence Mix 2 will be used as the optimum SCC mix design.

4.3 Experimental Results from Flexural Test

4.3.1 Ultimate Load From Static Loading Test

A total of 6 beams were tested under 4 point dynamic flexural test. Each specimen was tested with different load capacity. The load capacity was taken from the ultimate load to failure, based on static loading test. There were 3 load ranges used as variables which are:

- 40%-10%
- 60%-10%
- 85%-10%

40%, 60% and 85% of the ultimate load are used as upper loads while the lower load is taken as 10% from the ultimate load. The load is applied at a frequency of 5 Hz. In this experiment, the numbers of cyclic loads were limited 150000 cycles. So the analysis is done based on 150000 cycles.

Table 4.3: Results of ultimate load from static loading test

Type of Specimen	Ultimate Load (kN)	10% of Ultimate Load (kN)	40% of Ultimate Load (kN)	60% of Ultimate Load (kN)	85% of Ultimate Load (kN)
Conventional Concrete	92.90	9.29	37.16	55.74	78.965
Self Compacting Concrete	99.03	9.903	39.612	59.418	84.176

4.3.2 General Cracking and Failure Behavior of SCC and Conventional Vibrated Concrete Beams

Figure 4.3 shows crack patterns of SCC and CVC beams at failure. During early stages of loading, fine vertical flexural cracks appeared around the mid-span of all beams, as expected. The first visible cracks formed between the locations of the two point loads in the region of maximum bending moment. With the increase in load, new flexural cracks were formed away from the mid-span area. With further increase in load, those flexural cracks started to propagate diagonally towards the loading point and other new diagonal cracks began to form separately in locations farther away from the mid-span along the beam.

For both SCC and NC beams, the cracks extended up to 50% and 70% of the beam height respectively. Table 4.4 shows the number of cracks after failure and the maximum crack length for each beam.

Table 4.4: Crack characteristics of experimental beams

Beam designation	Number of cracks after failure	Maximum crack length (mm)
SCC 85/10	8	250
NC 85/10	10	545
SCC 60/10	8	238
NC 60/10	9	354
SCC 40/10	8	184
NC 40/10	6	192

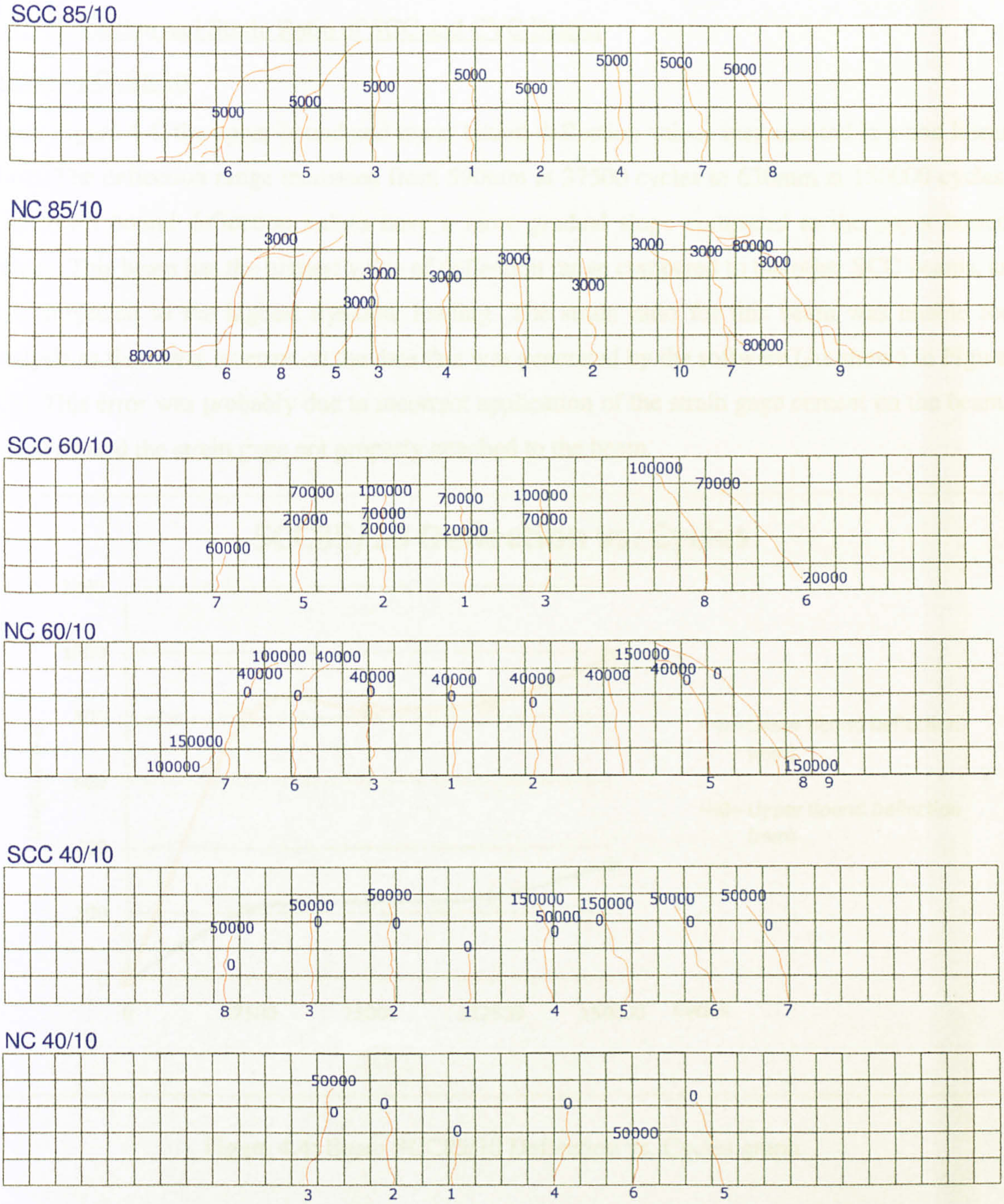
From Table 4.4, CVC beams recorded more cracks than SCC beams at 60% and 85% load ranges respectively. The maximum crack lengths on all CVC beams are higher than those on SCC beams.

From the testing, it was observed that CVC beams had more cracks. This may be due to compaction reasons. During the CVC beams casting, full compaction was not implemented. This may have resulted in a non-uniform distribution of aggregates in the beam thus created more pores in the beams.

At 85% load range, both CVC and SCC beams failed after 150000 cycles. The maximum crack length from beam NC85/10 propagated at an angle of 45° before causing the beam to fail. Even though the beams were designed for flexural testing, beam NC85/10 experienced shear failure. This may be caused by the link failure in the beam itself. From a tensile test conducted on a few R-bar specimens available at the laboratory, the average strength of the R-bars used as links were less than half of 250MPa. So it was assumed that the link in beam NC85/10 snapped and caused the shear failure.

At 60% load range, the beams experienced crack propagation with angles ranging from 45° to 65°. Even though both beams did not fail after 150000 cycles, the cracks manage to propagate to almost 90% of the beam height. More cracks appeared away from the mid-span after 100000 cycles.

At 40% load range, the SCC beam appeared to have several vertical cracks on the left side while few other cracks propagated with an average angle 80° at the right side. The SCC beam is observed to have experienced more cracks compared with NC40/10.



*Numbers at the cracks indicate the number of cycles where cracks stopped

Figure 4.3: Crack patterns of SCC and NC beams at respective number of cycles

4.3.3 Deflection and Strain Ratio of SCC and CVC Beams

i) Beam SCC85/10

From Figure 4.4, the upper bound and lower bound deflection values incremented in a non linear form. The deflection range increased from 590mm at 37500 cycles to 630mm at 150000 cycles. The lower bound deflection values have a more gradual slope compared to the upper bound values. This beam has the highest value of deflection range compared to the other SCC beams, as it is subjected to the highest dynamic loading. The strain ratio for this beam was unable for analysis as there was an error on the data that was generated by the software (As shown in Figure 4.5). This error was probably due to incorrect application of the strain gage cement on the beam, which caused the strain gage not properly attached to the beam.

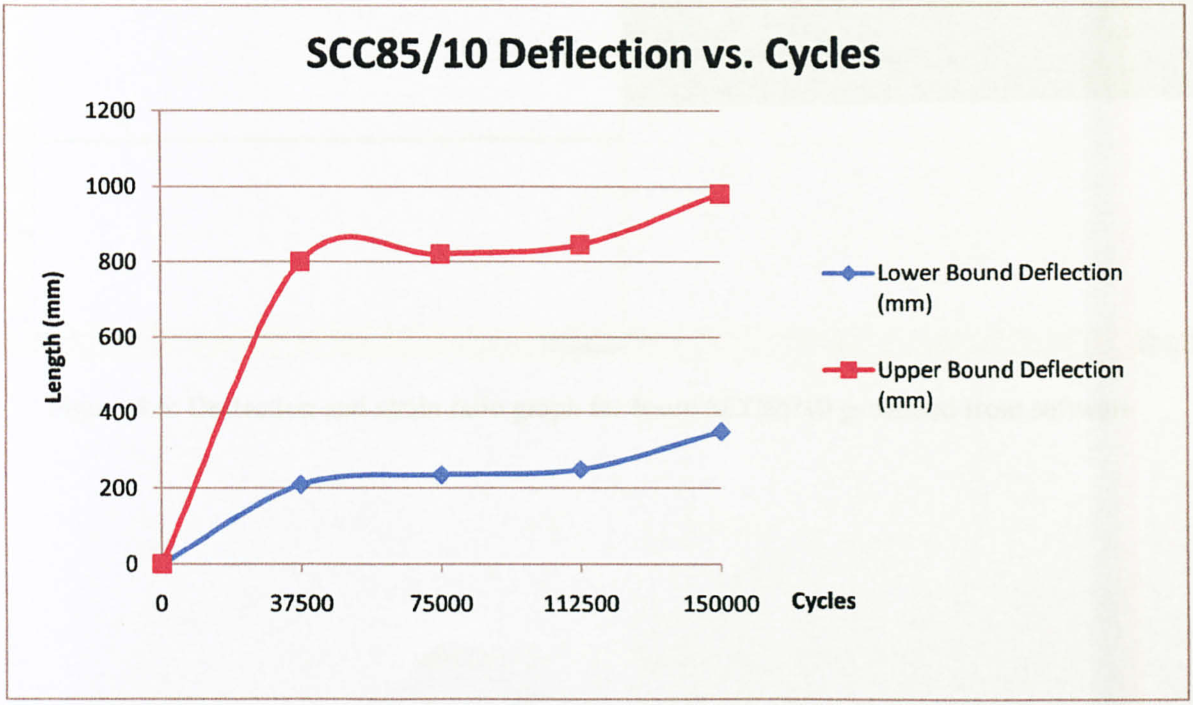


Figure 4.4: Beam SCC85/10 Deflection vs. Cycles graph

Table 4.5: Deflection and strain ratio values for beam SCC85/10

Cycles	Deflection (mm)			Strain Ratio (μm/m)		
	Lower Bound	**Upper Bound**	**Range**	**Lower Bound**	**Upper Bound**	**Range**
0	0	0	0	Not available due to error in strain gage channel		
37500	210	800	590			
75000	235	820	585			
112500	250	845	595			
150000	350	980	630			

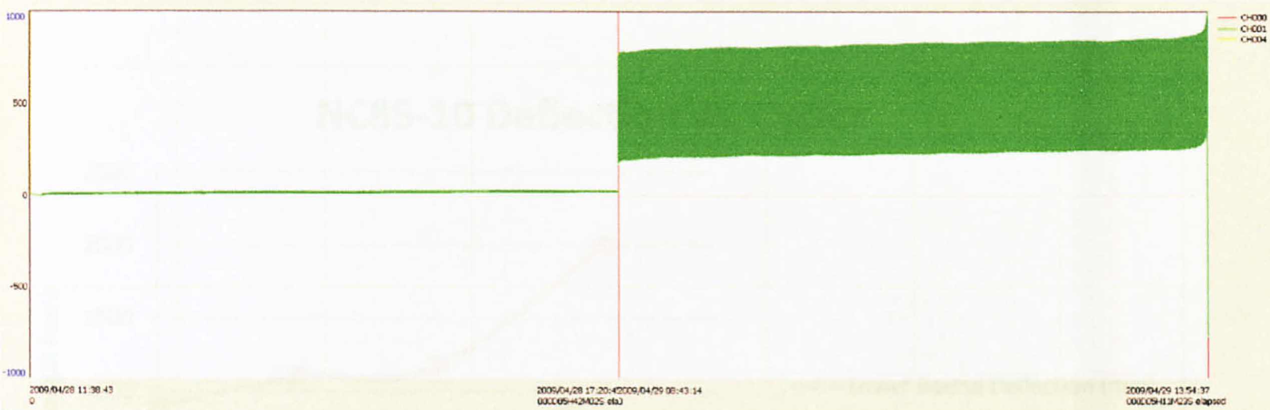


Figure 4.5: Deflection and strain ratio graph for beam SCC85/10 generated from software

ii) Beam NC85/10

From Figure 4.6, it showed that at the start of testing (around 100 cycles), this beam has experienced a very high deflection range which was 600mm and it remained constant after 50000 cycles. After 100000 cycles, the deflection range increased to 640mm. Upon failure at 120000 cycles, the beam recorded the highest value of deflection range which was 1000mm. From 0 to 75000 cycles, the upper and lower bound values experienced similar increment where the range increased constantly but it began to get higher as it reached 120000 cycles. The strain ratio for this beam was also not available for analysis as the software generated irrelevant values (refer Figure 4.7). This may be caused by human error, or simply the crack propagation that may have disturbed the stain gage placing.

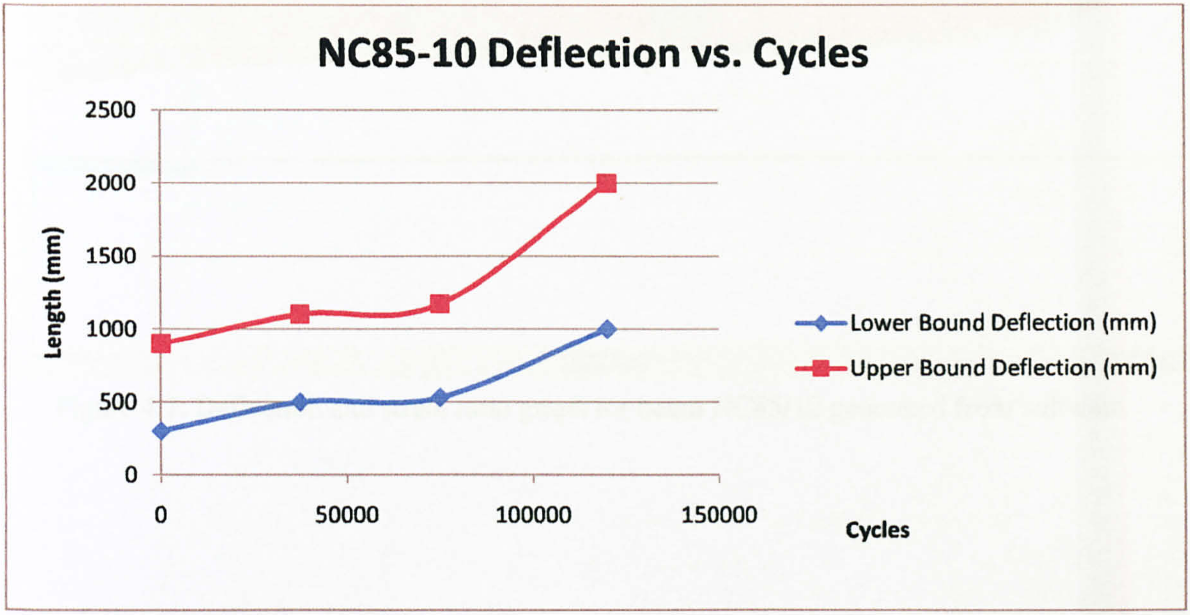


Figure 4.6: Beam NC85/10 Deflection vs. Cycles graph

Table 4.6: Deflection and strain ratio values for beam NC85/10

Cycles	Deflection (mm)			Strain Ratio (μm/m)		
	Lower Bound	Upper Bound	Range	Lower Bound	Upper Bound	Range
0	0	0	0	Not available due to error in strain gage channel		
<100	300	900	600			
37500	500	1100	600			
75000	530	1170	640			
120000	1000	2000	1000			

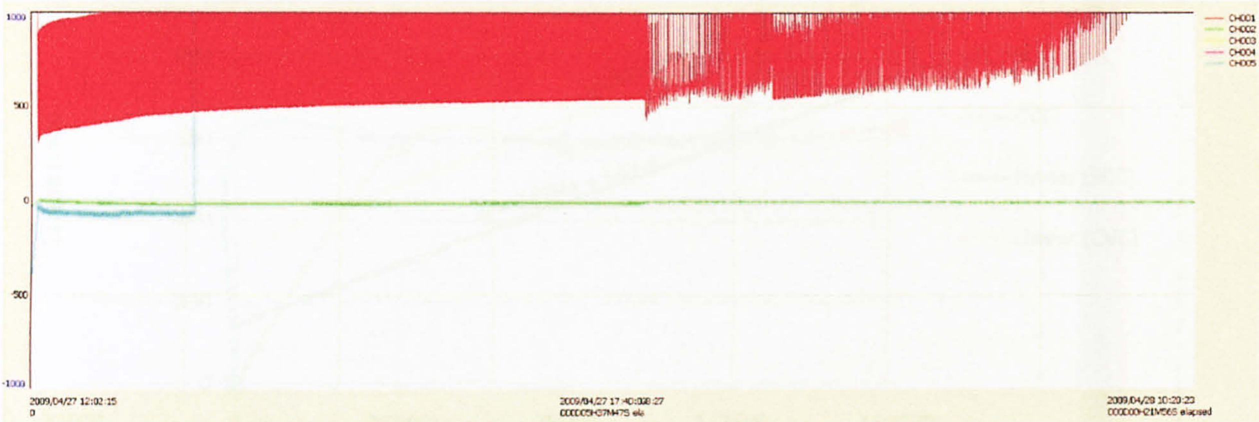


Figure 4.7: Deflection and strain ratio graph for beam NC85/10 generated from software

iii) Comparison between Beam SCC85/10 and Beam NC85/10

Based on the results obtained, it showed that the CVC beam recorded higher deflection range compared to the SCC beam. From Figure 4.8, both beams experienced almost similar deflection throughout the testing, even though the CVC recorded higher values. The difference between both beams was evident during failure (after 150000 cycles) when the CVC beam recorded a sudden increase in deflection compared to the SCC beam.

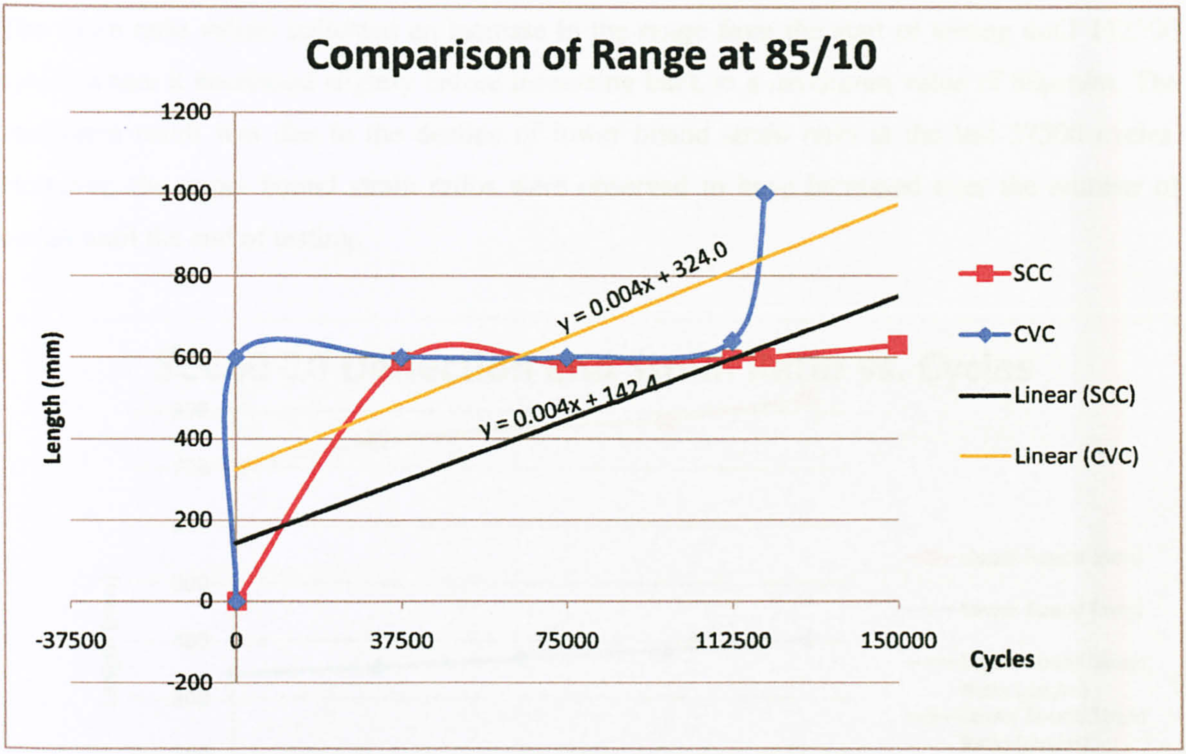


Figure 4.8: Comparison on the differences in upper and lower bound range between beam SCC85/10 and beam NC85/10

Table 4.7: Deflection range of beam SCC85/10 and beam NC85/10

Cycles	Deflection Range (mm)	
	CVC	SCC
0	0	0
100	600	0
37500	600	590
75000	600	585
112500	640	595
120000	1000	600
150000	Fail	630

iv) Beam SCC60/10

From Figure 4.9, the upper and lower bound values incremented not in a linear form with a range of 343 to 700mm at the start of testing. Towards the end of testing, the deflection range got bigger with a final value of 420mm at 150000 cycles. The upper bound values presented a steeper slope compared to the lower bound values.

The strain ratio values indicated an increase in the range from the start of testing until 112500 cycles where it decreased slightly before increasing back to a maximum value of 80μm/m. The maximum result was due to the decline of lower bound strain ratio at the last 37500 cycles. However, the upper bound strain ratios were observed to have increased over the number of cycles until the end of testing.

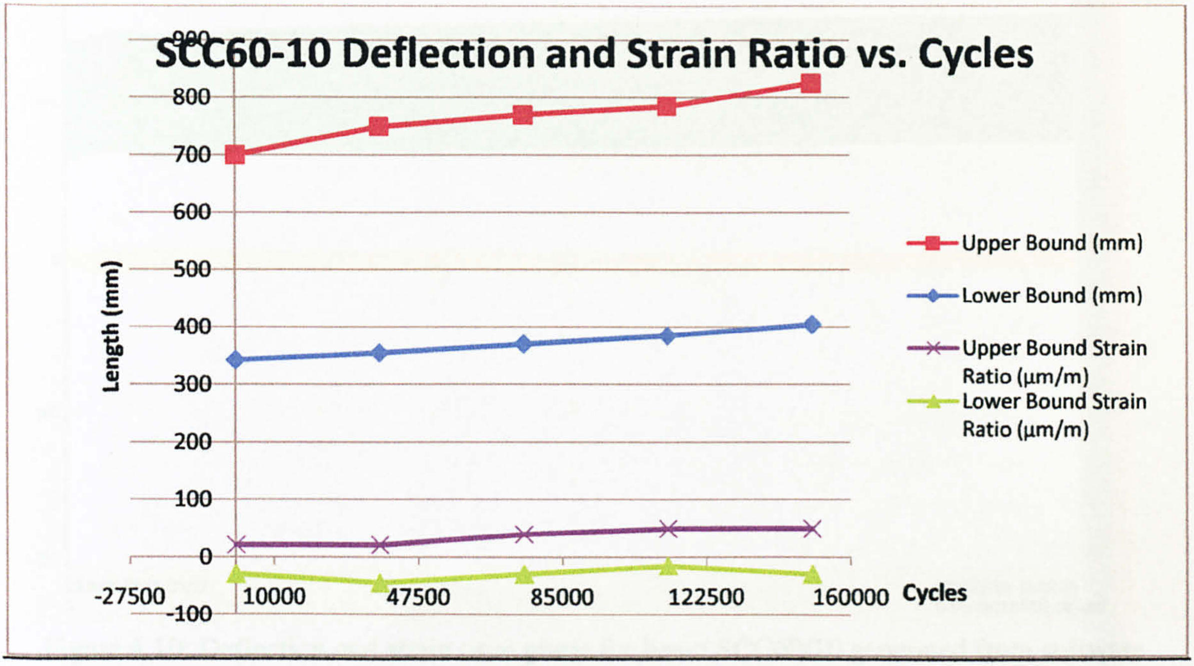


Figure 4.9: Beam SCC60/10 Deflection and Strain Ratio vs. Cycles graph

Table 4.8: Deflection and strain values for beam SCC60/10

Cycles	Deflection (mm)			Strain Ratio (μm/m)		
	Lower Bound	Upper Bound	Range	Lower Bound	Upper Bound	Range
<100	343	700	357	-30	21	51
37500	355	750	395	-45	21	66
75000	370	770	400	-30	40	70
112500	385	785	400	-15	50	65
150000	405	825	420	-30	50	80

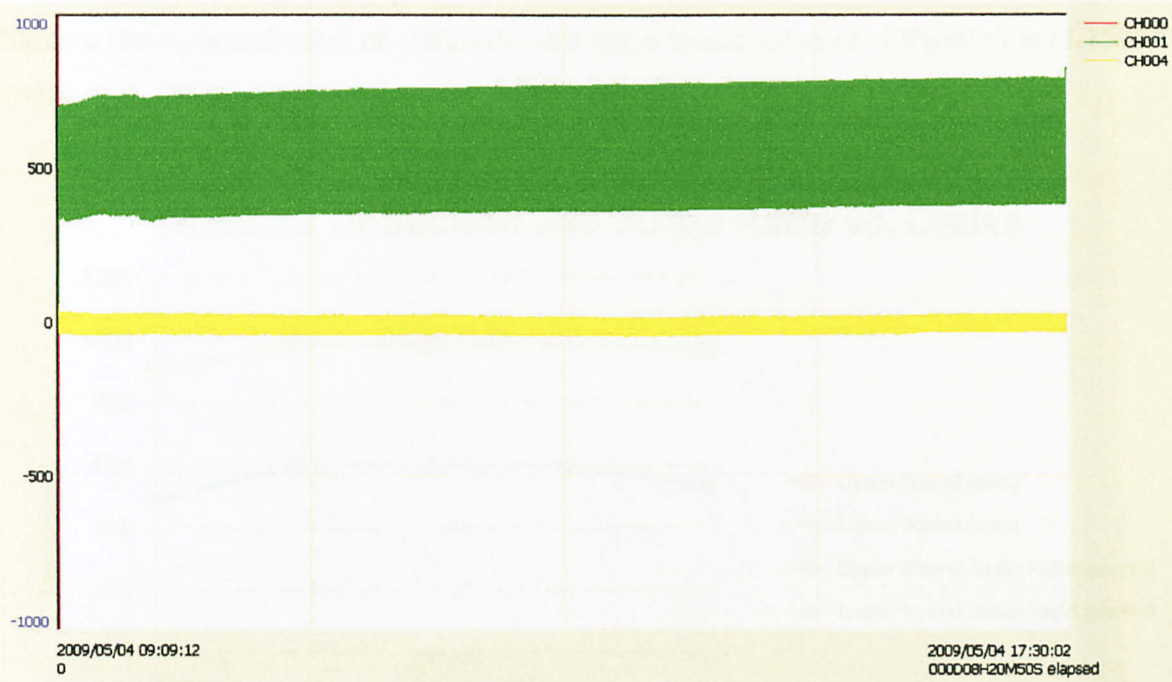


Figure 4.10: Deflection and strain ratio graph for beam SCC60/10 generated from software

v) Beam NC60/10

The lower bound deflection values increased from the start of testing and then maintained a constant value (600mm) throughout the whole testing period, but towards the end the value decreased to 530mm. The upper bound deflection experienced a 90mm increase from start until 37500 cycles where it went into smaller increments ranging from 5-10mm. Then, towards the end the upper bound deflection also decreased from 995mm to 970mm (as shown in Figure 4.11).

The strain ratio recorded had a very small range throughout the testing which was around 20μm/m, although at 37500 cycles the strain ratio range was 25μm/m. From Figure 4.11, it is observed that the strain ratio experienced a small decrease before being in a constant range of 20μm/m (lower bound value of -150μm/m and upper bound value of -130μm/m) until 150000 cycles.

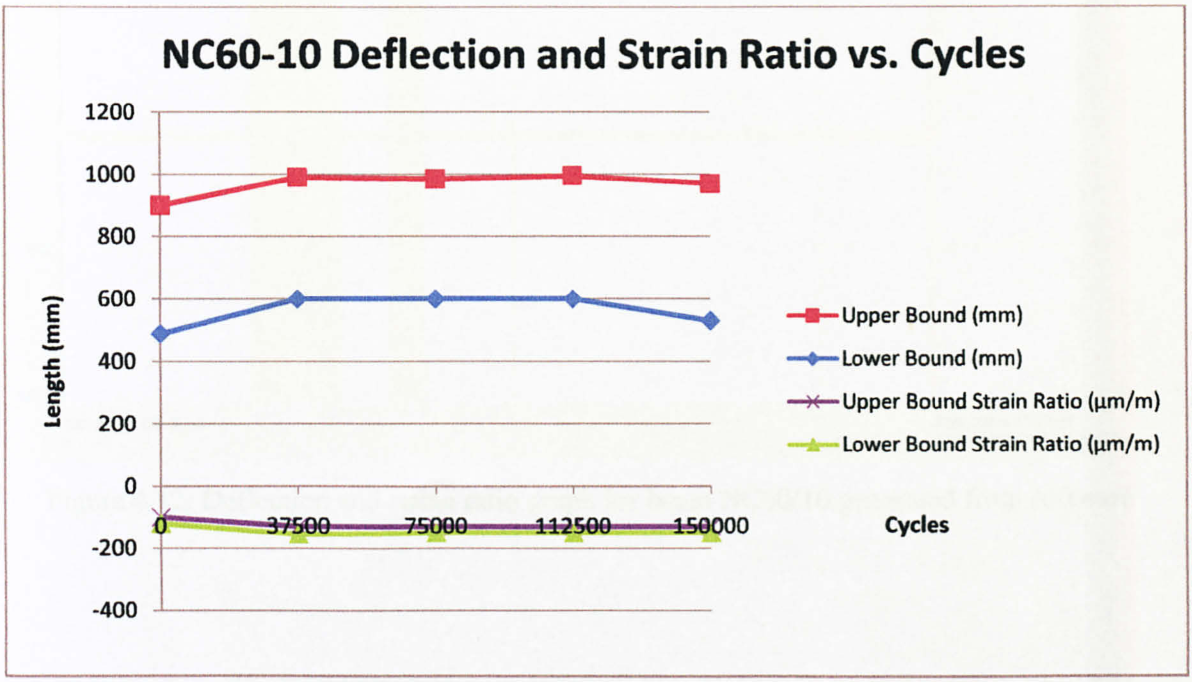


Figure 4.11: Beam NC60/10 Deflection and Strain Ratio vs. Cycles graph

Table 4.9: Deflection and strain ratio values for beam NC60/10

Cycles	Deflection (mm)			Strain Ratio (µm/m)		
	Lower Bound	Upper Bound	Range	Lower Bound	Upper Bound	Range
<100	490	900	410	-120	-100	20
37500	600	990	390	-155	-130	25
75000	600	985	385	-150	-130	20
112500	600	995	395	-150	-130	20
150000	530	970	440	-150	-130	20

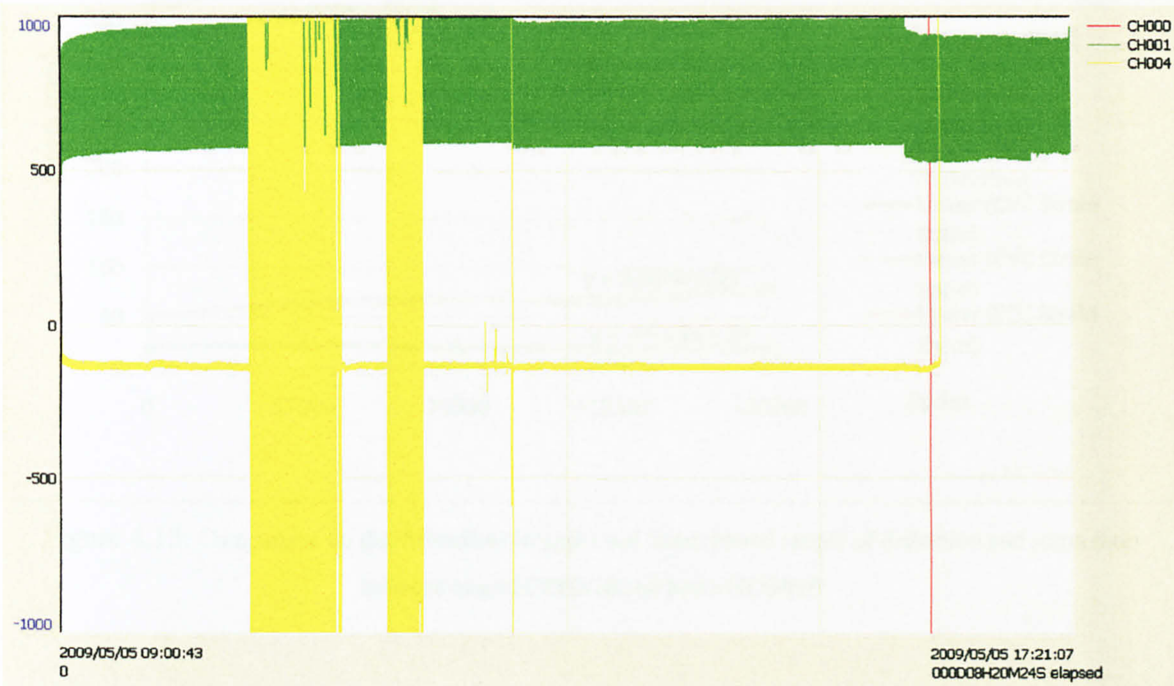


Figure 4.12: Deflection and strain ratio graph for beam NC60/10 generated from software

vi) Comparison between Beam SCC60/10 and Beam NC60/10

Based on the results obtained, it showed that the SCC beam recorded a very linear increasing deflection (in small increments) and constant strain ratio. This is quite contrast to the CVC beam where the deflection started to increase, maintained during the testing and declined at the end. The strain ratio for CVC is uniform albeit the small decrease at the start of testing.

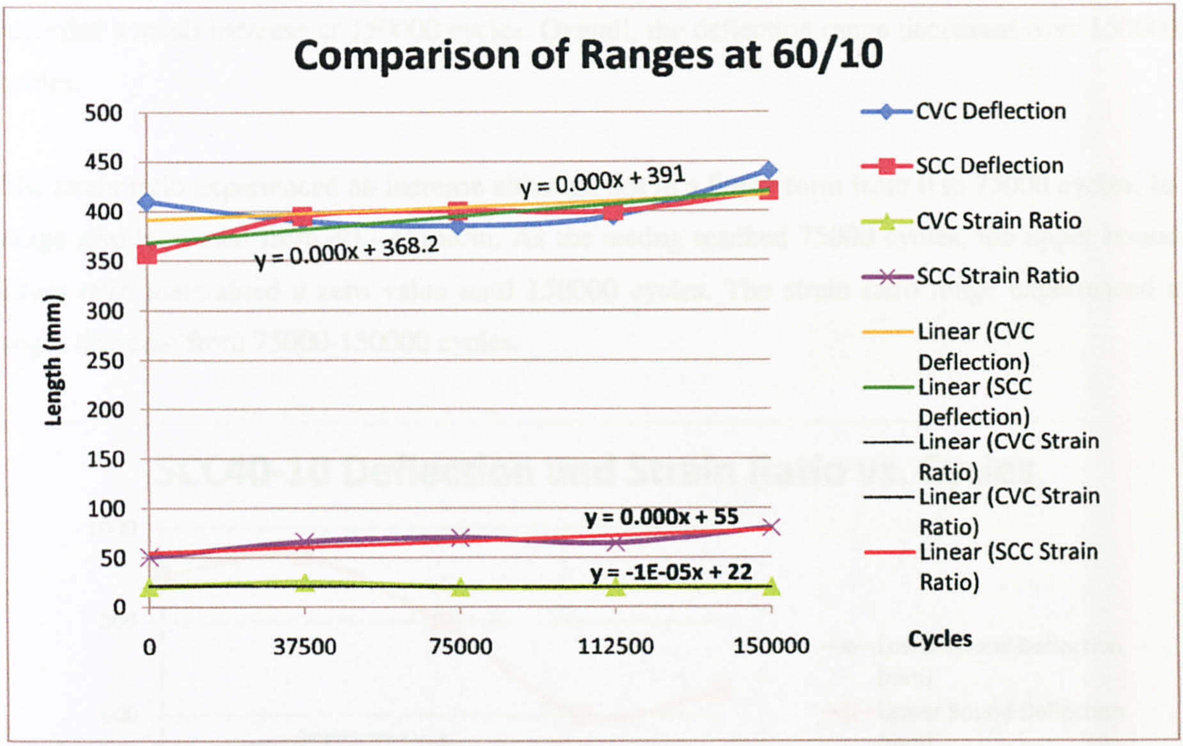


Figure 4.13: Comparison on the differences in upper and lower bound ranges of deflection and strain ratio between beam SCC60/10 and beam NC60/10

Table 4.10: Deflection and strain ratio range of beam SCC60/10 and beam NC60/10

Cycles	Deflection Range (mm)		Strain Ratio Range (μm/m)	
	CVC	SCC	CVC	SCC
<100	410	357	20	51
37500	390	395	25	66
75000	385	400	20	70
112500	395	400	20	65
150000	440	420	20	80

vii) Beam SCC40/10

From Figure 4.14, after around 100 cycles the deflection range began to increase in a linear form. But as soon as it reached 37500 cycles, there was a decline in the deflection and a sharp decrease on the upper bound deflection, which decreases the deflection range altogether from 390mm to 260mm. then it further decreased to a deflection range of 190mm at 112500 cycles before recorded a small increase at 150000 cycles. Overall, the deflection range decreased over 150000 cycles.

The strain ratio experienced an increase although not in a linear form from 0 to 75000 cycles. Its range also increased from 40 - 65µm/m. As the testing reached 75000 cycles, the upper bound strain ratio maintained a zero value until 150000 cycles. The strain ratio range experienced a slight decrease from 75000-150000 cycles.

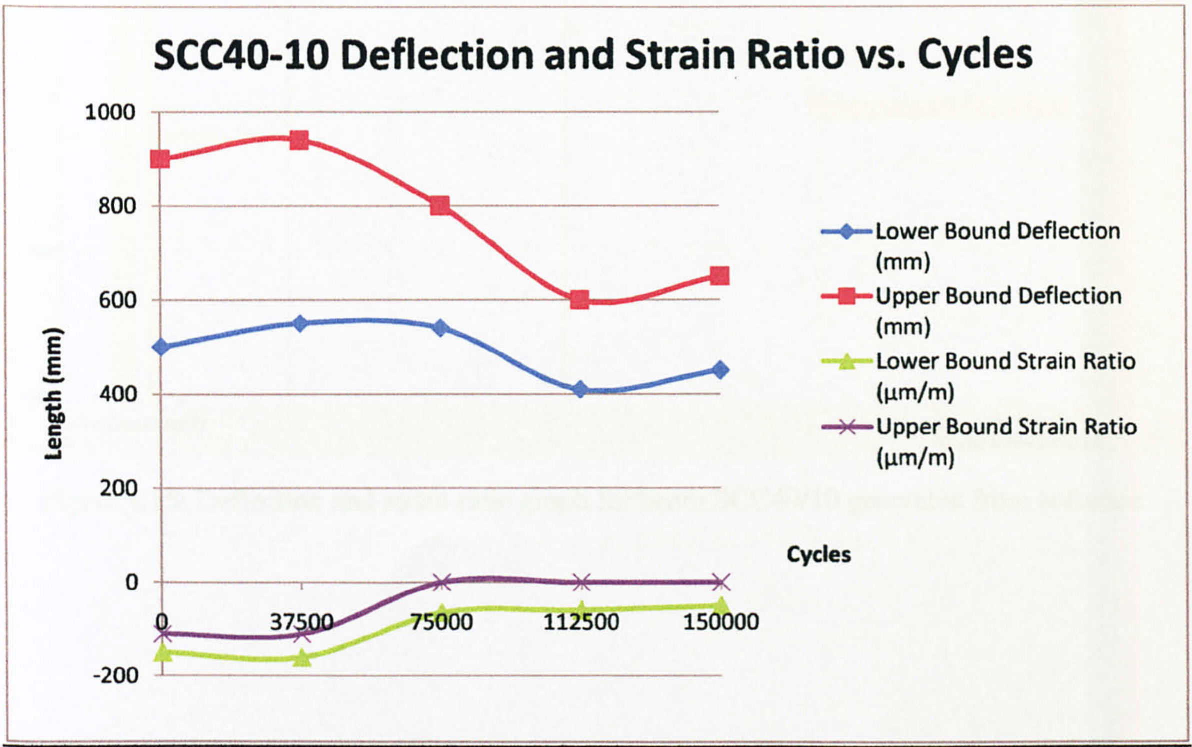


Figure 4.14: Beam SCC40/10 Deflection and Strain Ratio vs. Cycles graph

Table 4.11: Deflection and strain ratio values for beam SCC40/10

Cycles	Deflection (mm)			Strain Ratio (μm/m)		
	Lower Bound	Upper Bound	Range	Lower Bound	Upper Bound	Range
<100	500	900	400	-150	-110	40
37500	550	940	390	-160	-110	50
75000	540	800	260	-65	0	65
112500	410	600	190	-60	0	60
150000	450	650	200	-50	0	50

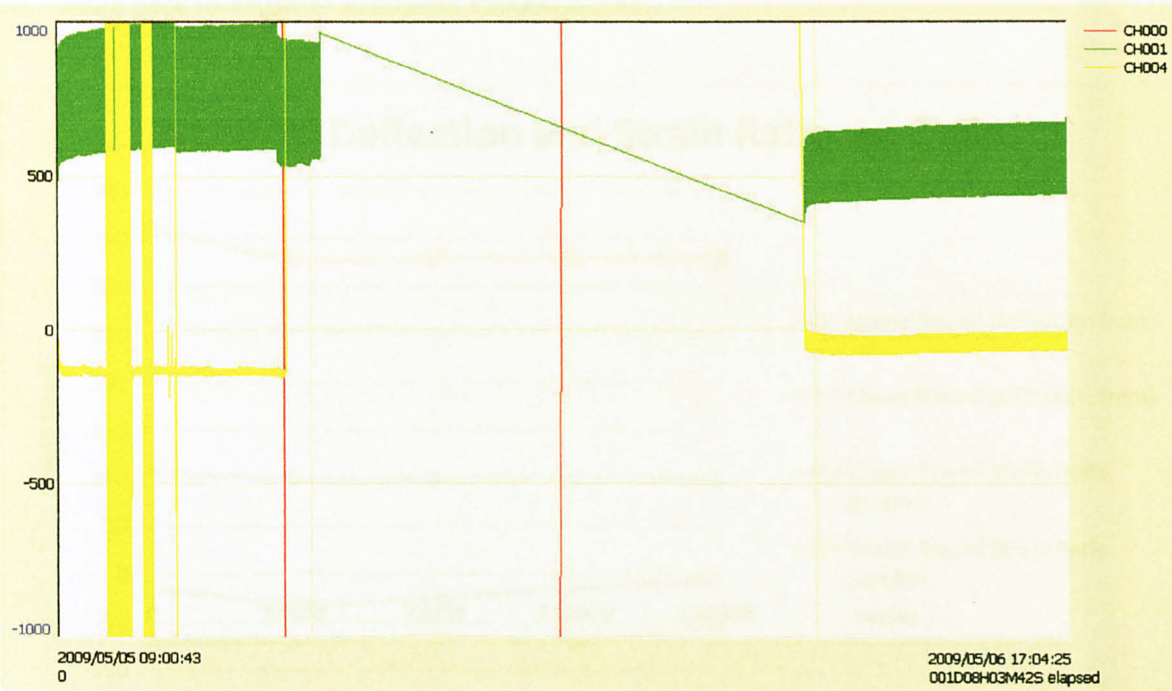


Figure 4.15: Deflection and strain ratio graph for beam SCC40/10 generated from software

viii) Beam NC40/10

From Figure 4.16, the upper bound deflection started at around 100 cycles with 360mm but then towards the end of testing, it maintained a value of 330mm. the lower bound deflection also experienced a small decrease from 105mm (at 100 cycles) to 100mm until the end of testing. So the deflection range is constant due to the small magnitude of load applied.

However, the strain ratio that was recorded showed a big range at start but gradually decreasing up until 75000 cycles. After that the strain ratio range increased from 40μm/m to 55μm/m before decreasing back to 45μm/m as it nears 150000 cycles.

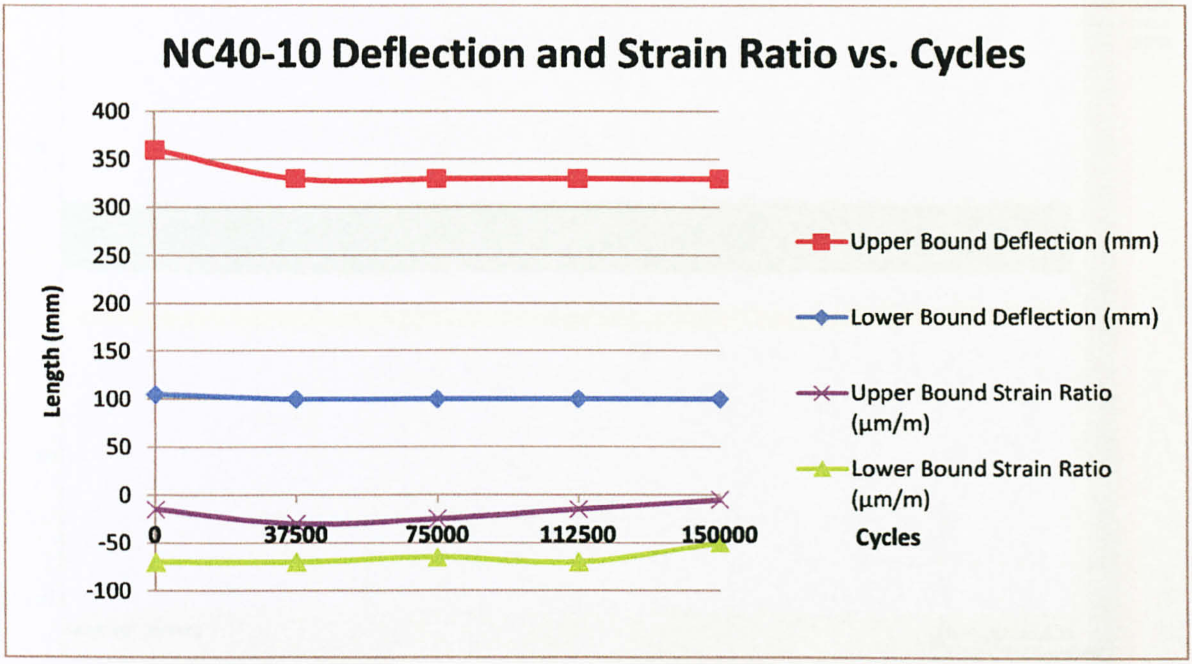


Figure 4.16: Beam NC40/10 Deflection and Strain Ratio vs. Cycles graph

Table 4.12: Deflection and strain ratio values for beam NC40/10

Cycles	Deflection (mm)			Strain (μm/m)		
	Lower Bound	Upper Bound	Range	Lower Bound	Upper Bound	Range
<100	105	360	255	-70	-15	55
37500	100	330	230	-70	-30	40
75000	100	330	230	-65	-25	40
112500	100	330	230	-70	-15	55
150000	100	330	230	-50	-5	45

Figure 4.17: Deflection and strain ratio graph for beam SCC40/10 generated from software

ix) Comparison between Beam SCC40/10 and Beam NC40/10

As shown in Figure 4.18, the deflection rates between CVC and SCC beams are quite in contrast with each other where the SCC deflection rate recorded a sharp decrease from start to end of testing, whereas the CVC deflection rate was more constant as it has a gentler slope.

In terms of strain ratio comparison, CVC strain ratio has an almost zero slope compared with SCC strain ratio which has a small linear increase towards the end of testing.

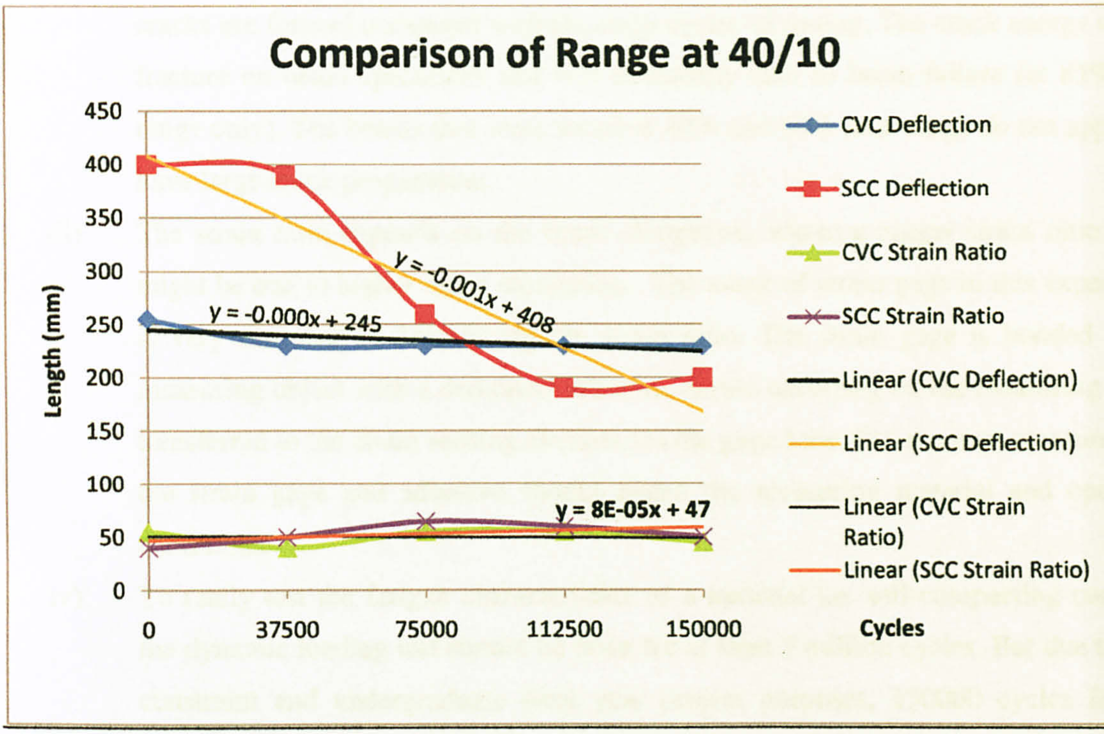


Figure 4.18: Comparison on the differences in upper and lower bound ranges of deflection and strain ratio between beam SCC40/10 and beam NC40/10

Table 4.13: Deflection and strain ratio range of beam SCC40/10 and beam NC40/10

Cycles	Deflection Range (mm)		Strain Ratio Range (μm/m)	
	CVC	SCC	CVC	SCC
0	255	400	55	40
37500	230	390	40	50
75000	230	260	55	65
112500	230	190	55	60
150000	230	200	45	50

Discussions

i) Generally, CVC beams appear to have more cracks than SCC beams. This can be caused by improper compacting during beam casting. Theoretically, SCC beams are more brittle as they contain more cement. But SCC beams are more ductile so they can withstand higher load.

ii) The crack energy increases with respect to time. So at the end of 150000 cycles, more cracks are formed compared with the early cycles of testing. The crack energy causes fracture on beam specimens and will eventually lead to beam failure (at 85% load range only). The beams that were tested at 40% and 60% load range do not appear to have large crack propagation.

iii) The strain ratio depends on the beam elongation, where a bigger strain ratio range might be due to higher beam elongation. The usage of strain gage in this experiment is very essential in determining the strain ratio. The strain gage is bonded to the measuring object with a dedicated adhesive. Strain occurring on the measuring site is transferred to the strain sensing element via the gage base. For accurate measurement, the strain gage and adhesive should match the measuring material and operating conditions.

iv) To really test the fatigue characteristics of a material i.e. self-compacting concrete, the dynamic loading test should be done for at least 5 million cycles. But due to time constraint and undergraduate final year project purposes, 150000 cycles for this experiment is adequate. Compared to 5 million cycles, this experiment is like an initial phase of how these beams behave when subjected to various ranges of dynamic loading.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The flexural resistance of self-consolidating concrete (SCC) is described and compared with Conventional Vibrated Concrete (CVC) based on test results of experimental beam specimens. The relationship between crack pattern, deflection, strain ratio and failure modes are critically analyzed to study the influence of varying the dynamic load ranges used to test the beams. Based on the results presented in this project, it can be concluded that:

i) SCC has higher ductility than CVC where it can withstand the same amount of dynamic load without generating high values of deflection.

ii) SCC is generally stronger than CVC. This is proven during testing at 85% load range, where the CVC beam failed at 120000 cycles (approximately 6 hours into testing) whereas SCC beams failed at 150000 cycles (8 hours of testing).

iii) SCC has higher strain ratio than CVC, which shows that the tested SCC beams elongated more than the CVC beams. So SCC can generate a higher magnitude of deformation compared to CVC.

iv) Testing both SCC and CVC beams at the lowest load range (40% of ultimate load) decreased their deflection. This may be due to both beams have fully deformed at an early deflection rate so the same amount of dynamic loading afterwards did not affect them greatly.

5.2 Recommendations

i) All the laboratory equipments should be well-kept and maintenance must be done periodically to ensure that experiments can be done safely and on schedule.

ii) The materials that the external suppliers provided for the laboratory (i.e. steel bars) to be used for beam reinforcement should be checked regularly to make sure that they comply with the construction standards issued by the authorities.

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Appendix 1: Gantt Chart for FYP I

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Selection of Project Topic															
	- Propose topic															
	- Confirmation of topic selection															
2	Preliminary Research Work															
	- Data selection															
	- Identify Material and Researches															
	- Literature review															
3	Submission of Preliminary/Progress Report															
4	Project Work															
5	Project work and Researches continue															
	- Practical/Laboratory work															
8	Submission of Interim Report Final Draft															
9	Oral Presentation															

Suggested milestone

Process

Appendix 2: Gantt Chart for FYP II

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Project Work Continue																
	- Practical/Laboratory work																
2	Project Work Continue																
	- Practical/Laboratory work																
3	Submission of Progress Report 2																
5	Project work continue																
	- Practical/Laboratory work																
6	Poster Exhibition																
7	Submission of Dissertation (soft bound)																
8	Oral Presentation																
9	Submission of Project Dissertation (Hard Bound)																

Suggested milestone

Process

Appendix 3: Photos Related to This Project

Figure 1: Materials used in preparing concrete specimens at the laboratory

a. Ordinary Portland Cement (OPC)
b. Super Plasticizer
c. Coarse aggregates
d. Fine aggregates

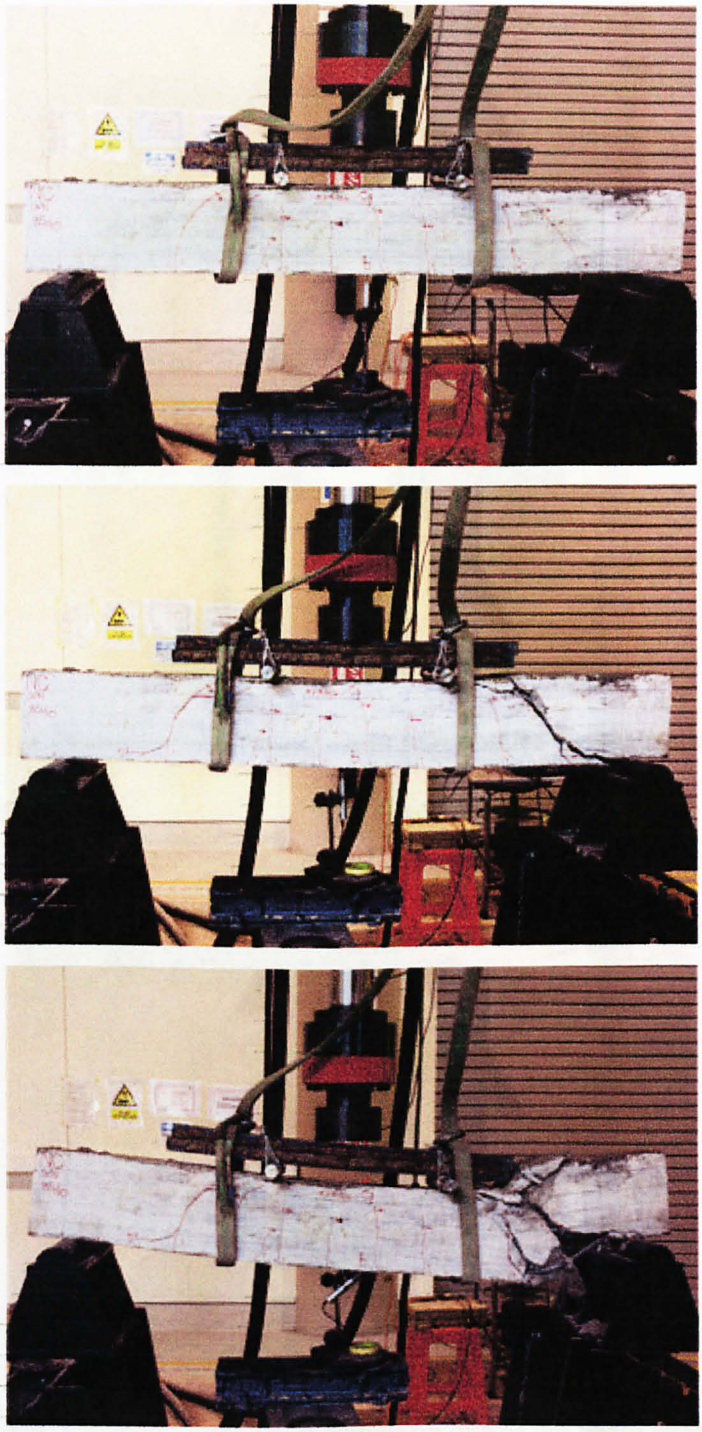

Figure 2: Sequence of beam failure after 150000 cycles of 85% ultimate load

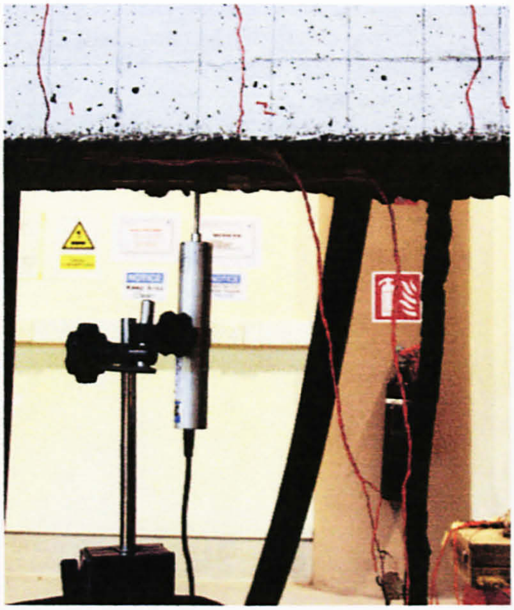

Figure 3: Placing of LVDT and strain gages under the beam specimen

Figure 4: Broken link which causes shear failure on one of the beam specimens (shown in red circle)