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# A COMPARISON BETWEEN INCLINED SHEAR REINFORCEMENT AND LOOP SHEAR REINFORCEMENT ON RC BEAM: FINITE ELEMENT APPROACH

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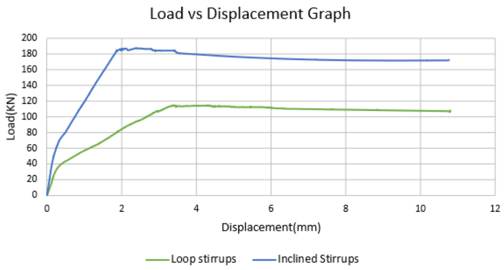
## Graphical abstract



## Abstract

In this present study, a numerical analysis has been performed to compare the shear resisting capacities between beams with conventional loop stirrup and inclined stirrup. Resisting the shear force is one of the key features of stirrups. A rarely used and uncommon inclined stirrup setup is analyzed in this study and new findings are compared with the results of loop stirrup. Two sets of beams (150x300x1960mm) are analyzed to determine the ultimate shear force resisting capacities, displacement, and stress resistance capacities. It was observed that the beam with an inclined stirrup showed ultimate shear resistance up to 187.24 KN compared to the beam with a loop stirrup setup which was 114.24 KN. Displacement of the inclined stirrup setup and the loop stirrup setup was 2.38 mm and 4.21 mm. Stress resistance and distribution pattern was also improved upon using inclined stirrup. Flexural and Shear Crack patterns of the beams at the ultimate load are also predicted from numerical analysis. Numerical study has been carried out by using Finite Element Software ABAQUS. Finally, these results were also compared with the theoretical formula available in the literature to justify the numerical analysis.

***Keywords***: Shear force, Inclined Stirrups, Displacement, loop stirrups, ABAQUS.

## 1.0 INTRODUCTION

Numerical Analysis is the study of algorithms that deals with the development and use of numerical methods for solving problems and it focuses on creating, analyzing, and implementing algorithms for solving the problems of continuous mathematics(Atkinson, 2007). In the field of structural analysis today, numerical analysis is using on a very large scale by simulating the result of a singular section or for a full model structure. Apart from that, it was seen from the previous research studies that Numerical analysis takes comparatively less time and is usually cost-effective than experimental study. The Finite Element Analysis (FEA) is one of the most used methods in Numerical Analysis. Perhaps it is known as the operation of simulating the behavior of a part under the provided prerequisites to assessing it by using the Finite Element Method (FEM). Moreover, Finite Element (FE) analysis can predict the experimental behavior and isolate the contributions of the individual elements of RCC Beam.

Reinforced Cement Concrete (RCC) Beam is a structural member and it carries all types of vertical loads and resists it from bending. The RCC beam is a composite solid in which the upper part takes compression and the lower part takes tension.

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Lower tensile strength and ductility of the concrete are counterbalanced by the addition of reinforcement which has great ductility and tensile strength. Moreover, Reinforced structures are majorly designed to survive tensile and shear stresses in specific regions of the concrete that can be the reason for unwanted cracks and structural failures. In RCC structure, how a beam section will behave and how its strength will vary with the differentiation of its property is important. It is significantly a very time-consuming and costly procedure to cast beams under different types of loads such as concentric and eccentric loads with various materials properties. That's why numerical modeling by finite element analysis (FEA) is encouraged nowadays.

A Beam fails in shear when the incoming shear stress crosses the permissible design limit of shear stress which concrete can sustain. That's why now RC beam is treated with shear steel to resist the shear failure by adding ductility. A lot of studies were done to find the working principle of shear of the concrete. But still now cracking mechanisms of the concrete due to shear isnot fully identified(Saravanakumar & Govindaraj, 2016) Meanwhile in a flexural member longitudinal strain is much smaller compared to the diagonal strain; that is why the shear cracks width iswider compared to flexural cracks (Adebar, P. & Leeuwen, J. V., 1999)(Adebar, 2001). Diagonal cracks generated besides flexural zone in RC beam are the indication shear failure. The wider crack pattern is the differentiating point between shear cracks and flexural cracks and these cracks happened in the shear zone closer to the supports because the shear force value is much higher near to the supports. The development of these shear cracks is so rapid and propagate without notice and causes sudden failure of the members. Shear reinforcement can lower this unexpected catastrophe and can also enhance the member ductility(Moayyad & M., 2013). Before the occurrence of diagonal crack, concrete was supposed to resist all the total shear alone. Redistribution of stress and debonding both occur in concrete and shear steel after the diagonal crack formation.(Theodor, 1992)( Michael & Daniel, 1999)(Young-soo, et al., 1996). In RC beams the diagonal width of the cracks was influenced by stirrup ratio and bonding between concrete and stirrups (Witchukreangkrai, et al., 2004)(Witchukreangkrai, et al., 2006). It was observed that the bonding between stirrups and concrete was increased significantly by decreasing stirrups spacing. Vertical shear reinforced beams have greater shear cracks width than inclined shear reinforced beams (Zakaria, et al., 2009)(Zakaria, et al., 2011)(Hassan, et al., 1985). Major shear crack load is caused by aggregate interlocking force so for resisting these shear forces the RC structure must have minimum shear reinforcement. (Songkram 2003) (Sato, et al., 2004). Inclined stirrups provided the most effective solution over conventional beams having high shear at the distributed areas(Saravanakumar & Govindaraj, 2016)(Suhaim, 2015)(Colajanni, et al., n.d.).Inclined stirrups effectively enhanced the shear capacity of RC beam rather than loop stirrup beam(Zamri, et al., 2018).

This paper focused on developing a verification model under two material characteristics (elastic and plastic) and verified with the standard theoretical procedure. FEM software (ABAQUS) is used to define the beam model and for their parametric studies further. Two simply supported RC beam is built up as a model in the platform. The beam models differ in the respect of steel ratio, and the placement of stirrups (45 degrees inclined and vertical loop) in the beam. The Model's capacity is investigated by varying the orientation of stirrups (inclined, loop-stirrup) and investigate whether any improvement in shear capacity, stress distribution, load capacity, and reduction in displacement can be achieved considering both geometric and materials nonlinearities along with the whole model. The whole study is performed through finite element investigation so that the experimental procedure of expensive laboratory materials can be avoided for future study. Besides, it can be seen that from this parametric study of the FEA model of the particular beams in FEM software (ABAQUS), all sort of critical portion of the model is analyzed by the nodal system which allows a very magnified study in the beam to justify the behavior variant.

## 2.0 METHODOLOGY

In this research, a 3D finite model has been developed to analyze the performance of Inclined stirrups over conventional stirrups on RC beams.

### 2.1 Geometric Profile Of The Model

Total 2 beams had been analyzed. All the beams had the same dimensions of (150x300x1960) mm. Longitudinal and transverse profiles of the beams are shown in Figure 1 and Figure 2. Two 12 mm and two 8 mm diameter bars are used as longitudinal bars for modeling the beam. For loop stirrup beam designated as LSB, 8mm diameter bars are used as stirrups andplaced perpendicularly to the bottom bars witha spacing of 100 mm center to center. For inclined Stirrup beam designated as ISB,the same size bars were used for modeling the stirrups and placed them making an angle of $45^0$ with the bottom reinforcementwhich is showed in Figure 3.

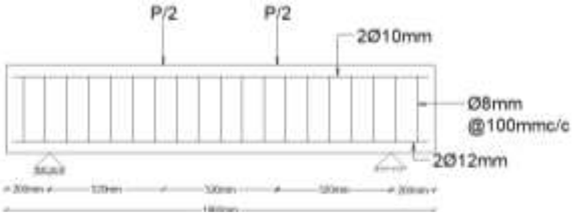


**Figure 1**: Longitudinal Profile of the loop stirrup beam (LSB).

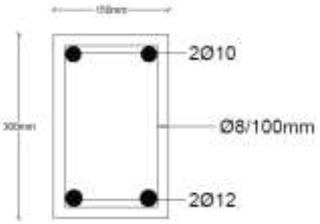


**Figure 2:** Transverse Profile of the loop stirrup beam (LSB).

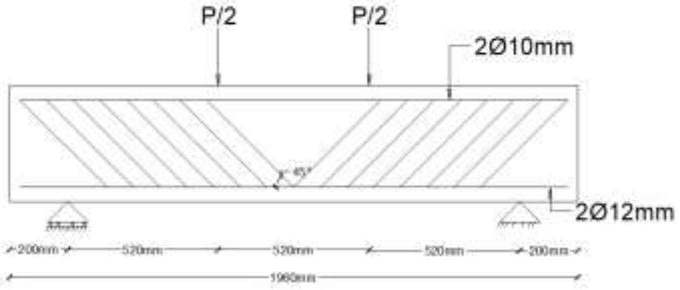


**Figure 3:** Longitudinal Profile of the inclined stirrup beam (ISB).

### 2.2 Material Property Of Concrete Used In Numerical Analysis

It was assumed that the concrete is homogeneous and initially isotropic. Concrete crushes under compression and cracks under tension. These are the two chief failure mechanisms of concrete. The Yield Stress-Cracking strain correlation in compression for concrete used in ABAQUS is characterized in Figure 4. Poisson's ratio of 0.20 was used for concrete. For tension, the stress-strain property trails a linear elastic connection till the value of the failure stress is reached. Material property data of concrete used in Table 1. Stress-Strain properties of concrete in tension used in ABAQUS as shown in Figure 5 (Hafezolghorani, et al., 2017). The failure stress relates to the onset of micro-cracking in the concrete material. Concrete damage plasticity (CDP) data shown in Table 2 are used in ABAQUS modeling to capture the cracking patterns of the concrete under compression and tension.

**Table 1:** Material property of concrete used in numerical analysis

| | |
|---|---|
| Modulus Of elasticity, E (MPa) | 26000 |
| Poisson's ratio | 0.20 |
| Compressive strength, $f'_c$ (MPa) | 30 |
| Tensile strength($f_t$), MPa | 1.81 |

**Table 2**: Concrete damage plasticity data used in numerical analysis

| | |
|---|---|
| DilationAngle | 31 |
| Eccentricity | 0.1 |
| fb0/fc0 | 1.16 |
| k | 0.67 |
| Viscosity parameter | 0.00001 |

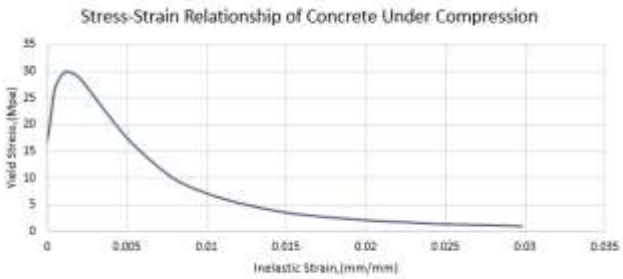


**Figure 4:** Stress-strain relationship for concrete under uniaxial compression used in FE analysis calculated as per Carreira & Chu ( Carreira & Chu 1984).

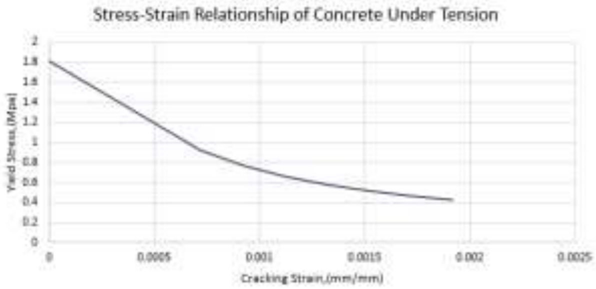


**Figure 5**: Stress-strain relationship for concrete under uniaxial compression used in FE analysis calculated as per Carreira & Chu ( Carreira & Chu 1984).

### 2.3 Material Property Of Steel Used In Numerical Analysis

Steel is considered to be a perfectly elastic-plastic material that is similar in both tension and compression behavior. Poisson's ratio was taken as 0.3 as a property of the steel reinforcement in this study. Properties of steel are shown in Table 3.

**Table 3**: Properties of reinforcing steel bars and stirrups.

| | |
|---|---|
| Elastic modulus E (GPa) | 209 |
| Nominal Diameter (mm) | 12 and 10 |
| Yield Stress (N/mm2) | 507 |
| Poisson's ratio | 0.3 |
| Density (tonne/mm$^3$) | 7.8e-8 |

### 2.4 Model Development with ABAQUS

For Concrete beam modeling a 3D linear brick element(C3D8) with reduced integration and hourglass control was used. For general-purpose linear brick elements,the C3D8 element is used which has 2x2x2 integration points. The node numbering follows the way of Figure 6 and the integration points are numbered according to Figure 7. The solid element (C3D8) has eight nodes. All of the nodes have three degrees of freedom which is translations in the nodal x, y, and z directions(Mohamed, et al., 2019). Cracking in three orthogonal directions, Plastic deformation and crushing are the significant property of the element.(Systèmes, 2013).

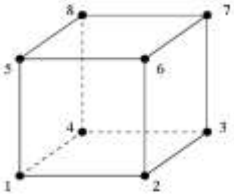


**Figure 6:** Nodes of the brick element.

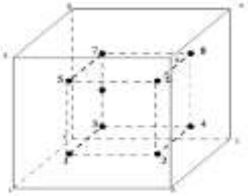


**Figure 7:** 2x2x2 integration point scheme in hexahedralelements.

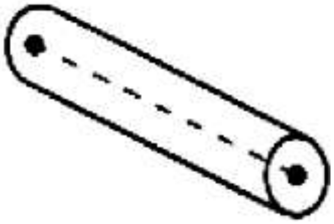


**Figure 8**: T3D2 truss element.

The embedded steel bars were modeled using linear two-node truss elements(T3D2) showed in Figure 8. Each of the nodes has three degrees of freedom. Truss elements (T3D2)are capable of modeling slender, line-like structures that support loading only along the axis or the centerline of the element. No moments or forces perpendicular to the centerline are supported on this element. Necessary partitions are made on the 3D beam (showed in Figure 9) to assign load application and meshing. Embedded region constraint is used to make the bonding between the beam and reinforcement. 3D model profile of Loop stirrup and inclined stirrup are shown in Figure 10 and Figure 11.

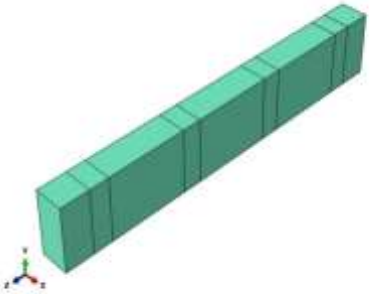


**Figure 9:** 3D-Solid beam developed for FE analysis.

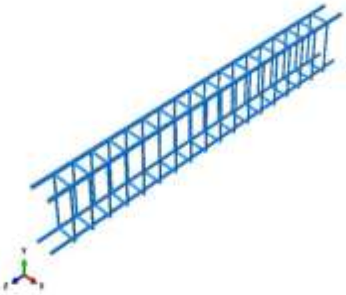


**Figure 10:** Reinforcement and Loop Stirrups 3D modeling.

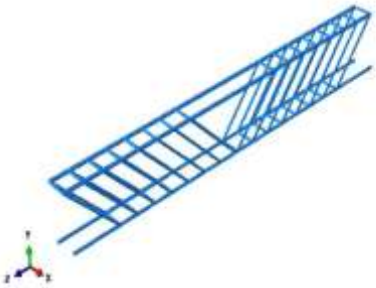


**Figure 11**: Reinforcement and Inclined Stirrups 3D modeling.

### 2.5 Mesh Sensitivity And Model Validation

For generating nodes and elements meshing is required. Mesh is created by nodes defining and used them to define the elements. Meshing is important for accruing the most logical results from a finite element analysis. After assembling and assigning the properties, a mesh sensitivity test (showed in Figure 12) had been done for finding the optimum mesh. It was seen that 25mm mesh showed the best result compared to experimental work done by(Obaidat, et al., 2010). Validation of the finite element model is an important criterion to make to model more acceptable. ABAQUS generated mashed beam are showed in Figure 13.

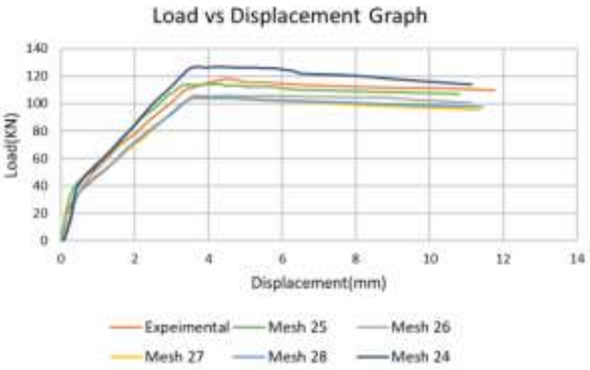


**Figure 12:** Mesh sensitivity test results of the numerical models.

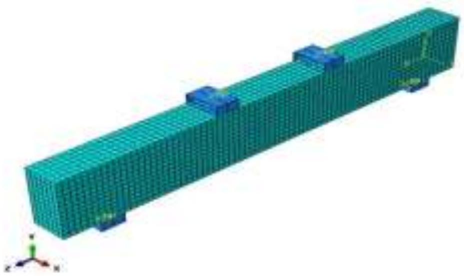


**Figure 13**: Final meshed condition of the beam.

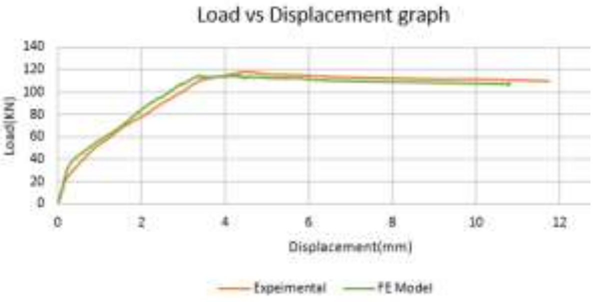


**Figure 14**: load-displacement graph of FE model and experiment work.

From the load vs Displacement graph shown in Figure. 14, it was seen that the behavior FE model is approximately identical to that of the experimental behavior. Which indicates the accuracy of the FEmodel.

## 3.0 RESULT AND DISCUSSION

### 3.1 Load-Displacement Behavior Of The Beam

Figure 15 illustrates the comparison between the loop and inclined stirrup beams in terms of the load-displacement relationship. From the figure, it is seen that the LSB showed a linear displacement till the onset of flexural cracks. The nonlinearity of the load-deflection curve indicates the initiation of the flexural cracks. During the post-cracking stage, the displacement amplified at a bigger ratio till the yielding of tension reinforcement took place. The maximum load carried by the LSB was 114.24 KN and the ISB was 187.24 KN. Displacement obtained for the maximum load of the LSB was 4.21 mm and for the ISB was 2.38 mm. The difference in deflection values for both beams may be due to the stiffness of the beam. Generally, stiffness is an initial slope of the load-deflection curve. All beams were displayed similar load-displacement performance up to the elastic limit. Then, for the effect of Stirrups, the stiffness of the beams amplified and it showed changed behavior. The behavior of RC beam with inclined stirrups was found more ductile than RC beam with loop stirrups. Thus, the RC beam with inclined stirrups had experienced smaller deflection compared with the RC beams with loop shear reinforcement.

**Table 4:** Comparison of ultimate load and displacement of the loop and inclined stirrup beam.

| Specimen | Ultimate load (KN) | Load capacity increased (%) | Displacement at ultimate load (mm) | Displacement decrease % |
|---|---|---|---|---|
| Loop stirrup beam | 114.24 | | 4.21 | |
| Inclined stirrup beam | 187.24 | 63.90 | 2.38 | 43.47 |

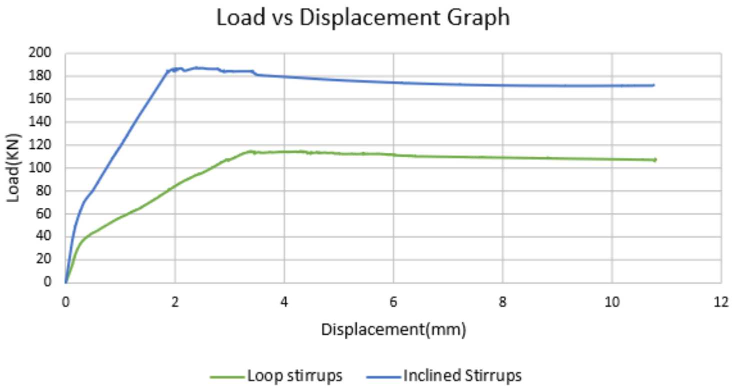


**Figure 15:** Load-deflection behavior of Loop and Inclined stirrup beams.

### 3.2 Ultimate Shear Force Capacities of Beam

Table 5 indicates that the inclined shear stirrups improve the load-carrying ability over conventional stirrups the beam. it reveals the 63.90% higher ultimate strength than the loop shear stirrups beam. Theshear force of the beams was estimated as per ACI 318-14 to compare with FE results.

The shear, force of the concrete beam was calculated through this equation,

$V$c =0.17λ√fc'bwd…………………………..(3.1)(ACI 318M-14, 2014)

Where Vc = Shear strength of concrete without reinforcement,
f’c= Ultimate compressive strength of the concrete
λ=1.0 normal weight concrete
bw and d are the section dimensions.

Ultimate shear strength of the concrete including shear reinforcement was calculated by,

$Vu = \frac{\emptyset Avfyd}{s} + \emptyset Vc$…………………(3.2)(ACI 318M-14, 2014)

Where Vu= Ultimate shear strength
Av= area of shear reinforcement
fy= yield stress of the shear reinforcement.
S= Spicing between two shear reinforcement.

And Ultimate shear strength of the concrete including inclined shear reinforcement was calculated by,

$Vu = \frac{\emptyset Avfy(Sin\theta + cos\theta)d}{s} + \emptyset Vc$………………(3.3)(ACI 318M-14, 2014)

Where θ is angle between horizontal reinforcement and shear reinforcement.

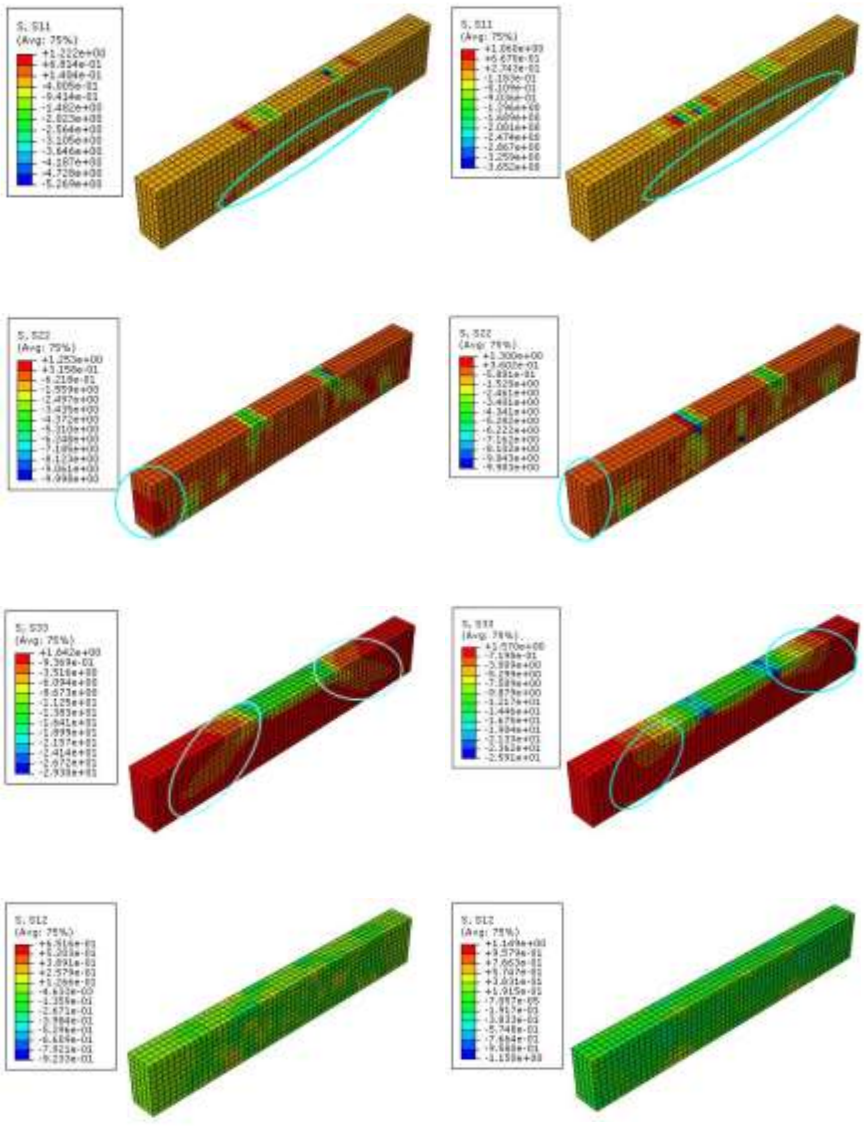
**Table 5**: Comparison between analytical and FE results.

| Specimen | FE Shear Result | Analytical Shear Result | $\frac{FE(cal)}{Analytical(cal)}$ |
|---|---|---|---|
| Loop shear rein. Beam (LSB) | 114.24 | 130.47 | 0.88 |
| Inclined shear rein. Beam (ISB) | 187.24 | 178.84 | 1.04 |

### 3.3 Shear Stress Capacities of Beam

Stresses generated on the beams can be also found from ABAQUS output results. In ABAQUS X, Y, Z directions are denoted by 1,2,3 accordingly. So S11, S22, S33indicates principalstress in X, Y, Z direction and S12 indicates shear stress of the beam.

Loop Stirrup Beam (LSB) Inclined Stirrup Beam (ISB) Description



The principal stress in the X direction is equally distributed in the lower portion of the model “ISB”. Whereas, in model “LSB” there were some nodes that are experiencing much more stress than the neighboring nodes.

In model “LSB” a certain amount of principal stress in the Y direction occurs in the mid-portion at the end of the beam. But this compressive stress was absent in model “ISB”.

Other than producing much less principal stress in the Z direction, model “ISB” helped to distribute stress more accurately than that of model “LSB”.

Having the same area, Model “ISB” resisted more shear stress of about 1.152 MPa than of Model “LSB” having the value of about 0.652 MPa, which concluded that Model “ISB” carries more Shear force than Model “LSB” before failing.

**Figure 19** Shear stress distribution

## 4.0 CRACK PATTENS

Once the principal tensile stress goes beyond the ultimate tensile strength of the concrete contour block changes its color from blue to red and indicates the sign of cracking or crushing. The cracking sign propagates perpendicularly in zero shear stress zone as shown in Figure 20 and Figure 21. Diagonal cracking is concentrated in the shear zone as revealed in Figure 20 and Figure 21

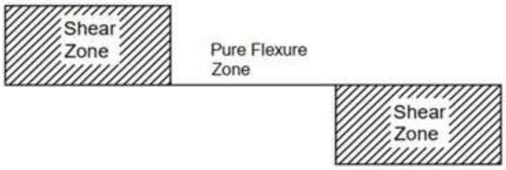


**Figure 20** Shear force diagram of the beams for 2-point loading.

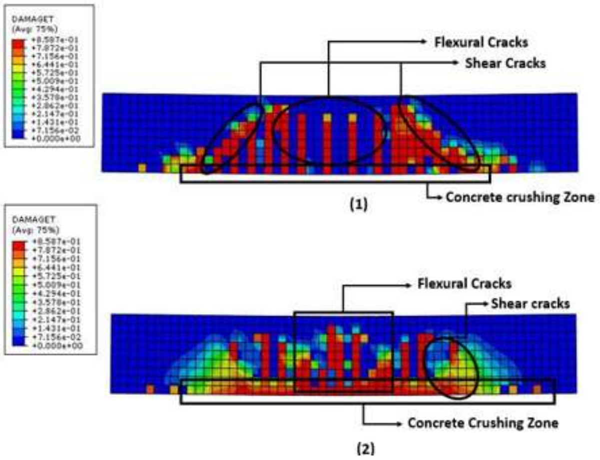


**Figure 21** (1) (2) Crack propagation simulation of LSB and ISB

## 5.0 CONCLUSION

The following conclusion can be made from the above study:

- From the analysis conducted above it is seen that the Inclined stirrups setup increased the shear capacities of the beam up to 63.90 % compared to the loop stirrups beam.
- The beam with inclined stirrups shows less displacement rather than the beam with loop stirrups. Displacement reduced about 43.47% on inclined stirrups beam compared to loop stirrups beam due to increase of stiffness.
- Shear stress resistance capacities increased significantly on inclined stirrups beam rather than loop stirrups beam.
- The predicted theoretical results justify the numerical results.
- From the Crack pattern analysis, it is seen that the inclined stirrup crushed the concrete at the bottom compared to the loop stirrup beam which increases the load-carrying capacities of the inclined stirrup beam.

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