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DEPARTMENT OF CIVIL AND ENVIROMENTAL ENGINEERING**



**EFFECTIVENESS OF SWIMMER BARS AS SHEAR REINFORCEMENT IN
RECTANGULAR REINFORCED CONCRETE BEAM UNDER HIGH CYCLIC
LOADING**

A Thesis in Structural engineering

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The undersigned have examined the thesis entitled effectiveness of swimmer bars as shear reinforcement in rectangular reinforced concrete beam under high cyclic loading presented by Molaligne Nibret Setegne , a candidate for the Degree of Master of Science and hereby certify that it is worthy of acceptance.

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UNDERTAKING

I certify that research work titled “**Effectiveness of swimmer bars as shear reinforcement in rectangular reinforced concrete beam under high cyclic loading**” is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

Molaligne Nibret Setegne

List of Symbols

The following symbols are used in this thesis:

Ac=Area of concrete crack

Ag=Maximum specified size of coarse aggregate

Ast, 2 = compressive area of steel

Ast, 1= tensile area of steel

Ast= area of steel

a_v= shear span

b = Width of the member at the section

b_w= width of web

d = effective depth

EC2 = Euro code 2

E_{cm}= young's modulus of concrete

E_s=young's modulus of steel

F =applied force on specimen

f_{ck}= compressive strength of concrete

f_{ctk}= tensile strength of concrete

F_u = ultimate tensile stress;

F_y = material yield stress

h= height of beam

I = Moment of inertia of the cross section

L = specimen length;

L = effective length

m = bending moment

θ = angle of strut

Q = First moment about the centroid axis

u = shear stresses,

$U1=U2=U3$ = displacement in X, Y and Z direction respectively

$UR1=UR2=UR3$ = rotations in X, Y and Z direction respectively

V = Shear force on the cross section

V_a = aggregate interlock

V_d = dowel action

V_{sd} = design shear stress

V_u = Ultimate Shear Strength

ρ_w = Percentage of reinforcement based on web width ($A_s/b_w d$)

σ_a = Stress Amplitude

σ_m = mean stress

σ_{max} = maximum stress

List of Acronyms

The following symbols are used in this thesis:

ACI = American Concrete Institute

CAD = Computer Aided Design

CAE = Complete Abaqus Environment

FEM = Finite Element Method

NSB = Normal Stirrup Beam

RSSWB = Rectangular Spliced Swimmer Beam

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ABSTRACT

Reinforced Concrete beams are important structural elements that transmit the loads from slabs and bridge decks, to structural column piers. The design of those beams must be safe against internal actions i.e. bending moments, shear forces and torsions so that they will perform effectively during their service life.

In building construction, stirrups are most commonly used as shear reinforcement. Stirrups may be vertical, inclined or bent up bars; but the cost and safety of shear reinforcement in reinforced concrete beams lead to the study of other alternatives. Swimmer bar system is a new type of shear reinforcement. It is a small inclined bar with its both ends bent horizontally for a short distance and spliced to both top and bottom flexural steel reinforcements.

Previous works on Swimmer bars revealed that the effect due to static load on beams reinforced with Swimmer bars has more shear carrying capacity than vertical stirrups and can be placed at larger spacing. The beam consisting of swimmer bars showed much more stiffness than beam with conventional bars.

This research focuses on the potency of using swimmer bars instead of normal shear reinforcements with the same amount of reinforcement area under single sided high cyclic loading. In addition to the experimental test, a validated Finite Element Model (FEM), created in ABAQUS V6.13-1 is used to investigate the effect of rectangular spliced swimmer shear reinforcement bars.

Based on the experimental investigation and finite element analysis of this research, the ultimate load capacity of the beam is increased by 3.75% and the respective deflection is less in rectangular spliced swimmer bar beam as compared to normal stirrup beam. As a result, rectangular spliced swimmer bar improved the shear load carrying capacity in the reinforced concrete beams. Besides, compared to the normal stirrups, fewer and smaller cracks were observed when using spliced swimmer bars.

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1. INTRODUCTION

1.1. General

Shear failure of reinforced concrete beams is usually sudden and occur without sufficient advanced warning. For structural members, this brittle type of shear failure is considered to be high risk type of failure and also this shear force at a section gives rise to diagonal tension in the concrete and leads to cracking. Hence, the design of beams must depart from any brittle modes of local or global failure and let the overall structural behavior to be mainly controlled by ductile and tough modes. Reinforced concrete beam members might be shear critical due to different reasons. Some of the main reasons are inadequate shear reinforcement on the support, change in loading mechanism on the structure, inadequate provision of end anchorage and poor construction.

Cyclic loading on a beam is a continuous and repeated application of a load that lead to fluctuating stresses, strains, forces and tensions. These repeated cyclic loads generate through different mechanisms and expose the member to shear mode of failure. Non reversal single sided high cyclic loading can be generated from bridge beams and machine carrier beams. Since the load is frequently applied with a high magnitude, it can easily degrade the strength of a beam which ultimately leads to fatigue.

The sudden failure of the reinforced concrete beams due to shear made it necessary to explore more effective ways of designing beams. So far, shear reinforcement are used to prevent failure in shear, by increasing the ductility of a member and subsequently reducing the likelihood of unexpected failure. Spacing between stirrups is reduced at the supports to resist high shear stresses. This decreasing of spacing at the support leads to reinforcement congestion and this congestion in turn increases the cost and time required for installation. Consequently, the cost and need of additional safety from shear reinforcement in reinforced concrete beams led to the study of other alternatives.

Now days, in order to enhance the targeted shear resisting capacity of a structural member and to remove the limitations of normal stirrups, swimmer bars are widely used (Moayyad M. Al-Nasra, 2013). The use of swimmer bar system improved the shear load carrying capacity in the reinforced concrete beams. The width and length of the cracks were observed to be less using swimmer bars compared to the traditional stirrups system. (Naiem M, 2012).

1.2. Statement of the problem

Previous works on swimmer bars effect due to static load found out that Swimmer bars have more shear carrying capacity than vertical stirrups and can be placed at larger spacing. The beam consisting of swimmer bars showed much more stiffness than beam with vertical bars.

Applied loads on the structures are rare to be static loads, that is, they do not refer exclusively to loads that do not change over time. Therefore, when considering realistic loads on a structure, it is important to distinguish all load conditions which will take place and may lead to complete collapse or local failure of the structure. Reversal cyclic loading, the most sever of such realistic loads may result from earthquakes, moving loads, and wind. Similarly, non-reversal single sided cyclic loads may arise from bridge decks and structures supporting machineries.

This repeated single sided cyclic loads cause fatigue on reinforced concrete beam. The fatigue life of a reinforced concrete beam depends as much on the stress levels as on the stress range and the number of loading cycles. Failure is often a consequence of many factors and the failure modes can have significantly different characteristics. Consequently, studying the effectiveness of swimmer bars as shear reinforcement in rectangular concrete beam under non reversal high cyclic loading needs further researches.

1.3. Objective of the Study

1.3.1. General objective

- To investigate shear performance of rectangular spliced swimmer bars as shear reinforcement in rectangular reinforced concrete beam under single sided high cyclic loading.

1.3.2. Specific objectives

- To create a converging, validated Finite Element Model that effectively display the effect of swimmer bars as shear reinforcement in rectangular simply supported beams that are exposed to high cyclic loading.
- To verify experimental investigation result through nonlinear finite element modeling software.
- To analyze the influence of Swimmer bars in the overall deflection of the beam, if any.

1.4. Scope and Limitation of the Research

The numerical study of effectiveness of Swimmer bars as shear reinforcement in reinforced rectangular concrete beams that are exposed to non-reversal high cyclic loading will be conducted using experimental investigation and through ABAQUS 6.13 Software verification. The influence of concrete grade, depth, ratio of shear reinforcement and shear span to depth ratio is taken as constant for both normal beam and swimmer beam.

This research is conducted for structures which have non reversal single sided repetitive load carrier beams. Flexural and torsional effects of rectangular spliced swimmer bars are not part of the study.

1.5. Methodology

In this entire research three stages are carried out to find the respective solution for the objective of the research. In the first stage, a review of essential literature on the new type of shear reinforcement, swimmer bar and their corresponding response towards shear was covered. The second phase of the study includes the experimental investigation and six reinforced concrete beams were casted in two different category; normal beam and swimmer beam. In each broad category three beams were casted. In order to have the same compressive strength of concrete between two comparable beams, larger mechanical mixer machine was used and the mixing process held once. Consequently, the amount of slump and mix proportion was the same. From each category of specimen as a control beam static load is applied on the first beam was applied similarly on the second beam 90% load of sectional capacity is applied as a cyclic load and on the third branch 85% was applied as a cyclic load. On this experimental investigation; testing setup, test specimens, materials used, specimen fabrication, specimen preparation, and instrumentation development of an analytical model by using previous works as a starting blueprint. Subsequent to the analytical work, a comprehensive experimental program was conducted to generate a reliable data.

Finite Element Analysis (FEA) has become accepted widely as a powerful method for the solution of highly complex problems in structural and continuum mechanics. In the finite element method and actual continuum is replaced and modeled by a finite number of discrete elements. The assemblage of these elements idealizing the geometry of a structure is specified by

selected points in space called nodes (grid points). Constitutive relationships within each element, replacing an infinite number of degrees of freedom at grid points, and balance laws were then applied to the complete system to develop a matrix equation.

In both experimental investigation and finite element modeling verification the specimens are arranged in the same manner. For a control beam 8mm diameter vertical stirrups at 200mm c/c as shear reinforcement was used and with the same amount of reinforcement area i.e. 8mm diameter rectangular spliced swimmer bars placed at 250mm c/c with 45° inclination. Besides knowing on a software simulation, the section capacity of the specimen was first checked by applying a static load. Throughout the test in studying the effectiveness of rectangular spliced swimmer bars, shear resistance capacity and deflection were the parameters chosen for investigation. After the physical test, by spall the cracked concrete post cracking behavior of both types of reinforcements were studied.

1.6. Layout of Chapters

Chapter 2 provides a review of relevant literature on the new type of shear reinforcement; swimmer bars. Basic theories in reinforced concrete beam and properties of reinforced concrete beam expose to cyclic loading and their failure mode are discussed. Recent studies with regard to swimmer bars are also incorporated.

Chapter 3 deeply elaborates the experimental program of the research. It describes materials, loading conditions, instrumentations, and small scale modeling about concrete.

Chapter 4 discusses the nonlinear finite element study using ABAQUS 6.13-1 CAE software. Here the boundary conditions, loading mechanism, meshing and different assumptions taken are discussed.

Chapter 5 covers the result and discussion of experimental and finite element simulation outputs. A brief assessment of swimmer bars in comparison of traditional stirrups is done.

Chapter 6 offers the conclusion of the study with recommendation for future works.

2. LITERATURE REVIEW

2.1. Basic Theory

Shear reinforcements are provided to resist the sudden failure of concrete in shear failure mode. Tan et al. (1997b) showed that shear reinforcement can play an important role in determining the shear strength of high strength concrete beams. The effect of web reinforcement in the overall shear capacity of beam depends on the shear span to depth ratio (Tan et al, 1997c) and therefore, no effect of web reinforcement was considered for beams with $a/d < 1.0$ (Gilbert, 1998).

The presence of stirrups in reinforced concrete beam opposes widening of the cracks, which maintains the aggregate interlock within the concrete (Nilson et al, 2004). Moreover, stirrups are tied to the longitudinal reinforcement and due to this confinement effect the splitting of concrete along the longitudinal main bars is controlled more effectively. Hence, the extent and amount of shear resisted by the shear stirrups and concrete depends upon the configuration and connection of stirrups with longitudinal bars (Nilson et al, 2004).

A swimmer bar is a small inclined bar, with its both ends bent horizontally for a short distance, welded or spliced at the top and the bottom of the longitudinal reinforcement bars. In order to improve the shear performance of the reinforced concrete beams, swimmer bars are arranged in different shapes like single swimmer bars, rectangular swimmer bars, rectangular swimmer bars with cross bracings, rectangular swimmer bars with horizontal or vertical partitions (Kishori and Vivek, 2016).

Swimmer bar system is integrated fully with top and bottom longitudinal reinforcement bars. Based on the way of connection between this newly invented stirrup and the main flexural reinforcement bars, swimmer bars are classified as bolted swimmer bars, welded swimmer bars and spliced swimmer bars (Moayyad, 2013).



Figure 2-1 images showing assembled space swimmer bars loop (Moayyad Al-Nasra, 2017)

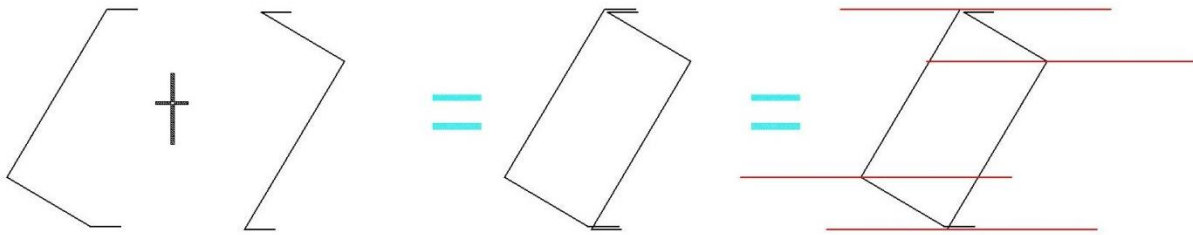


Figure 2-2 assembling of swimmer bar

Shear force in a region indicates that the moment is changing along the length of the member. The moment can change either by tension in the reinforcement changing, which is called beam action, or by the internal lever arm changing along the length, which is called arch action. If arch action is to carry the entire shear in a region that has constant shear, then the concrete compression zone must form an inclined strut going from the load to the support. It was shown that, because of the geometric incompatibility of the two mechanisms, with beam action typically being much stiffer than arch action, nearly all of the shear would be carried by beam action until this mechanism failed. After failure of the beam mechanism, an internal redistribution of stresses could occur and the remaining arch mechanism could then carry even higher shears if the distance between the applied load and the support was sufficiently short. (Lei Wang, 2015)

2.2. Shear Resisting Mechanism

In reinforced concrete beam, shear can be resisted by different mechanisms. These mechanisms have their own contribution in enhancing the capacity of the section towards carrying the applied load. Some of them are concrete compression zone (V_c), dowel action (V_d), aggregate interlock (V_a), arch action and presence of stirrups (V_s).

Forces are transmitted across a shear crack plane by a combination of aggregate interlock at the interface of the crack that is enhanced by clamping action of transverse stirrup reinforcing and by dowel action of stirrups crossing the crack. As crack lengths increase to approach a horizontal projected length equal to the depth of the member and concurrently widen to the extent that aggregate interlock cannot occur, and as transverse stirrups if present begin to yield or display loss of anchorage so as to threaten their integrity, the member is assumed to be approaching imminent shear failure. (Al-Nasra, 2012)

Aggregate around the longitudinal bar tries to resist shear and deflection by interlocking with each other and those entire forces sum up as the total shear resistance of dowel action in a concrete. Similarly Aggregate interlock transfers a large part of the total shear force to the supports through a bond created between aggregates (Govindaraj, p. S, 2012). As the crack widens aggregate interlock decrease and much of the resistance is resisted by the dowel action. In a similar manner as dowel action gets larger it leads to splitting crack in the concrete along the reinforcement. Consequently, when shear resistance caused by dowel action and aggregate interlock increases the amount of shear reinforcement required in a reinforced concrete beam will decrease.

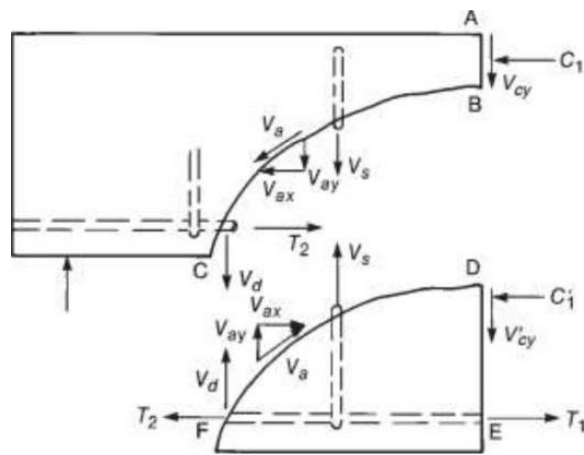


Figure 2-3 shear transfer mechanism

As one mechanism of shear resisting in RC beam, the contribution of stirrups will start after crack is generated i.e. when capacity of dowel action and aggregate interlock is weakened. Hence, the main reason behind the provision of shear reinforcement is to increase confinement between concrete aggregate which in turn enhances aggregate interlock and decreases the crack opening. Besides this, shear reinforcement will handle tensile stress by itself and transfer back to the concrete and act as a tendon by applying the principle of prestressed concrete. These transfers of shear stress into the concrete lead to the formation of secondary cracks. Consequently, the presence of shear reinforcement has a great contribution for reinforced concrete beams in resisting sudden shear failure. (Finnay, 1990)

2.3. Recent studies on swimmer bars

Shear reinforcements are necessary to improve the shear resisting capacity of the beams if the permissible shear stress is lesser than the actual shear stress. Since the diagonal strain of the flexural member is larger than the longitudinal strain the width of shear cracks is generally wider than flexural cracks (Adebar & Leeuwen, 1999; Adebar, 2001).

The quantity and arrangement of web reinforcement in a beam has been found to have a very significant influence on shear resistance behavior. In practice, shear reinforcement is provided in different forms; normal stirrups, inclined bent-up bars and combination system of stirrups and bent-up bars. The other option is the newly invented shear bar system, called swimmer bar.

A number of investigations are done to identify the behavior of swimmer bar in reinforced concrete beam that exposed to static loading mechanism. Though these researches discussed the effect of swimmer bars under static load, cyclic loads are not well covered. .

Moayyad M. Al- Nasra et al. (2013 b) studied the use of Swimmer bars as shear reinforcement in reinforced concrete beam under static loading. Experimental study was conducted to compare the shear strengths of beam reinforced with stirrups with the beam reinforced with single swimmer bars. Substantial improvement in the shear performance of the reinforced concrete beams was observed by using the new swimmer bars system in comparison with the traditional stirrup system. But the research didn't analyze the effect of fatigue due to single sided non reversal high cyclic load.

Similarly Muneeb Ullah Khan et al. (2015) assessed the shear capacity of reinforced concrete beams using the same amount of shear reinforcement ratio as vertical stirrups for swimmer bars under static load. The shear performance of beam without any shear reinforcement was experimentally investigated against the shear capacity of beam with normal shear reinforcement and with beam having single swimmer bars as shear reinforcement. Swimmer bars are found to have more shear carrying capacity than vertical stirrups and can be placed at larger spacing. The beam consisting of swimmer bars showed much more stiffness than beam with vertical bars. Also the ultimate load carrying capacity of swimmer bars is more than the vertical stirrups. Less number of cracks is formed in beams having swimmer bars. But in

this research in addition to unstudied behavior of cyclic loading, the configuration of rectangular spliced swimmer bar is not covered.

Revathy S and Anup Joy (2015), the comparative study on the shear strength, crack pattern and load-deflection characteristics of seven reinforced concrete deep beams are studied. Based on this research finding single swimmer bars showed more strength than rectangular shaped swimmer system and new swimmer bar system offered better performance than vertical stirrups. Though this research tried to compare the potency of single swimmer bar with rectangular swimmer bar, similar to other researches it's done for monotonic loading. In addition this study didn't clearly indicate the length of shear reinforcement bar anchorage in the case of rectangular swimmer bar. The method of connection for rectangular swimmer bar also not mentioned.

P. Saravana kumar and A. Govindaraj on International Journal of Civil Engineering and Technology (IJCIET) Volume 7, Issue 6, experimentally and analytically investigated RC beams. The research findings indicated that when compared to traditional stirrup system, inclined stirrup system showed improvement in the shear resistance and stiffness. But due to the challenges while applying inclined bars on the real construction industry, it is necessary to find alternative configuration of stirrups that easily implemented.

Although the mechanisms of shear resistance through web reinforcement with swimmer bar orientation have been studied by different researchers under static loading, reinforced concrete beams under cyclic loading are not thoroughly studied. Ultimately all failures under cyclic loads are shear failures incurred by either desegregation of concrete between doubly diagonal cracks or the localized slip between two faces of large flexural cracks (Petrangeli et al. 1999). Hence, shear mechanisms usually dominate the behavior of RC members subjected to impacts loads. Therefore, consideration of shear-related mechanisms is essential for accurate simulations of beam behavior under cyclic loads. As a result, this research will address gaps which are listed as a critique for previous works

Generally, it is possible to conclude that the researches previously done on swimmer bar have their own gaps with respect to addressing the effect of rectangular spliced swimmer bars, considering the fatigue effect of single sided high cyclic loads, indicating the length of stirrup

anchorage and way of connection with flexural reinforcement bars. Having the limitations of mentioned researches, this study tried to investigate shear resisting effect of these swimmers bars for rectangular reinforced concrete beam under single sided high cyclic load.

2.4. Behavior of reinforced concrete structures under cyclic loading

If a certain load on a structure is repeatedly applied and then removed (cyclic load), a structural part would break after a certain number of load-unload cycles. When a progressive and localized structural damage is happened due to cyclic loading it is known as fatigue. This failure due to fatigue will happen even if when the maximum cyclic stress level applied was much lower than the ultimate tensile stress, and in fact, much lower than the yield stress (K. Pilakoutas and A. S. Elnashai, 1995). The fatigue failure originates from a brittle failure due to stress concentration effect at the surface of a concrete beam.

R.C .Fenwick*and A .Fong** (1998) have shown that cyclic loading condition decreases the capacity of shear resisted by concrete and unless adequate amount of shear reinforcement is provided, diagonal tension failure mode will suddenly happen and leads to rapture of concrete. In addition, ability of hinge to dissipate energy and stiffness of beam will decrease while the beam is exposed to cyclic load even at lower cycle load level. Cyclic load on a structure will cause fatigue failure on a structural member. Crack initiation, crack propagation towards un cracked concrete cross section (progressive cyclic growth of crack) and sudden fracture of concrete are the stages of fatigue failure according to (R.C .Fenwick*and A .Fong**, 1998): In reinforced concrete structures under cyclic loadings, the members will enter the post elastic range. An accurate analysis of inelastic reinforced concrete components are complicated by a number of factors.

Brown and Jirsa (1971) investigated the hysteretic behavior of reinforced concrete cantilever beams under a small number of reversals of overload. The research on twelve specimens indicated that after the first quarter of loading, the behavior of components were non-linear due to a combination of shear deformation, closure of residual cracks and slippage behavior of the anchored longitudinal reinforcement. And the research concludes that the specimens were mainly affected by shear under loading and unloading. The rate of shear force which is influenced by

changes in load history or forces acting on a beam led to the improvement of the energy absorbing capacity as well as the number of cycle of failure.

Bresler and Bertero (1966), considered the performance of reinforced concrete structures exposed to cyclic load. The Experimental investigation part of the research showed that the stiffness of the reinforced concrete structures decreased when they were subjected to repeated working load and cyclic changes. This is due to the slippage and loose confinement of bond between concrete and steel (Naiem M, 2012).

3. EXPERIMENTAL PROGRAM

This chapter will describe the experimental work conducted at the Materials Laboratory of Addis Ababa Institute of Technology (AAiT). The experimental work is aimed to study the effectiveness of rectangular spliced swimmer bar as shear reinforcement in rectangular reinforced concrete beam under high cyclic loading.

In the experimental program, six reinforced concrete beams in two sets having a category of conventional/Normal stirrups and rectangular spliced swimmer bar. For the consistency purpose throughout the experimental test different parameters like shear reinforcement ratio, longitudinal reinforcement, loading mechanism, length, width and depth were made to be fixed except the configuration of web reinforcement. Beams having a traditional stirrups configuration are named as NSB, Normal stirrups beam, and those with swimmer bars are named as RSSWB, rectangular spliced swimmer bar.

Fixed Parameters		Description	Remark
Cross section		Rectangle	
Depth (D)		300mm	
Width (B)		200mm	
Total Length(L)		1850mm	
Effective length (l)		1600mm	
Shear reinforcement ratio		0.25	c/c 200
Concrete Grade		C-25/30	EBCS-code
Steel Grade	Flexural reinforcement	S-566	Test results
	Shear reinforcement	S-475	
Loading mechanism		Non reversal single sided cyclic	
Shear span to effective depth ratio (a/d) of beam		3.13	Partially Slender Beam

Table 3-1 definition of fixed parameters

All six rectangular reinforced concrete beam specimens have a width of 200 mm and depth of 300mm with a total length of 1.85 m having effective length of 1.6m. In order to depart the research from unexpected failure mode of beam during experimental test, analytical simulation using ABAQUS 6.13, a nonlinear finite element software has been conducted. In this research chapter following sections will be discussed; testing setup, test specimens, materials used, specimen fabrication, specimen preparation, and instrumentation.

The experimental program strives to answer the following questions:

- Is the swimmer bar beam effective with respect to shear resisting capacity of conventional stirrups having the same shear reinforcement area?
- Is the presence of swimmer bar affect the overall deflection of the beam, if any?
- What the load deflection characteristics, strength characteristics, shear crack pattern and failure mode of both swimmer and normal beam look like?
- Check the workability and feasibility of using swimmer bars?

3.1. Design of beam specimen

Since the research focuses on studying the effectiveness of swimmer bars as shear reinforcement under high cyclic loading, the beam is designed to fail in pure shear deliberately. Consequently, the flexural capacity of the beam is very high in comparison with shear resistance.

The experimental test of beams is mainly to study the effect of using the special type of swimmer bars called here rectangular spliced swimmer bars on shear strength. The results of the shear strength test of beams made with the spliced swimmer bars are compared with the results of beams made with normal regular stirrups. The swimmer bars effect in overall deflection of the beam specimen is also a factor in this experimental research though it is expected that the deflection is insignificant since sufficient flexural steel is used for all beams to make sure that the beam failure is controlled by shear failure.

Based on the configuration of web reinforcement, there were two groups of specimens. Each group will have three RC beams which are reinforced with the same amount of shear reinforcement area and amount of weight. In the first group traditional shear reinforcements with spacing of 20cm was provided and on the second group a rectangular spliced swimmer bars with a spacing of 25cm was provided.

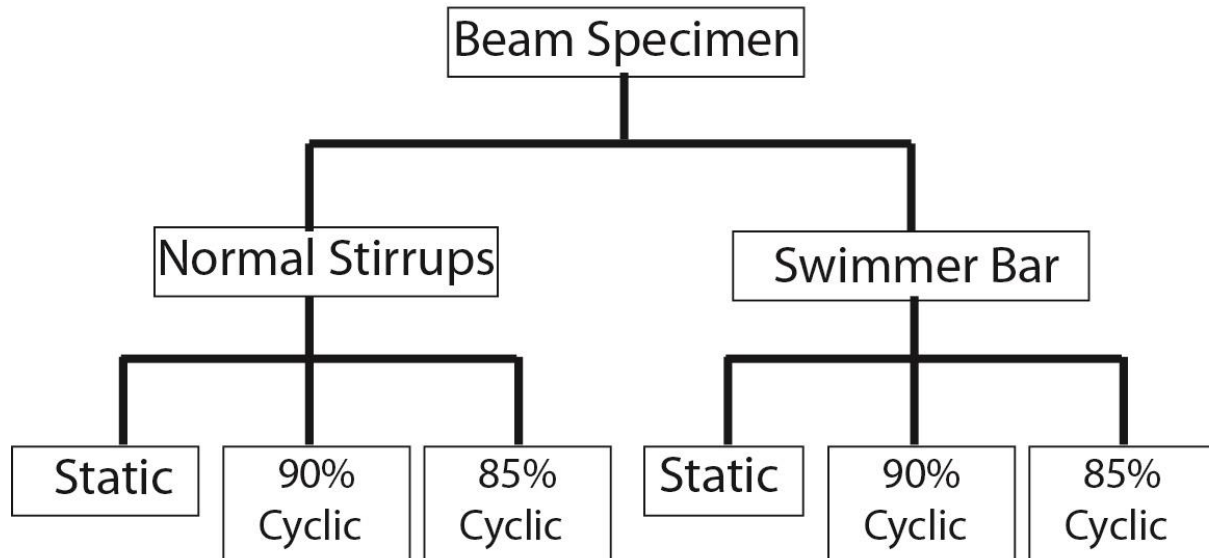


Figure 3-1 category of beam specimen

In order to assess the effect of swimmer bars on performance of beam shear strength, as shown in the table 3.2 the amount of shear reinforcement is the same.

Loading case	Weight of shear reinforcement (kg)		Total Length of reinforcement bar (mm)	Nomenclature of beam respectively
	Normal stirrups	Rectangular spliced swimmer bar		
Static load	3.17	3.18	8102	NSB 2, RSSWB 2
Cyclic with 90% of section capacity	3.17	3.20	8104	NSB 3, RSSWB 3
Cyclic with 85% of section capacity	3.20	3.21	8104	NSB 1, RSSWB 1

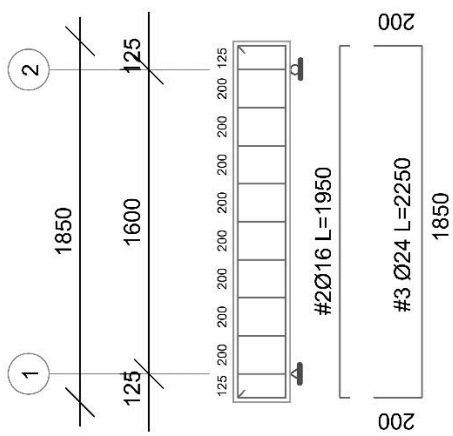
Table 3-2 amount of shear reinforcement in each specimen

Group	Nomenclature	Flexural reinforcement		Shear reinforcement	
		Bottom (mm ²)	Top (mm ²)	Normal stirrups	Swimmer bar
1	NSB-1	3 Ø24	2 Ø16	Ø8mm @200mm c/c	-
	NSB-2	3 Ø24	2 Ø16	Ø8mm @200mm c/c	-
	NSB-3	3 Ø24	2 Ø16	Ø8mm @200mm c/c	-
2	RSSWB-1	3 Ø24	2 Ø16	-	Ø8mm @250mm c/c
	RSSWB-2	3 Ø24	2 Ø16	-	Ø8mm @250mm c/c
	RSSWB-3	3 Ø24	2 Ø16	-	Ø8mm @250mm c/c

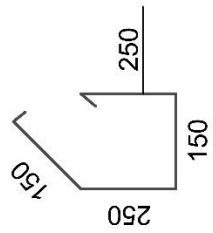
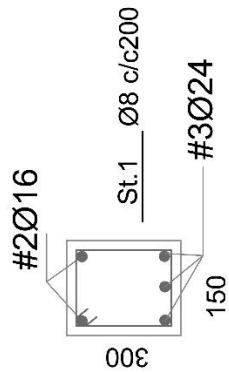
Table 3-3 details of beam specimen

A diagrammatic sketch of a specimen, detailing a cross section is shown in figure 3-2. The ends of the beam were enlarged to provide sufficient end anchorage and additional reinforcing steel was used to prevent splitting of the concrete at the end of the specimen. Rectangular spliced swimmer bars have 45° inclination and the end hook length is designed as 5d, 5cm.

Normal stirrups beam



BEAM SECTIONS



Swimmer beam

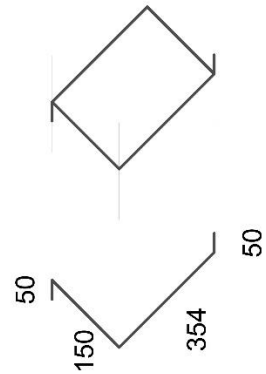
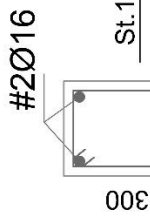
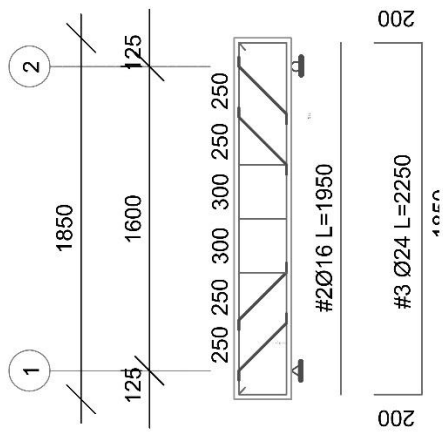


Figure 3-2 Test Beam model

3.2. Material

3.2.1. Concrete and concrete mix

Concrete mixes are designed in order to achieve a defined workability, strength and durability. The two most empirical relations that control the design of plastic and hardened concrete of the required strength are;

- The compressive strength of concrete that is governed by its water to cement ratio
- Workability of concrete which is also governed by water to cement ratio and content of fine aggregate.

In this research, the targeted compressive strength of 25MPa concrete was planned using ACI mix design method. The qualities of concrete ingredients were well tested in the laboratory by taking Professor Abebe Dinku construction laboratory manual as a handbook. Hence, Course and fine aggregate were washed with water to remove any impurities and then, the aggregates were weighted and packed using plastic bags to preserve and avoid a fluctuation of moisture content. The moisture and silt contents of the aggregates were tested before sealing of the bags and the results from the tests were carefully documented.

A number of control cylinders were tested to determine the actual concrete characteristics using different trial mix proportions and materials. Thus, a slump of 50mm-75mm was selected from ACI mix design manual to carry out control cubic testing as a micro-concrete mix proportion. “Micro mix proportion” termed for small scale model due to reduction of size of test.

Crashed basaltic aggregate and sand were air dried prior to mixing. To determine the strength of concrete, companion cylinders of size 150mm cube were cast from the batch. The cube was tested after 3rd, 7th and 28th day from the day of casting. The concrete strength result of each specimens are summarized in table 3-4

No.	Age of test (day)	Dimension (mm)			Weight (Kg)	Failure load (kN)	Compressive strength (MPa)
		L	W	H			
1	3	150	150	150		238.71	10.61
2						247.60	10.98
3						240.80	10.70
Average						242.37	10.76
1	7	150	150	150	7.85	490.5	21.80
2					7.74	501.8	22.30
3					7.62	528.8	23.50
Average					7.73	507.03	22.53
1	28	150	150	150	8.36	606.2	26.94
2					8.54	587.9	26.12
3					8.45	573.2	25.47
Average					8.45	589.1	26.18

Table 3-4 Cubic test result

3.2.2. Characteristics of coarse and fine aggregates

For both coarse and fine aggregate a crashed basaltic rock and Metehara lake sand was used. According to ASTM C 33 Grading of aggregate is the particle-size distribution of an aggregate as determined by a sieve analysis using wire mesh sieves with square opening and this helps to get a well-graded, smooth, rounded aggregates that improve the workability of a mix.

Sieve analysis was done to get good grading and this implies that a sample of aggregates contains all standard fractions of aggregate in required proportion such that the sample contains minimum voids. Specific result related to sieve analysis like specific gravity and absorption capacity, unit weight, moisture content, silt content are presented in appendix B

Physical test	Coarse Aggregate (%)	Fine Aggregate (%)
Silt content: Before washed	-	8
Silt content: After washed	-	4.36
Absorption Capacity	1.13	4.5

Bulk Specific Gravity	2.77	
Apparent Specific Gravity	2.89	

Table 3-5 Physical property of aggregates

3.2.3. Reinforcing steel

To analyze the configuration change of shear reinforcement and to simulate the behavior of reinforced concrete beam, specimens were provided with similar ratio of lateral reinforcement and transversal reinforcement. The longitudinal bars in both top and bottom had the same diameter. Both tensile and compression zone flexural reinforcement bars are from Turkish factory and shear reinforcement bars are from Abyssinia factory. In order to know the exact capacity of both flexural bars and shear reinforcement bars, tensile test was done in the laboratory. Accordingly, the test results are as shown in the table 3-6 below.

Specimen code	Specimen No	Diameter(mm)		Yield Load (kN)	Yield stress (kN)	Failure Load (kN)	Failure stress (kN)	Elongation (%)
		D1	D2					
Stirrups φ8	1	7.48	8.49	25.6	509.29	34.4	684.36	22
	2	7.48	8.51	21.7	431.70	24.2	481.44	21.2
	3	7.47	8.48	24.4	485.42	32.3	642.58	21.5
	mean	7.47	8.49	23.9	475.47	30.30	602.86	21.56
Top bar φ16	1	23.73	26.68	253.6	560.57	315.4	697.18	22.3
	2	23.37	26.57	260.3	575.38	321.6	710.89	22.5
	3	23.34	26.56	255.6	564.99	318.2	703.37	22.5
	mean	23.48	26.60	256.50	566.98	318.4	703.81	22.43
Bottom bar φ24	1	23.73	26.67	254.6	561.57	315.4	697.18	22.3
	2	23.37	26.58	260.3	575.38	321.6	710.89	22.5
	3	23.34	26.56	255.6	564.99	318.2	703.37	22.5
	mean	23.48	26.60	256.50	566.98	318.4	703.81	22.43

Table 3-6 tensile tests for reinforcing result



Figure 3-3 reinforcement tensile test

3.2.4. Water

Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. In this research Potable water was used throughout the concrete mix.

3.3. Test Specimen fabrication

The specimens had a rectangular cross-section with 200mm width, 300mm depth and a total development length of 1850mm. Extreme care was taken for the proper alignment of forms and positions of reinforcement. These reinforcements were prepared as per the design proposed for this research. The reinforcement cage was also properly done based on the design. Metal formwork was used as a mold and mechanical concrete mix was used to keep inconsistency concrete mixes for those reinforced concrete beams. These metal Formworks were oiled and blocked at the end prior to placement of the reinforcement cage. A concrete cover of 25mm spacer was prepared to tie and keep the cover on the longitudinal and shear reinforcement bars.

During the casting of the specimens, the reinforcement cages were assembled by strictly following the design. The reinforcement cages were then placed inside the formwork after maintaining a concrete cover of 25mm. In order to depart mix inconsistency between beams and to discard problems related to initial settlement, a mechanical mixer was used throughout the samples. Consequently, the slumps for all the samples were nearly the same and this means the compressive strength of concrete in each and every sample is the same.

The specimens were cast outside the laboratory and high frequency vibrator was used to ensure good concrete compaction around steel reinforcement. The concrete was allowed to set for one day until it stopped bleeding. The casted concrete was cured by covering with wet cotton for 28days. The cotton was constantly saturated and covered by plastic sheets to avoid water loss due to evaporation.

The quality of the material had been checked for each gradient as per the mix design proposed on the appendix A. Each ingredient that is the water, cement, fine and coarse aggregate were weighed and prepared. The figure shows the laboratory site ready for casting.



a)



b)

Figure 3-4 sample reinforcement cage for a) RSSWB and b) NSB

3.4. Instrumentation

All tested beams were fully instrumented to measure the applied loads and its output, deflection. The instrumentation consisted of a load cell which measures the applied load; transducer, deflection measurement tool to measure the mid span deflection and flexural test machine were used. All of the instrumentations were connected to a data logger and the experimental data was directly obtained in a USB Drive.



a) Displacement measuring tool



b) Load Cell



Figure 3-5 tools for center point loading test

3.5. Details of test set-up

A diagrammatic test set-up provided in figure 14 illustrates the overall arrangement of typical test specimen and the instrumentation set-up. A concentrated load was applied using manual hydraulic jack, which have a maximum capacity of 320 KN. The load cell was placed directly below the hydraulic jack and connected to the data logger. To make a smooth contact between

the sample beam surface and load distributor plate, gypsum material was used as a binder. The data recorded by the data logger was arranged to save in every one seconds to increase the accuracy of the result. During this experiment the loading rate was ranged between 8-20KN per cycle. Rectangular Aluminum plate that holds the transducer, deflection reading instrument, was pinned on the verge of beam. On such nodes displacement is zero and rotation is present. Hence, as figured below, this plate was anchored to a beam on both ends by drilling at the axis of rotation.

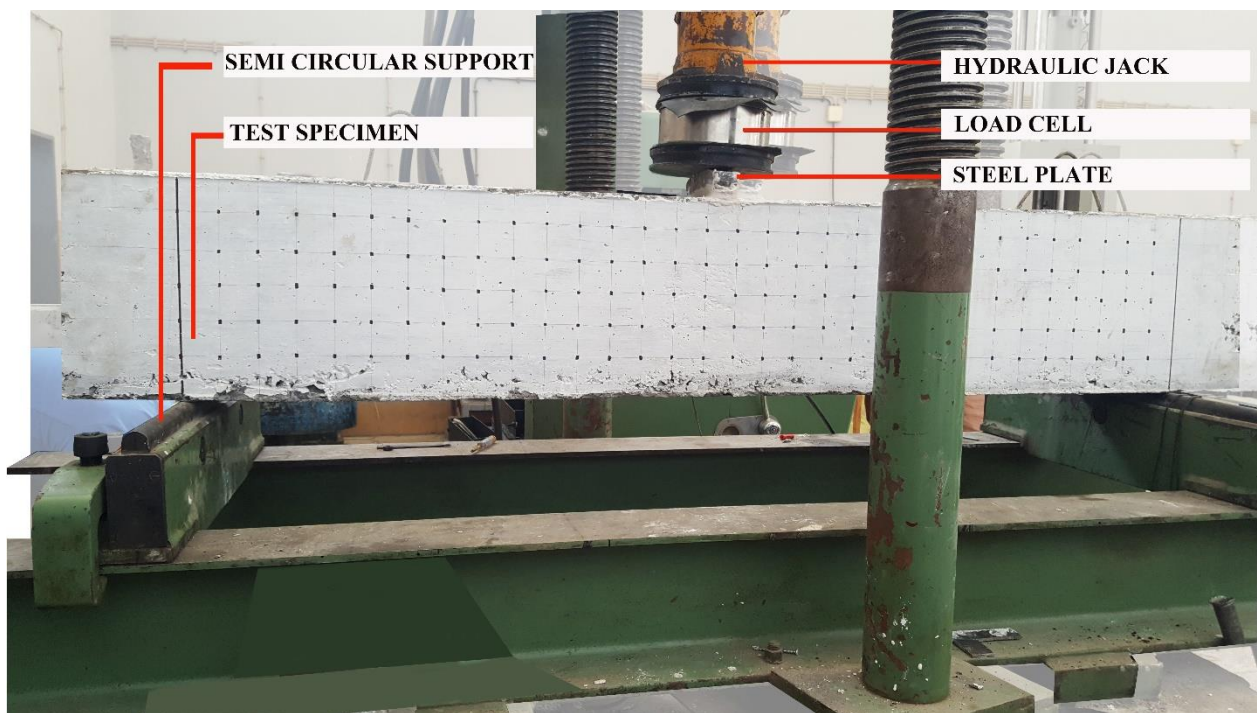


Figure 3-6 Diagrammatic arrangement of preliminary test set-up

4. NON LINEAR FINITE ELEMENT ANALYSIS

4.1.1. General

Nonlinear finite element model is conducted using Abaqus 6.13-1 with the identical specimens used in the experimental program. The compressive strength of the concrete for each specimen was directly taken from the experimental physical test program. The mechanical behavior of longitudinal and transverse reinforcements was also taken from the tensile tests result which is conducted in the laboratory.

The material behavior for both concrete and steel is presented in this section along with the parameters used for the elastic state and the parameters inputted for the yield conditions adopted for the plasticity of the materials. Idealized elastic-perfectly plastic stress-strain behavior is used for every analysis, this approach leads to the assumption that plastic yielding can occur only when the stress in the material reaches the value of the yielding stress and a perfectly straight yield plateau is formed with a constant stress and increasing strain until failure. (Ali Ahmed, 2017).

In modeling reinforced concrete structures a solid element is chosen. Steel is considered as homogeneous material and its material properties are generally well defined. Concrete is, on the other hand, a heterogeneous material made up of cement, mortar and aggregates. Its mechanical properties scatter more widely and cannot be defined easily. For the convenience of analysis and design, however, concrete is often considered a homogeneous material in the macroscopic sense.

Nicolás Toro Martinez (2017) the nonlinear response of concrete is caused by two major effects, namely, cracking of concrete in tension, and yielding of the reinforcement or crushing of concrete in compression. Nonlinearities also arise from the interaction of the constituents of reinforced concrete, such as bond-slip between reinforcing steel and surrounding concrete, aggregate interlock at a crack and dowel action of the reinforcing steel crossing a crack. The time-dependent effects of creep, shrinkage and temperature variation also contribute to the nonlinear behavior. Furthermore, the stress-strain relation of concrete is not only nonlinear, but is different in tension than in compression and the mechanical properties are dependent on concrete age at loading and on loading mechanism.

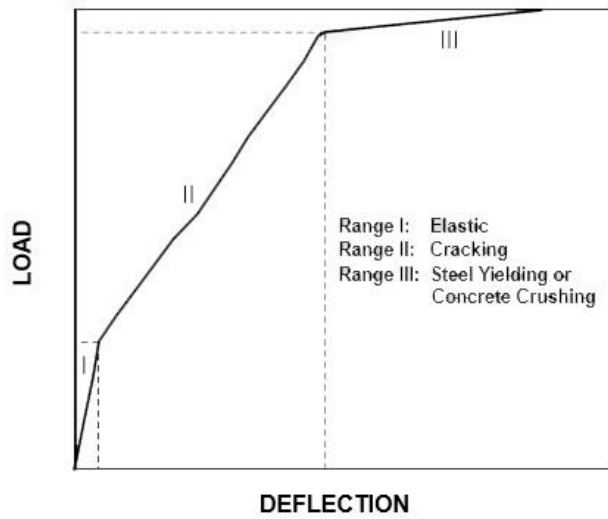


Figure 4-1 typical load displacement response of RC element

4.2. Concrete

Concrete is considered a brittle material, i.e., it breaks when subjected to specific stress without long plastic deformation. This behavior is shown in Figure 4.2

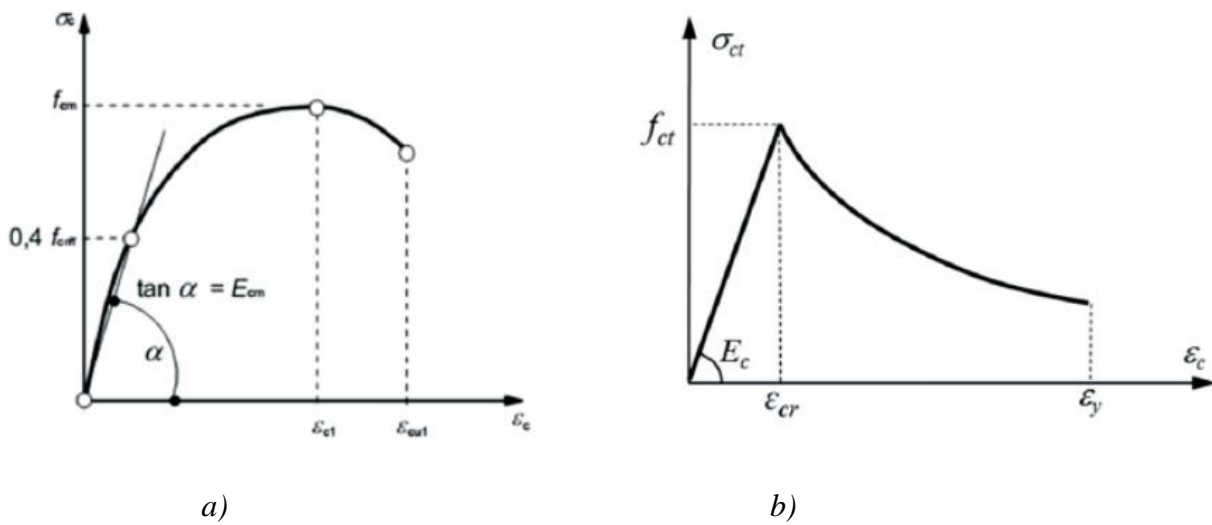


Figure 4-2 a) compressive and b) tensile concrete behavior

In the compression figure, it is observed an initial slope concerning the linear elastic behavior of concrete which can be defined in terms of the Young's modulus E_{cm} that ends with the value of the concrete compressive strength f_{ck} . Increasing the stress, concrete will enter into the plastic region defined with a curve and will reach the upper point corresponding to the load bearing capacity of the material. After this, concrete undergoes softening (material becomes weaker and continues deforming with less stress due to a reduction of its yield surface) and finally breaks. As for the figure representing tension, elastic region is likewise defines with the Young's modulus (straight line with slope) which ends in the concrete tensile strength f_{ctk} . Thereafter, plasticity takes place represented by a curve that ends with the breaking of the material due to tensile stresses.

The elastic behavior of the concrete in ABAQUS 6.13-1 finite element software is modeled by considering simple linear elasticity with Young modulus of elasticity and Poisson ratio as the material constants. Young modulus of elasticity, E represents a stiffness parameter and is defined as the ratios of the stress over strain. Poisson ratio, ν is defined as the negative ratio of transversal rate of expansion of the strain over the axial contracting rate of strain when subjected to compression. The values for both parameters are presented in Table 4.1

Property	Value
Modulus of elasticity	29000 MPa
Poisson ratio	0.2
Thermal Expansion Coefficient	$10 \times 10^{-6} \text{ } ^\circ\text{C}$
Density	2400 kg/m^3
Compressive strength	25MPa
Maximum size off aggregate	25

Table 4-1 concrete parameters

4.3. Steel

Similarly to concrete, there is an initial elastic region marks with a slope defining the steel Young's modulus E_s . However and contrary to concrete, steel undergoes hardening (material becomes stronger after yielding and thus, the yield surface is increased) and

reaches fracture after a long development within the plastic region. The most important steel features apart from hardening is its equal compressive and tensile behavior.

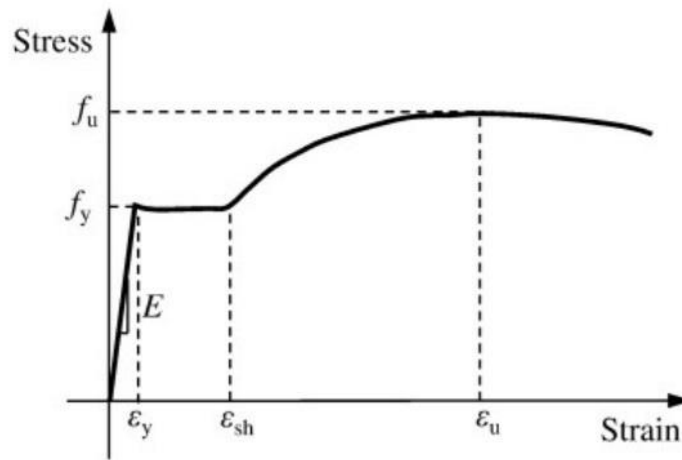


Figure 4-3 stress strain curves for steel

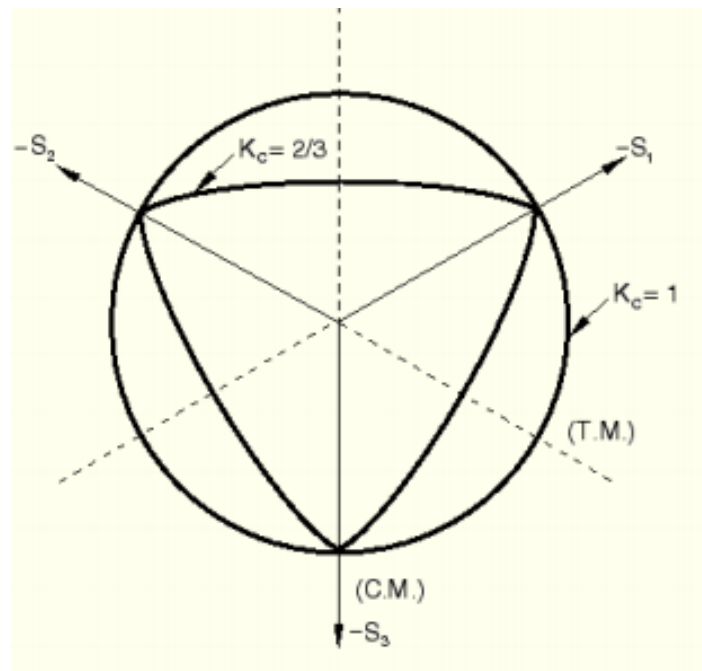
Property	Value	Remark
Modulus of elasticity	200000 MPa	
Poisson ratio	0.3	
Yield stress	566 MPa	flexural reinforcement
	475 MPa	Shear reinforcement
Plastic strain	0	
Thermal Expansion Coefficient	$10 \times 10^{-6} / ^\circ\text{C}$	
Density	2780 kg/m^3	

Table 4-2 steel parameters

4.4. Elastic parameters for concrete

Concrete Damage Plasticity model represents an adaptation of the Druker-Prager criterion and it accounts for various evolution of strength under tension and compression. The adjustment made for this model is that the failure surface in the deviatoric plane is not necessarily a circle and its shape is given by a parameter K_c . As seen in Figure 4.4 the shape of

the failure surface used in this analysis is the one when $K = 0.667$, value recommended by Abaqus User's Manual.



Concrete damage plasticity deviatoric plane

Figure 4-4 concrete damage plasticity deviatoric plane

The inclination that the plastic potential reaches for high confining pressure is measured by dilation angle. It describes the behavior of concrete under multiple stresses. Small value leads to brittle behavior but greater values produce ductile behavior. According to second-order FE Analysis axial loaded concrete members according to EC-2 done by Nessa Yosef Nezhad Arya, the dilation angle should be chosen between 25° and 40° to describe both tension and compression for normal grade concrete. In this research the value of dilation angle is taken as 31° and other default parameters of concrete damage plasticity model is as follows.

- Eccentricity=0.1
- $f_{bo}/f_{co} = 1.16$
- Viscosity parameter $\mu=0$
- Stress invariant ratio $k=0.667$

4.5. Beam Modeling

There are two methods of modeling elements in finite element software. One is the smeared modeling method and the other one is using discretized modeling method. In this research discretized modeling mechanism is used. The three-dimensional model of the beam was created by Auto CAD 2014 and then imported to ABAQUS 6.13, due to Solid Works modeling features which would allow modeling the beam in a faster and easier fashion.

For this research, the beams were modeled with a cross - section of 200mm x 300mm and a development length of the beam is 1850mm and the effective length of 1600mm by taking a shear span to effective depth ratio as 3.13, the length of shear span become 800mm. All the beams were provided with a tension reinforcement of #3 ϕ 24mm diameter deformed bars having yield strength of 566N/mm² and compression reinforcement of #2 ϕ 16mm diameter deformed bars having a similar yield strength with tension reinforcement. Traditional Web reinforcements are provided in every 200mm and swimmer bars are arranged with a spacing of 250mm hence, the reinforcement ratio of both swimmer bars and traditional stirrups are similar.

Individual parts of reinforcement; longitudinal and shear reinforcements are modeled as a truss member. Similarly 3D plan concrete members and steel load plate are modeled as a three-dimensional deformable solid element. A steel load plate is used to transfer the concentrated applied load to the beam specimen as it is clearly discussed on experimental part. The properties of each part/element of the model are indicated on table 4.1 and 4.2 of this chapter.

After creating different individual parts and defining the corresponding material and sectional properties of the parts, assembling the whole model by use of the “Assembly” module is the next step. In this step, instances are created from parts to build the complete model of the reinforced concrete beam which consists of traditional stirrups, swimmer bars, and the solid plain concrete. All these instances are created and added to the model one by one.

Element modeling in ABAQUS concerning reinforced concrete can be done in different ways. As discussed on a thesis done by Nicolás Toro Martinez, Advanced finite element modeling of reinforced concrete, Aalborg University, Concrete is normally modeled as a “solid” material whereas steel can be modeled as a solid, wire truss or wire beam: In this study steel is modeled as wire truss, and thereafter it is assigned a truss section accounting for its cross sectional area and material properties.

4.6. Boundary Conditions and Loading

The beam is modeled as a simply supported beam having 2 supports according to table 9. Both supports have different behavior of restrain mechanism along the beam; roller supports free to move in the X and Z directions, pin supports only free to move in the Z direction. There is no out of plane movement for pin and roller support condition for three dimensional members. Here, the supports are placed at the bottom surface of the beam specimen and steel plate is provided to restrain the specimen.

In order to realistically model the support conditions in the three-dimensional model of the beam, restrictions for boundary conditions have been applied along two lines parallel to X-axis, rather than one point so that no excess stress concentrations would occur at supports. The beam was modeled as a pinned support with restrictions in movement in every direction, $U_1=U_2=U_3=0$. The U_1 , U_2 and U_3 correspond to X, Y and Z major axis of the model. The beam boundary condition orientation is shown in the following picture.

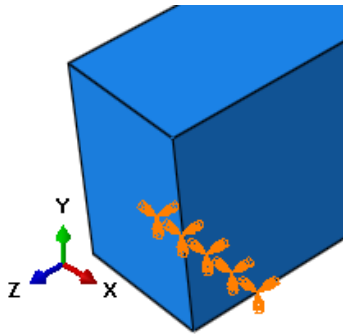


Figure 4-5 Boundary condition of the model

The boundary conditions of the beam are shown in the following table.

Direction	Restrain condition	
	Left support/Pin	Right support/Roller
$U_1=X$	0	0
$U_2=Y$	0	0
$U_3=Z$	0	-
$UR_1=X$	-	-
$UR_2=Y$	-	-
$UR_3=Z$	-	-

Table 4-3 Restrain condition

The loading is non-reversal repetitive loading; therefore the amplitude is smoothly incremental until it reaches the expected percentage of sectional capacity. The dimensions of the specimen and setup and supporting condition are modeled like in the experimental study. The beams were simply supported as indicated on the figure 4-6

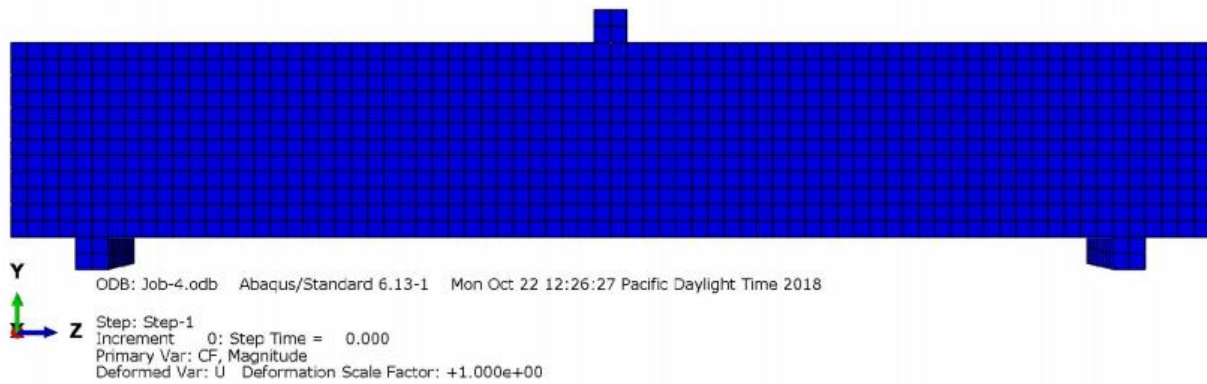


Figure 4-6 Abaqus finite element modeling setup

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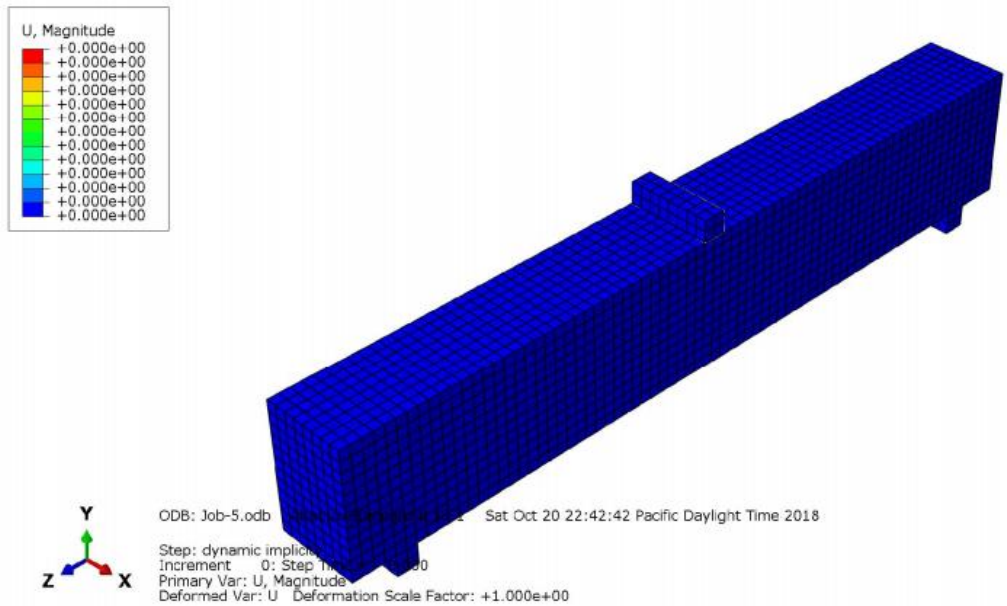


Figure 4-7 Illustration of meshed beam

4.7. Meshsystem

A very crucial issue while using Finite Element analysis is that the regions must discretize into small part, so called finite elements, and the software calculates a solution over each individual element. The first step in meshing the model is choosing the right type of element. There are several types of element available in Abaqus for three dimensional analyses. However due to the round geometry inside the model created by the reinforcement and as the software states in the mesh module that the RC beam is unmeshable with hexes or wedges, the tetrahedral quadratic element is used in this research.

The loading is non-reversal repetitive loading which is expected in less seismic area; therefore the amplitude is smoothly incremental until it reaches the expected percentage of sectional capacity. The dimensions of the specimen and setup and supporting condition are modeled like in the experimental study. Snap shot of the FEM mesh is given at Figure 4.7 While the size and refinement of the FEM mesh determined, a finite mesh size of 25mm is chosen and then refinement is done up to reaching a threshold between the results of two consecutive runs. If the results of two run is close enough, refinement is stopped. The experimental and FEM results such as deflection and energy absorption values, ultimate load and failure modes are compared.

5. RESULTS AND DISCUSSIONS

The purpose of this research was to assess the effectiveness of rectangular spliced swimmer bar as shear reinforcement for rectangular reinforced concrete beam. Based on observations, the theory that the swimmer bars are effective in enhancing the shear capacity of rectangular reinforced concrete beam under cyclic loading was studied through experimental test and validated against finite element model.

5.1. Investigation of Control Beams

5.1.1. Failure Pattern of Control Beams under Static Loading

During loading of beam NSB-2, first surface crack that appeared was a flexure crack at 143 kN load. In contrast it's 135kN on a beam which is reinforced with rectangular spliced swimmer beam named as RSSWB-2. In both cases, these initial cracks appeared near the bottom of beam around the mid span. The First shear crack was observed near right support at 205 kN load and the center deflection at this point was measured to be 2.59 mm in NSB-2 and 2.71 for RSSWB-2.

As it is clearly shown on the figure 5.1, (A) and (B) and noted that RSSWB-2 and NSB-2 face a widening of shear crack at left support point at 255 kN and 275kN respectively. Similarly, normal stirrup beam shear crack on the left support started widening at 205kN load and the spoiling of concrete under the load point was observed at 245 kN. With the ultimate load of 285kN for NSB and 296kN for RSSWB the failure of the beam specimen was abrupt and the mode of failure becomes pure diagonal shear crack at left support. During testing it was observed that less of shear cracks were formed within the left and right shear spans. For a normal stirrups beam, the inclined cracks were formed 200mm far from the face of support and on the verge of beam failure it approaches to 120mm to the support. The failure of beam was sudden and due to the slippage of concrete along the shear crack. The final failure of beam NSB-2 is shown in figure 5.1

The ultimate sectional capacity of the sample, NSB-2, is 285.34kN and its equivalent RSSWB-2 reinforced with the same amount of shear reinforcement ratio is failed at 296kN and the corresponding maximum deflection at the center of the beam was found to be 6.03mm and 5.95mm respectively. In the experimental investigation it is noted that a beam reinforced with the same amount of shear reinforcement with a normal stirrups beam, swimmer bar, enhance shear resistance capacity of a beam by 3.77% and reduce the deflection by 1.33%.

5.1.2. Cyclic Loading

For this research the experimental test for a cyclic loading is done manually and the overall cyclic loading process is non-reversal loading. Consequently, the time change and loading rate between consecutive loading and unloading mechanism is not exactly the same but tried to minimize the errors for a better precision through a careful loading. Since the research objective is to study the effect of rectangular spliced swimmer bar under high cyclic loading, as shown in the table, 5.1, the applied repetitive load is taken as 90% and 85% of the section capacity for both cases. Generally this test investigated the responses of swimmer beams under high cyclic loading conditions.

Naming of specimen	Sectional capacity (kN)	90% of sectional capacity (kN)	85% of sectional capacity (kN)
NSB	285	256.50	242.25
RSSWB	296.2	266.58	251.77

Table 5-1 values for cyclic loading

5.1.2.1. Failure Pattern of Control Beams Under 90% Cyclic Loading

NSB-1 and RSSWB-1

In this case the traditional or normal stirrup beam was loaded at 256.50kN and the equivalent swimmer beam was loaded with 266.58kN. After a flexural crack was generated at 167kN, the swimmer beam finishes the first cycle with scattered but insignificant shear cracks. While the normal reinforced beam tried to generate the first shear crack at 158kN on the right shear zone of beam and the cracks were well distributed around the support and clear shear cracks are visible after the third cycle. As indicated on the chart 2, until the load become 57.02kN for swimmer

beam the data logger indicates a zero center deflection and 4.91mm at the end of first cycle, 256.50kN. On the contrary it was 5.09mm midpoint deflection at the end of first phase of loading on normal beam. On both situations the first cycle deflection rate grows gently due to the contribution of uncracked concrete but after fifth cycle of normal beam and twenty seventh cycle of swimmer beam it increased rapidly. A beam reinforced with a normal shear reinforcement suddenly failed on ninth cycle and swimmer beam failed with the same mode of failure, diagonal shear failure, at fourth ninth cycle. The inclined cracks were formed 300mm far from the face of the right support and on the verge of beam failure the crack width was widen to 8mm at the middle span. The final failure of beam NSB-1 is shown in figure 20.

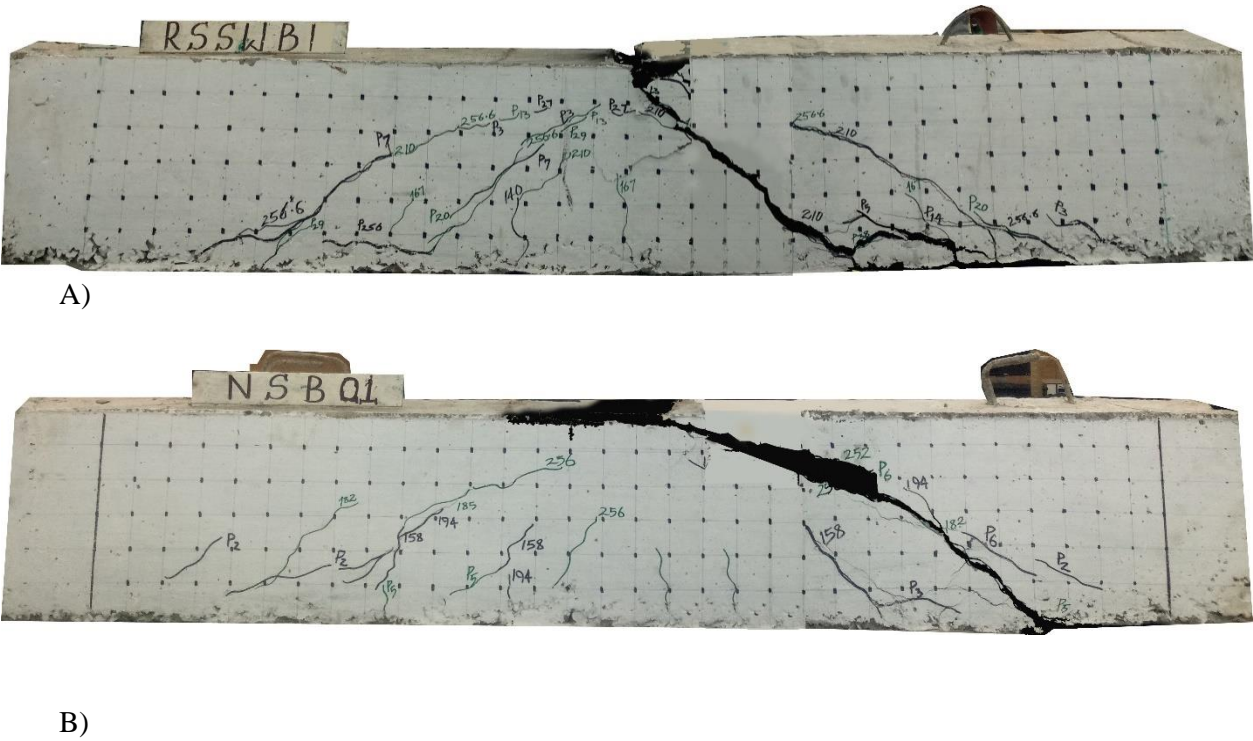


Figure 5-2 crack pattern of A) RSSWB-1 and B) NSB-1

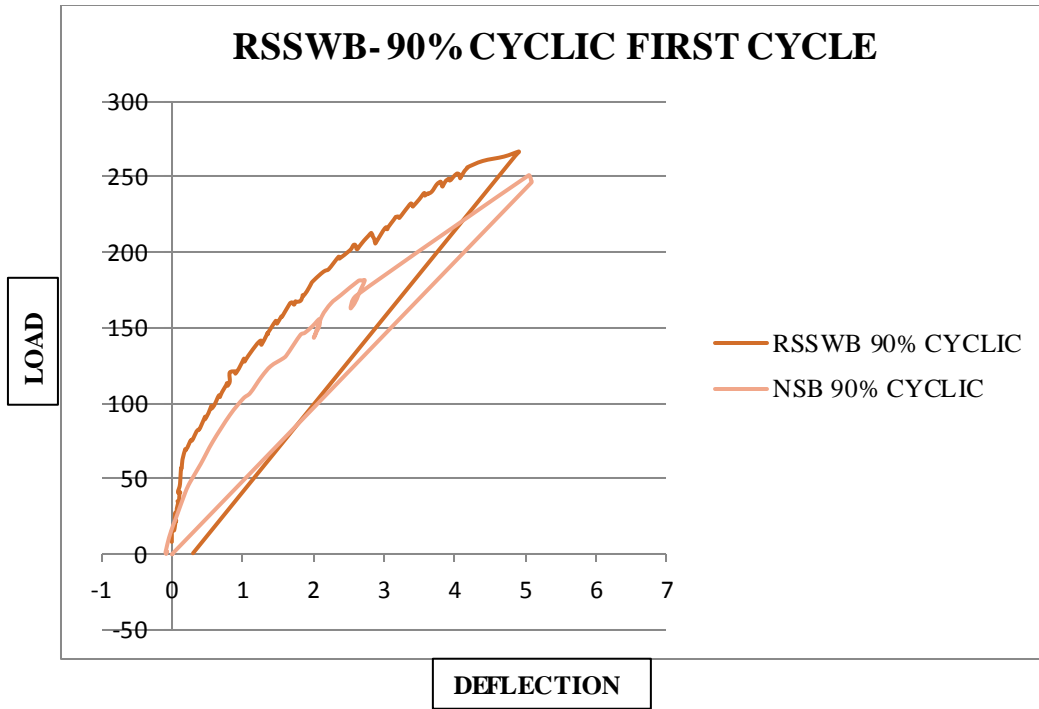


Chart 2 Load deflection curves of RSSWB and NSB after first cycle of 90% cyclic load

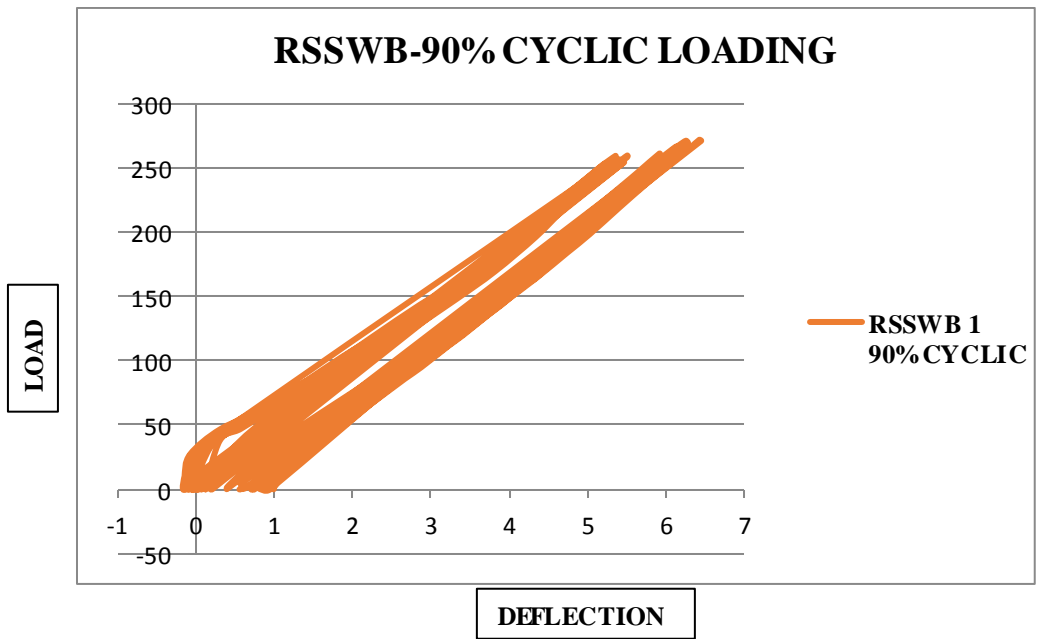


Chart 3 Load- Deflection Curve for RSSWB-1 under 90% cyclic loading

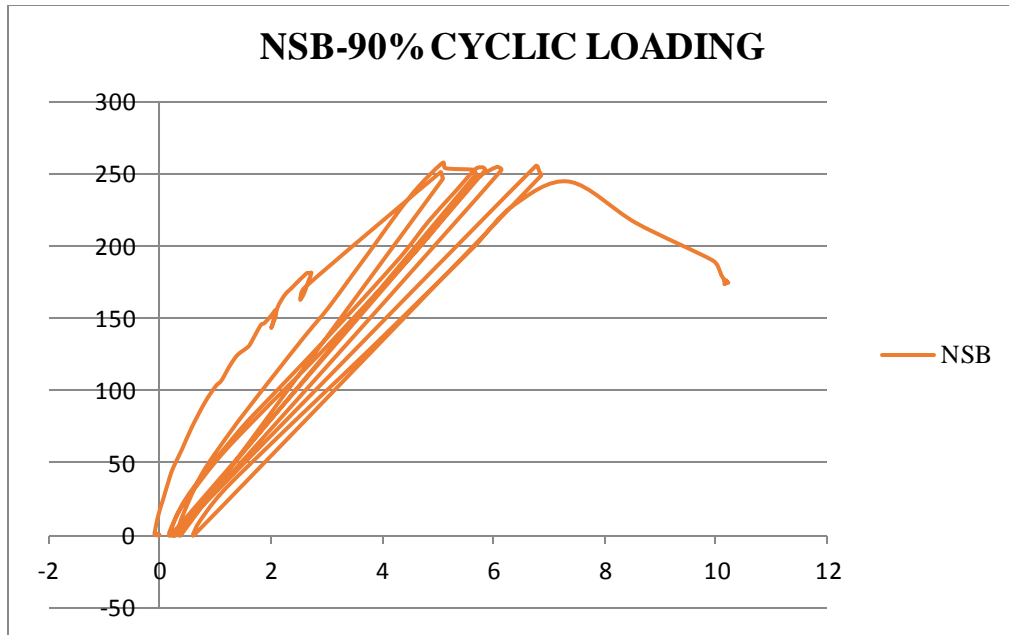


Chart 4 Load-Deflection Curve for NSB-1 under 90% cyclic loading

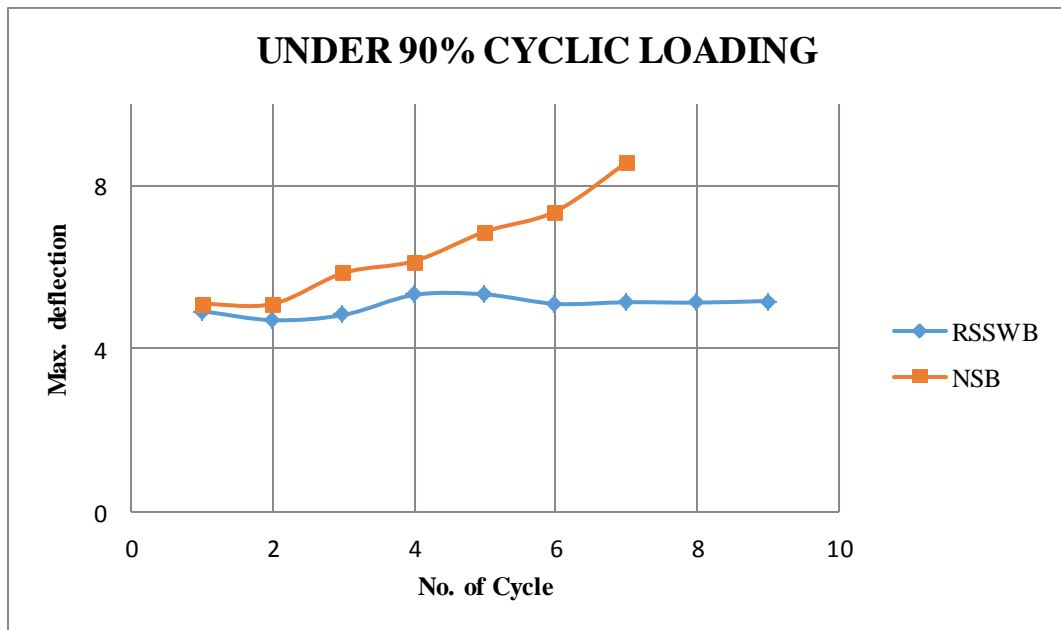


Chart 5 Max. Deflection- No. of cycle curve under 90% cyclic load

5.1.2.2. Failure Pattern of Control Beams Under 85% Cyclic Loading

NSB-3 and RSSWB-3

In this Second phase of the experimental case the traditional or normal stirrup beam was loaded at 242.25 kN and the equivalent swimmer beam was loaded with 251.77kN. The loading

mechanism was exactly the same as the test done for 90% cyclic loading. The first shear crack in the normal beam was started at a load of 242kN after a flexural crack was generated at 146kN. In addition to the primary crack there were two secondary shear cracks formed on the normal beam. On the other hand the swimmer beam failed with the primary or main crack only.

The rectangular spliced swimmer beam took 223 cycles to fail and rapture which is higher value in comparison with the normal stirrups beam that failed on 126 cycles. In a similar fashion with a test done on 90% cyclic loading, both type of beams failed in diagonal shear. As shown in the figure 5.2 in some extent the NSB faced a local failure around the point of application. Since, the concrete rapture was on the concrete cover part the core confined concrete was the ability to resist further 16 cycles before failure and there was no change in deflection change rate.

The inclined cracks for a NSB were formed at 150mm far from the face of the left support and 300mm from the same side. At the age of failure, the normal beam formed a very deep, wide and scattered shear cracks and one critical crack with relatively narrow shear crack was seen on swimmer beam. Due to the nature of concrete mix and symmetric loading parallel cracks were formed on the opposite side of the beam. By increasing the confinement and minimizing the crack width, the contribution of swimmer bars is better. The deflection assessment of this beams are shown in the chart 7

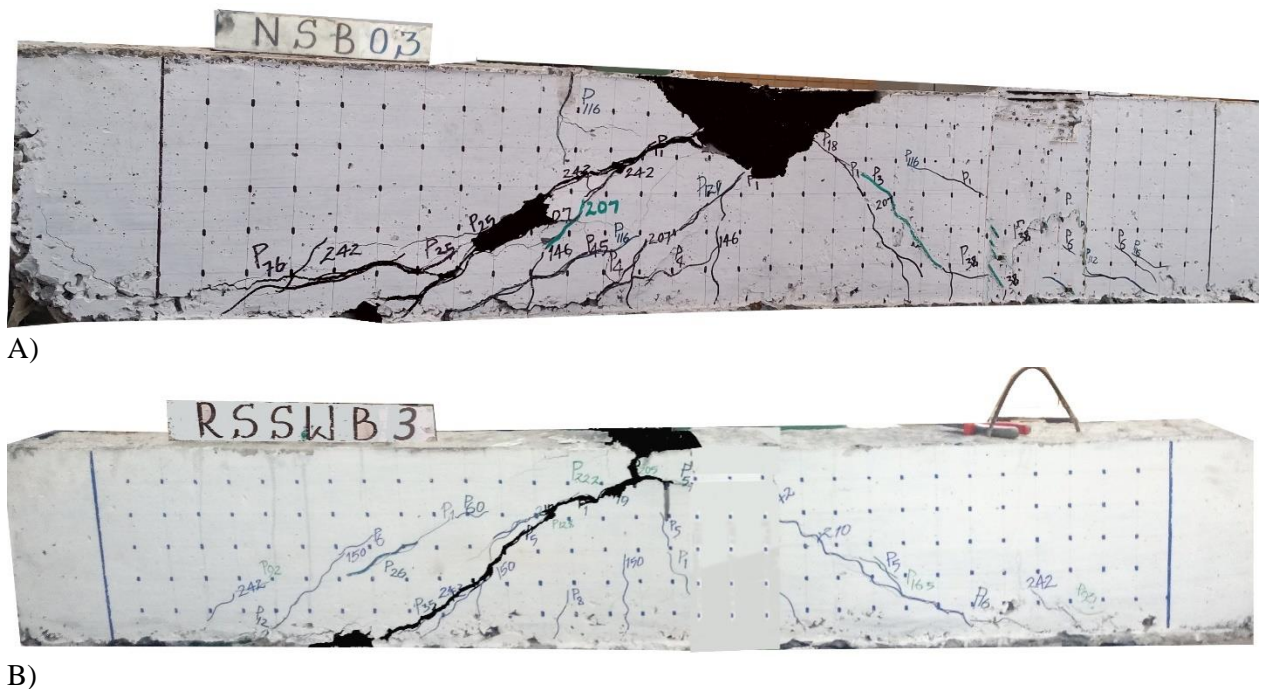


Figure 5-3 crack pattern of A) NSB-3 and RSSWB-3

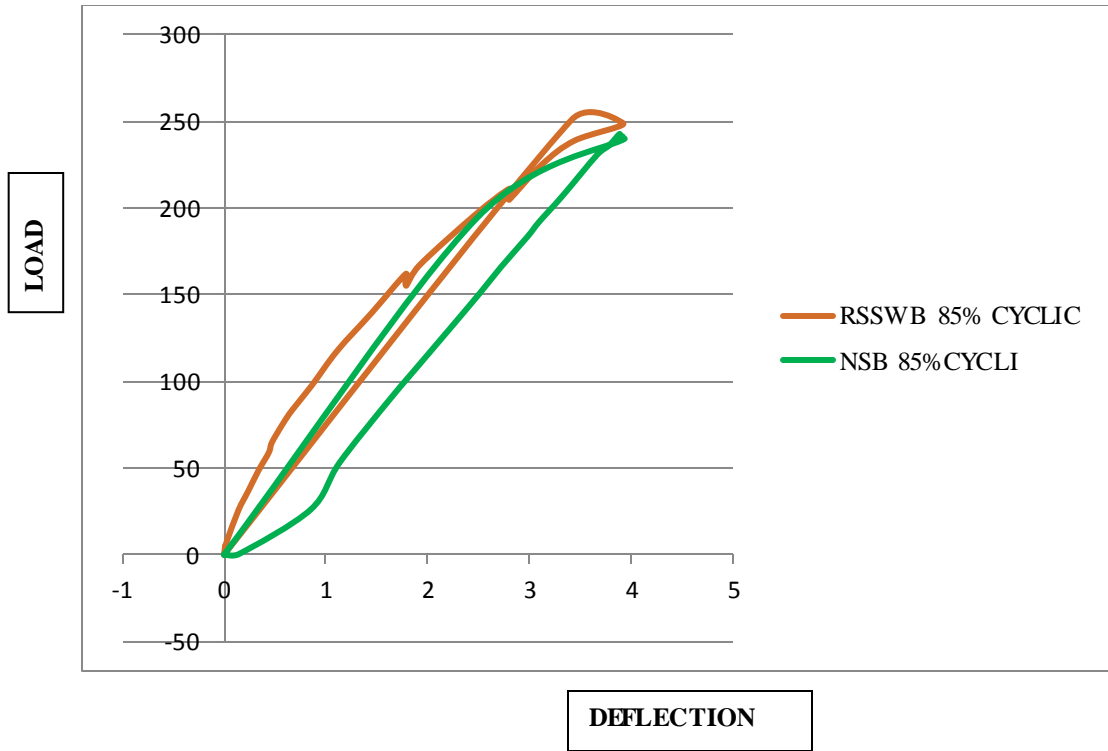


Chart 6 Load deflection curves of RSSWB and NSB after first cycle of 85% cyclic load

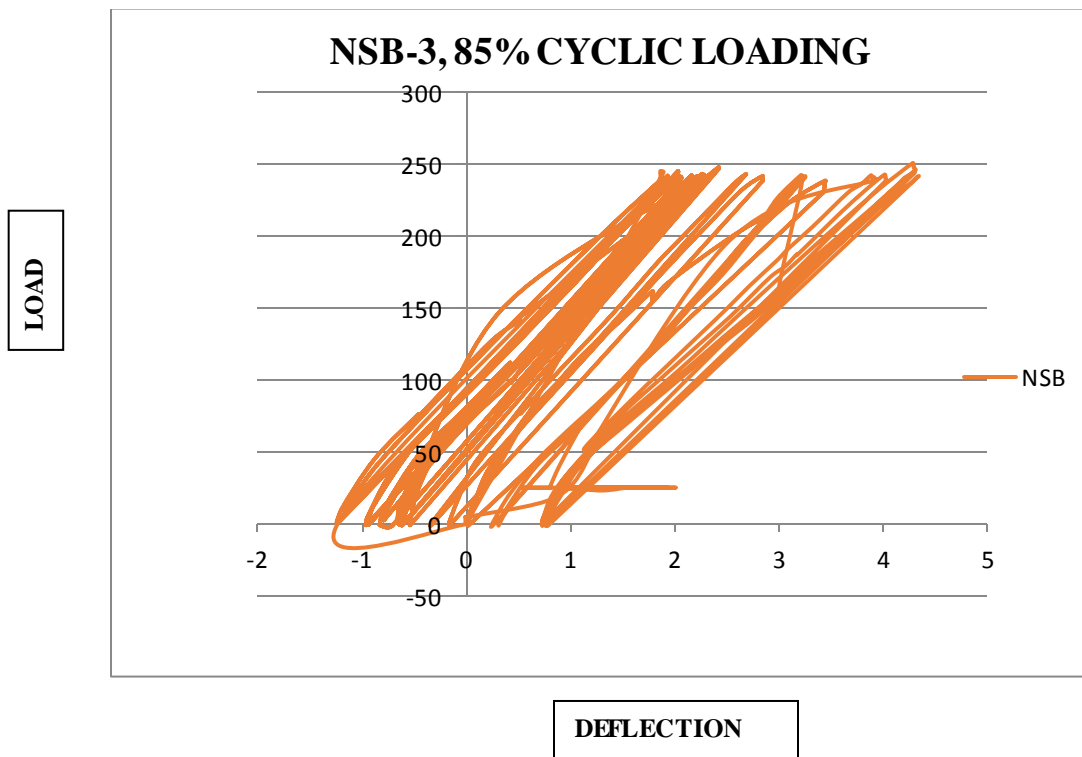


Chart 7 Load-Deflection Curve for NSB-3 under 85% cyclic loading

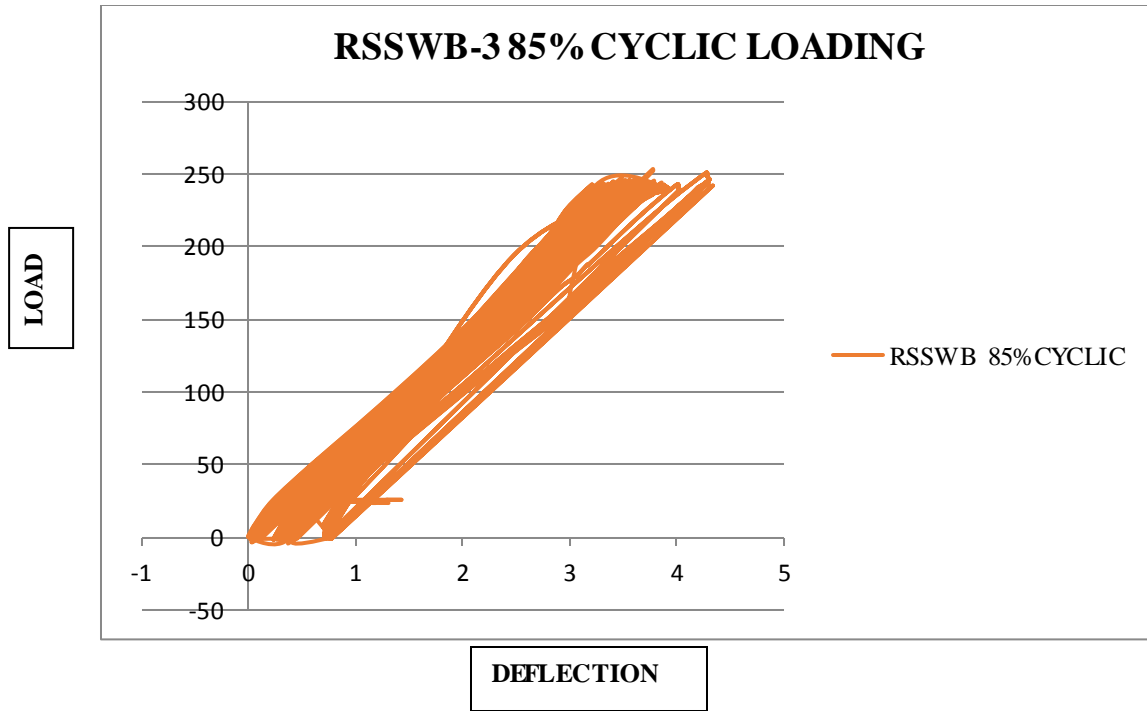


Chart 8 Load-Deflection Curve for RSSWB-3 under 85% cyclic loading

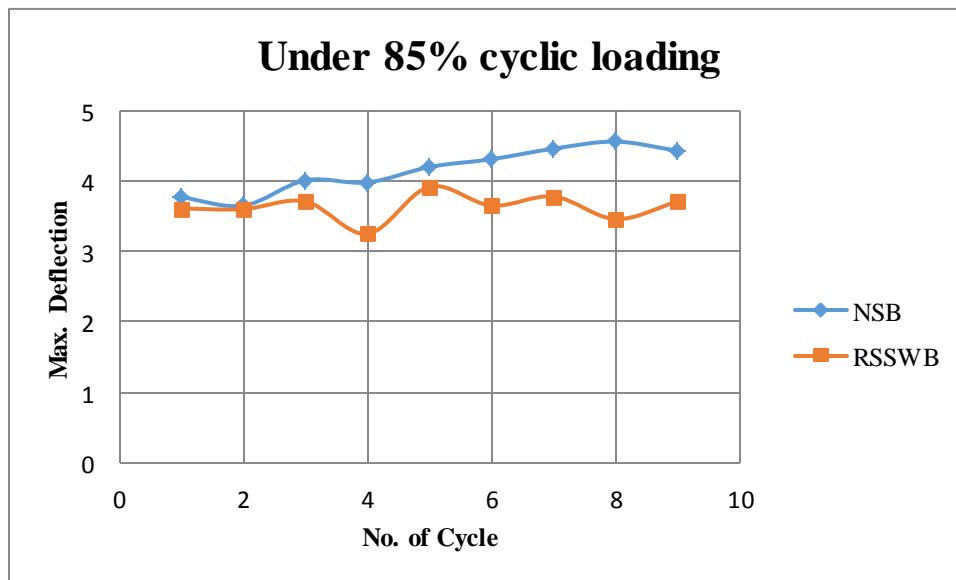


Chart 9 Max. Deflection- No. of cycle curve under 85% cyclic load

5.2. Post cracking analysis

In this research, post cracking analysis was done for the experimental investigation part and the overall analysis process was done manually by slightly demolishing/peel out/ the cracked concrete and damaged beam surface. The removing of concrete was done till the concrete cover is completely removed and stirrups are clearly visible. The aim of this demolishing is to know the feature of stirrups after the beam failure, crack depth, identify the extent of damage in the beam.

It is known that at the cracked section all tension is carried by the steel reinforcement. Tensile stresses are, however, present in the concrete between the cracks, since some tension is transferred from steel to concrete through bond. The magnitude and distribution of bond stresses between the cracks determines the distribution of tensile stresses in the concrete and the reinforcing steel between the cracks.

Based on the analysis the feature of shear reinforcements is as follows:

- The area on which diagonal shear crack become widens, stirrups are yielded and in some extent there is an elongation of shear reinforcement bar in normal stirrups beam. This elongation is due the opposite force applied between center point load and the cantilever beam created due to the cracked surface. The contribution of shear reinforcements and aggregate becomes less to handle the widening of crack and this leads to the stretching of stirrups parallel to its plane. As it's shown in figure 5.4, though they are stretched due to the tensile capacity of steel, shear reinforcements are not cut at a point.
- The damage styles and depth of cracks are differing for the normal and swimmer beam specimens. Due to the fact that the contribution of aggregate for dowel action and tensile capacity of reinforcement bar, the crack width in rectangular spliced swimmer bar become less due to the increasing of its length confined with concrete as compared with normal stirrups beam.
- The normal stirrup beam has a parallel shear crack which is formed directly parallel to the face on which the main crack is generated.
- For statically loaded member the crack width of normal beam becomes 8.1mm at the center of the beam and 6.3mm for rectangular spliced swimmer bar.



Figure 5-4 Spall concrete cover

5.3. Output from Finite Element analysis

The result of Abaqus 6.13.1 simulation load deflection curve characteristics under static loading of a specimen is as follows. The ultimate sectional capacity of the sample, NSB, is 315.56KN and RSSWB-2, a specimen reinforced with the same amount of shear reinforcement ratio of swimmer bar was failed at 335.55KN and the corresponding maximum deflection at the center of the beam was found to be 9.12mm and 9.54mm respectively. In the finite element analysis both reinforced concrete beam specimens show better sectional capacity though still swimmer beam have 3.16% enhancement over normal stirrups beam.

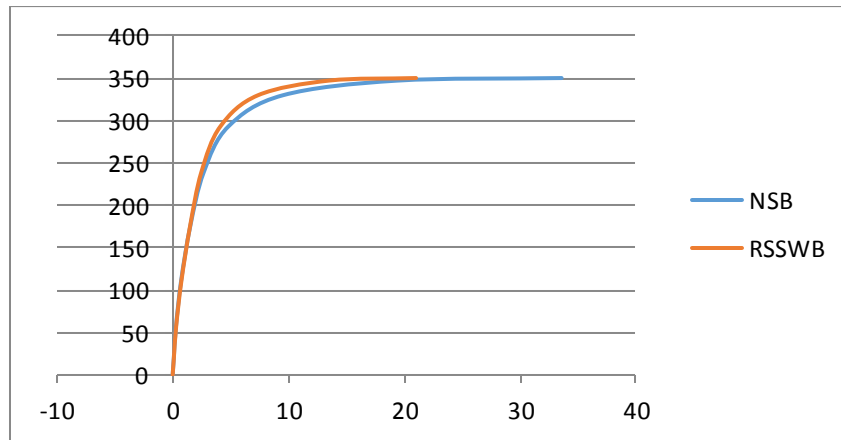


Chart 10 combined NSB and RSSWB under cyclic loading

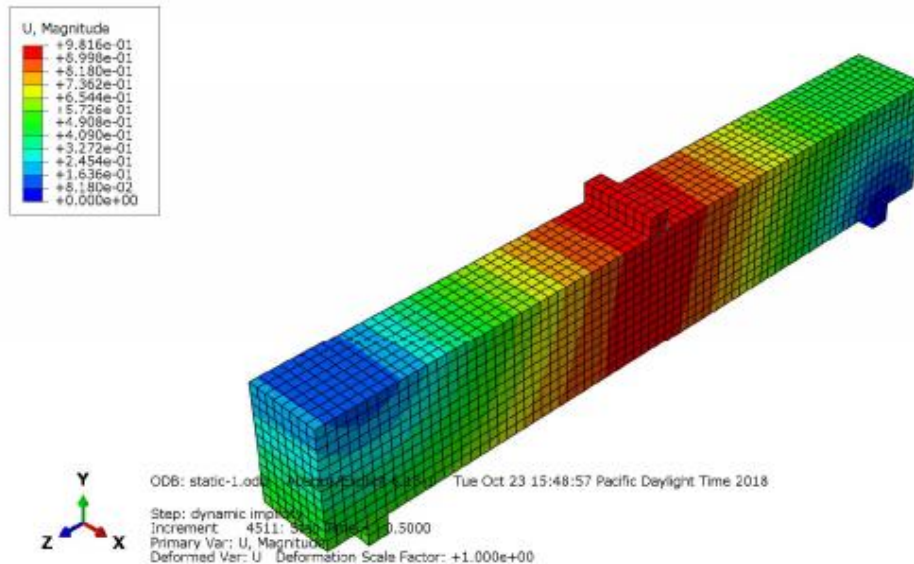


Figure 5-5 FEM under static loading

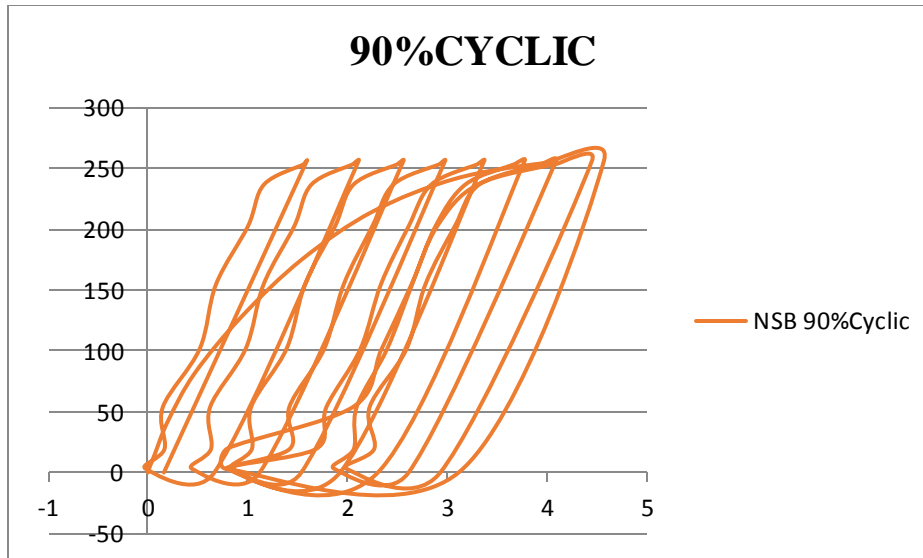


Figure 5-6 NSB under 90% cyclic loading

In this result it is possible to conclude that the sectional capacity of reinforced concrete beam was high while doing finite element analysis. But the response of concrete towards repetitive high cyclic load was not perfect. The behavior of concrete was modeled as an elastic behavior but the increasing in residual stress in this result shows the plastic behavior of concrete dominate the elastic one. Consequently, the hysteresis behavior of the beam is affected and elastic behavior of reinforced concrete need deep consideration.

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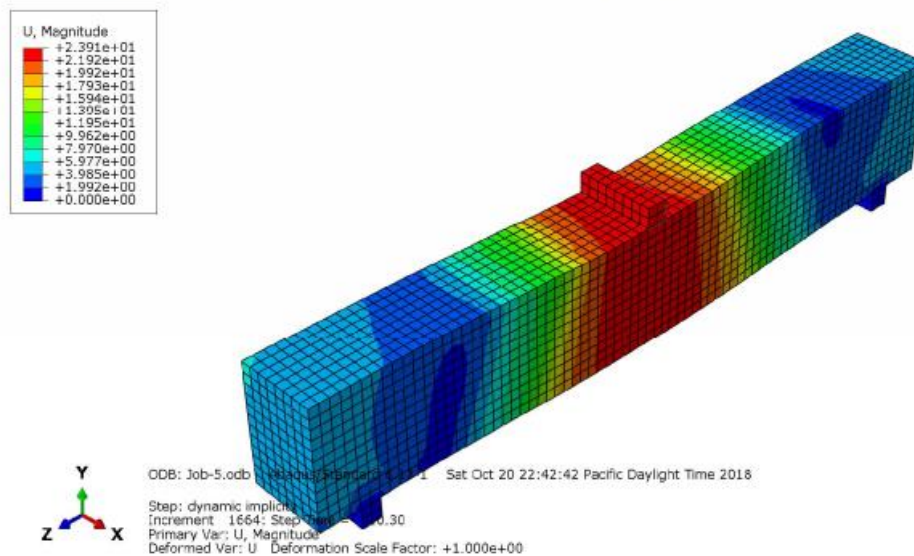


Figure 5-7 deflected beam FEM after last cycle

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusion

This research assessed a new type of shear reinforcement called swimmer bar system. Swimmer bar type of shear reinforcement can be formed in many shapes such a single swimmer, rectangular spliced swimmer bar, rectangle with cross bars, and multiple swimmer bars. Specifically, in this research rectangular spliced swimmer bar is deeply investigated through experiment and finite element software simulation.

The use of rectangular spliced swimmer bar system as shear reinforcement is assessed using experimental investigation and finite element software simulation, ABAQUS 6.13.1 software. Based on the experimental investigation the ultimate load capacity of the beam is increased by 3.75% and the respective deflection indicates better in rectangular spliced swimmer bar than normal stirrups and improved the shear load carrying capacity in the reinforced concrete beams.

In both experimental investigation and finite element software simulation result, rectangular spliced swimmer bars show more capacity in resisting single sided high cyclic loads than under static loading mechanism. In a high magnitude cyclic load the crack pattern, width and length were observed to be less while using swimmer bars as compared to the traditional stirrups system. Also it can be noticed that the new type of shear reinforcement configuration can replace the use of normal stirrups without any loose of energy in resisting shear stress.

Bridge beams and machine carrier beams are major elements that are exposed to non-reversal repetitive cyclic loads. For such shear critical structures, using rectangular spliced swimmer bar as shear reinforcement can enhance their shear resistance capacity. As a result, using this swimmer bars on bridge decks and machine carrier beam increase the life span of a structure.

While using normal stirrups there will be a congestion of reinforcements and this concentration of shear reinforcement around the support decreases workability. This condition affects the quality of construction and lead to structural problem. Due to the brittle behavior of shear, the structure will not be efficient enough to resist shear failure. Congestion of reinforcement also increase the overall construction cost. Hence, for less seismic areas by using the same amount of shear reinforcement with normal stirrup; it is possible to avoid problems related to congestion of reinforcement.

6.2. Recommendation

This thesis presented the effectiveness of rectangular spliced swimmer bars in rectangular reinforced concrete beams that exposed to single sided high cyclic repetitive loads. Based on the experimental investigation and finite element software simulation the result was better in comparison with normal stirrups. Regarding to the application of swimmer the following recommendations are made;

- The absences of defined analytical formula like vertical/normal and inclined stirrups, the implementation of swimmer bars on real projects become difficult. Hence, additional works are necessary to overcome the problem.
- The residual stress while using ABAQUS 6.13 FE software is too large and the area is open for other researchers to check and investigate the contribution of swimmer bars on shear by using other finite element software.
- Since swimmer bars are recently discovered shear reinforcement bars, flexural and torsional behaviors of swimmer bars are not deeply studied and making a research on such internal stress of beam member can increase the applicability of this new type of shear reinforcement.
- Due to the presence of insufficient written literatures, magazines and journals on swimmer bar, the application of swimmer bar is not well addressed to the construction industry and it is not too much familiar for the construction industry to apply swimmer bars on shear critical zones of a beam. Consequently, the area need further studies and publishes to handle this problem.

REFERENCE

- Al-Nasra. (2012). *International Journal of Civil and Structural Engineering*, Volume 3, No 2.
- Al-Nasra. (2013). *International Journal of Civil Engineering and Technology (IJCIET)*, Volume 7, Issue 6.
- Al-Nasra, 1. (2013). *International Journal of Civil Engineering and Technology (IJCIET)* , Volume 7, Issue 6.
- Al-Nasra, M. (2017). Innovative Use of Space Swimmer Bars System as Shear Reinforcement in Reinforced Concrete Beams . *International Journal of Scientific and Engineering Research* , volume 8.
- Al-Nasra, M. m. (2013). Shear failure investigation of reinforced concrete beams with swimmer bars. *Department of Engineering Technology*.
- Chopra, A. K. (August 1-6, 2004). *Estimating seismic demands for performance-based* . Canada: University of California.
- CODE. (1995). *Structural Use of concrete*. Ethiopia: Ministry of works and urban development.
- Filippou, H.-G. K. (November, 1990). *Finite Element Analysis of reinforced concrete structures under monotonic loads*. California: university of California berkeley, California.
- Govindaraj, P. S. (n.d.). *International Journal of Civil Engineering and Technology*, Volume 7, Issue 6.
- Govindaraj, p. S. (2012). Experimental and analytical investigated reinforced concrete beam. *International Journal of Civil Engineering and Technology*, Volume 7, Issue 6.
- Institute, A. C. (ACI 318M-02). building code requirements for structural concrete and commentary.
- Institute, A. c. (n.d.). building code requirements for structural concrete and commentary. *ACI 318M-05*.
- Jaafar, E. K. (January 2017). Experimental Study on Anchorage Bond In High Strength Reinforced Concrete Beam. *International Journal of Civil Engineering and Technology (IJCIET)*, pp. 63–71.
- Jaafar, E. K. (January 2017b). Experimental Study on Anchorage Bond In High Strength Reinforced Concrete Beams. *International Journal Of Civil Engineering And Technology (Ijci et)*, 61–69.
- James K Wight and James G Mac Gregor. (2009). *Reinforced Concrete mechanics and design fifth edition*.

- Kishori V. R.¹ and Vivek Philip². (2016). Effectiveness of Swimmer Bars as Shear Reinforcement in Rectangular Concrete Beams. *International Journal of Research in IT*, Volume 06 Issue 08.
- Lei Wang, X. Z. (29 August 2015). Effects of stirrup and inclined bar corrosion on shear behavior of RC beams. *Elsevier Ltd*, 538-547.
- Li, Z. (2011). *Advanced Concrete Technology*. New Jersey: John Wiley & Sons, Inc., Hoboken.
- Longman, A. W. (1998). *concrete structure*. UK: Addison Wesley Pty Limited.
- M C Limbachiya, A. K. (2004). *Performance of Recycle Aggregate Concrete*. UK: Kingston University.
- Moayyad M. Al-Nasra, N. M. (2013). Shear Reinforcements in the reinforced concrete beams. *American Journal of Engineering Research(AJER)*, 191-199.
- Naiem M. Asha, M. M.-N. (2012). optimizing the use of swimmer bars as shear reinforcement in the reinforced concrete beam. *International Journal Of Civil And Structural Engineering*, Vol. 3.
- P.K.Joshi and Jyoti B. Chavan. (2015). *International Research Journal of Engineering and Technology.*, volume 2.
- Rad, T. (1994). *reinforced concrete beams under cyclic loads*. university of wollongoing.
- Slowik, M. (2014). Shear failure mechanism in concrete beams . *ScienceDirect*, 1977 – 1982.
- Steedman, C. E. (1999). *Reinforced Concrete Designer's Handbook, tenth edition*. UK: Taylor & Francis Group.
- Stoelhorst, W. &. (2008). *Tailor Made Concrete Structures* . London: Taylor & Francis Group.
- Wight, J. K. (2004). *ACI 318M-02 Building code requirements for structural concrete and commentary*. USA: IHS.
- Wight, J. K. (2004). *ACI 318M-05 Building code requirements for structural concrete and commentary*. USA: IHS.
- Wight, J., & Macgregor, J. (5th ed. 2009.). *REINFORCED CONCRETE Mechanics and Design*. University of Michigan.

APPENDIX

APPENDIX 1 SIEVE ANALYSIS RESULT FINE AGGREGATE

sieve size (mm)	weight of sieve (gm)	wt. of sieve and retained (gm)	wt. retained (gm)	Percentage retained (%)	Cumulative coarser (%)	Cumulative passing (%)	ASTM 33 %	Remark
9.5	585	585	0	0	0	100.00	100	passed
4.75	435	445	10	2.22	2.22	97.78	95-100	passed
2.36	390	410	20	4.44	6.67	93.33	80-100	passed
1.18	355	410	55	12.22	18.89	81.11	50-85	passed
600µm	325	455	130	28.89	47.78	52.22	25-60	passed
300µm	300	460	160	35.56	83.33	16.67	10-30	passed
150µm	285	335	50	11.11	94.44	5.56	2-10	passed
pan	255	280	25	5.56	100.00	0	0	passed
weight of sample taken			450					
fines modulus of fine aggregate					2.53			

APPENDIX 2 SIEVE ANALYSIS RESULT COARSE AGGREGATE

sieve size (mm)	weight of sieve (gm)	wt. of sieve and retained (gm)	wt. retained (gm)	Percentage retained (%)	Cumulative coarser (%)	Cumulative passing (%)	ASTM 33 %	Remark
25	1198		0	0	0	100.00	95-100	passed
19	1175	2075	900	41.19	41.19	58.81	30-70	passed
9.5	1160	2005	845	38.67	79.86	20.14	10--35	passed
4.75	1265	1665	400	18.31	98.17	1.83	0--5	passed
pan	735	775	40	1.83		0	0	passed
weight of sample taken			2185					

APPENDIX 3 ACI MIX DESIGN PROCEDURE

The selection of concrete proportions is based on laboratory physical test data with the material actually to be used. Hence, the following information's are gathered as previously indicated from the test.

- Sieve analysis of fine and coarser aggregates.
- Unit weight of coarse aggregate
- Bulk specific gravity and absorption of aggregates
- Specific gravity of Portland cement
- Optimum combination of coarse aggregates to meet the maximum density grading.

Step 1

- Large nominal maximum size of well graded aggregates has fewer voids than smaller sizes, 25mm.
- Nominal maximum size of aggregate should be the largest that is economically available and consistent with dimension of the structure.

Step 2

Estimation of mixing water and air content

Water to cement ratio is the single largest factor or parameter affecting the strength of fully compacted concrete. From the table having a nominal maximum size of 25mm with a slump of 25-50mm and non-air entrained concrete the estimated water, Kg/m^3 of concrete for the indicated maximum size of aggregate, is 179 Kg/m^3 .

Step 3

For several condition of exposure, the water to cement ratio should be kept low even though strength requirement may be met with a higher value. In this research a water to cement ratio is taken as 0.61 to achieve a 28 day compressive strength of 25MPa.

Step 4

Calculation of cement content

The amount of cement per unit volume of concrete is fixed by the determination made in step 3 and 2 above and the ratio of water to cement ratio taken. Hence, for a W/C ratio of 0.61, the amount of cement will be 293.44 kg/m^3 .

Step 5

Estimation of coarse aggregate content

From ASTM codewith a 2.53 finesse modulus of sand and 25mm nominal maximum size of coarse aggregate, volume of coarse aggregate per unit volume of concrete is 0.69. Consequently, the quantity of coarse aggregate will be 1171.94 kg/m^3 .

Step 6

Estimation of fine aggregate content

The estimated weight of fresh concrete with the indicated nominal maximum aggregate size and non-air entrained condition of concrete is 2380 kg/m^3 . Then it's possible to calculate the weight of fine aggregate by deducting the total weight sum of water, cement and aggregate from the total estimated weight of fresh concrete.

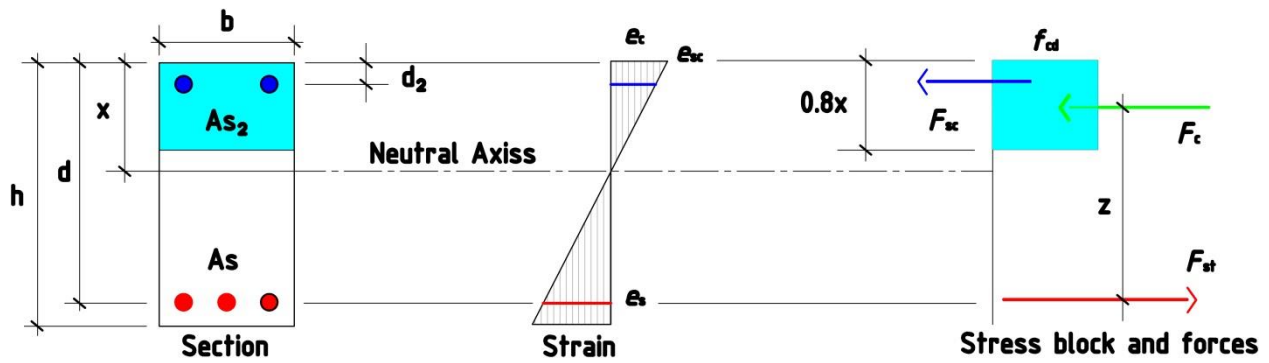
Mass already known are

1. Weight of water	179 Kg/m^3
2. Weight of cement	179 Kg/m^3
3. Weight of coarse aggregate	<u>1171.94 Kg/m^3</u>
Total weight	<u>1644.38 Kg/m^3</u>

But the estimated weight of fresh concrete is 2380 Kg/m^3

Amount of fine aggregate = $2380 \text{ Kg/m}^3 - 1644.38 \text{ Kg/m}^3 = 735.62 \text{ Kg/m}^3$

APPENDIX 4 REINFORCED CONCRETE BEAM



$$A_s = \pi r^2 = 452.38 \text{mm}^2$$

$$A_{s2} = \pi r^2 = 201.06 \text{mm}^2$$

Material Property

C-25, 25Mpa concrete

S-475, 475Mpa steel for shear reinforcement

S-566, 566Mpa steel for flexural reinforcement

Section property

B=200mm D=300mm

d=255 d'= 45

MOMENTS CALCULATIONS

Based on EC-2, flexural strength of beam member for a class \leq C50/60, $k=0.196$

$$k = \frac{M}{bd^2 f_{ck}}$$

$$M = kb d^2 f_{ck}$$

$$= 0.196 * 200 * 255^2 * 566 * 10^6$$

$$= 174.31 \text{kNm}$$

For simple supported member the maximum moment is calculated as,

$$M = \frac{PL}{4}$$

Hence, resistance capacity of beam become

$$P = \frac{4M}{L}$$

$$P = \frac{4 \cdot 174.31 \text{KNm}}{1.6} = 435.77 \text{KN}$$

SHEAR CALCULATION

Based on EC-2, shear strength of beam member for a class \leq C50/60, $z=0.9d$, $\cot \theta = 2.5$

Area of shear reinforcement

$$\frac{A_{sw}}{S} = \frac{V_{Ed} b_w}{f_{ywd} \cot \theta}$$

$$V_{Ed} = \frac{A_{sw} f_{ywd} \cot \theta}{S b_w}$$

$$V_{Ed} = 298.44 \text{KN}$$