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Investigation on Static Behavior of Multi-Stud Shear Connectors for Composite Bridges

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Abstract: **Steel-Concrete composite beams have been used for a considerable time in bridge and building construction. Shear connector is important for steel concrete composite structures. It is used as a shear resistance in the steel concrete interface. This study presents an investigation on static behavior of multi-stud shear connectors in composite beams, suitable for transferring shear force in composite structures by analytical way. The composite section have been modeled in ANSYS with the help of finite element modeling and analyzed, the results have been documented for comparison. Once the composite sections have been casted, it is made to undergo Standard Push out tests. The test is been carried out to analyze various parameters like load-slip behavior, shear resistance, bearing capacity, ductility and also the failure modes of multi-stud shear connectors used will be detailed. The effective and economical ways of using the stud shear connectors in Steel-Concrete composite sections will be discussed. Finally the result shows that the ultimate strength of multi-stud is about 18% larger than single stud. The slip of single stud specimen is about 25% larger than multi-stud specimens. These results may be useful in the design of steel-concrete composite bridges. Furthermore the comparisons of the results of various arrangements of multi-stud shear connectors used will be documented.**

Keywords: **Steel-Concrete, composite structures, static behavior, multi-stud, single stud, ANSYS, finite element, ultimate strength, slip.**

I. INTRODUCTION

The component that assures the shear transfer between the steel profile and the concrete slab in steel-concrete composite construction is the shear connector. Composite sections will get split or damaged due to shear forces and loading conditions if they are not provided with proper shear connections. If there were no connection, a beam and slab would bend easily. The presence of a shear connection prevents the slip between the two components and achieves a much stiffer and stronger beam. The transmission of shear forces and the intensity of stress in the steel beam, the weld that connects the shear connector to the flange of the beam, material of connector itself and the surrounding concrete of the slab, which all determines the strength, are highly dependent on the form of the shear connector. There are very different forms of means for composition that are used in practice. Steel-Concrete composite beams have been used for a considerable time in bridge and building construction. In this type of beams, concrete is assumed to take most of the entire compression load while steel takes all the tension. The two materials in the composite structure need to be firmly held together to make the structure rigid and strong. In steel and concrete composite beams the two materials are held together by means of headed shear connectors. Composite action can be obtained through mechanical connection commonly provided by headed shear studs or some other shear connectors.

II. ANALYTICAL INVESTIGATION

A. General:

Analytical work can be carried out using ANSYS, a finite element analysis (FEA) software package. Finite element analysis is a numerical method of deconstructing a complex system into very small pieces called elements. The software implements equations that govern the behavior of these elements and solve them all; creating a comprehensive explanation of how the system acts as a whole. These results then can be presented in tabulated or graphical forms. This type of analysis is typically used for the design and optimization of a system far too complex to analyse by hand. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations. Finite element analysis is a numerical method for solving problems of engineering and mathematical physics and also useful for problems with complicated geometries, loadings and material properties where analytical solution cannot be obtained. In order to obtain solutions for problems with lot more complex and to obtain higher order accuracy solution we need finite element method to solve and also to understand the physical behavior of complex object such as strength, heat transfer, capability, fluid flow, etc.., finite element method is needed. The finite element method is computational technique used to obtain approximate solutions of boundary value problems in engineering, Boundary value problems are also called field problems. The field is the domain of interest and most often represent a physical structure

B. Analytical Study On Composite Member:

A composite member with steel I section ISMB 250 as beam and concrete slab on both flanges of steel I section is connected with the help of various arrangements of shear stud connectors and the behavior of shear studs with respect to loading is studied with the help of ANSYS software.

C. Structural Dimensions:

Table I: DETAILS OF SPECIMEN TO BE MODELLED IN ANSYS

Width of both top and bottom flange of steel I section	125mm
Depth of steel I section	250mm
Thickness of top and bottom flange of steel I section	12.5mm
Thickness of web of steel I section	6.9mm
Size of concrete slab	300x150x150mm
Grade of concrete slab	M30
Grade of steel	Fe415

D. Dimension Of Shear Connectors:

The most widely used shear connector in bridges is stud, bolt...etc. Standard sizes for shear studs, which are readily available from suppliers and typically used in steel composite bridge decks, are of heights (in mm) 125, 150, 175, 200, 250 and diameters 16, 19, 22, 25(in mm). Shear studs are generally attached to the top flanges of girders using a welding gun. The stud is held in the welding gun and an arc is struck between stud and the flange plate. Arc melts a portion of both the stud and the plate in a set time. In this study three types of arrangement of shear studs are used they are single shear stud, square arrangement of shear studs with 3d spacing (48mm) and linear arrangement of shear studs with 2.5d spacing (40mm) in which the length and diameter of connectors are kept common as 100mm and 16mm for comparing the behavior of various arrangements of shear studs.

E. Spacing Of Stud Connectors:

As per BS EN 1994-2 Clause 6.6.5.7 gives minimum dimensions for headed shear studs. The minimum spacing in the direction of the shear force is 5d and the minimum spacing in the direction transverse to the shear force in ‘solid slabs’ is 2.5d. If the distance between headed studs are smaller than the prescribed minimum value of 5d, full shear resistance can be achieved by adopting the headed stud height in excess of 4d.

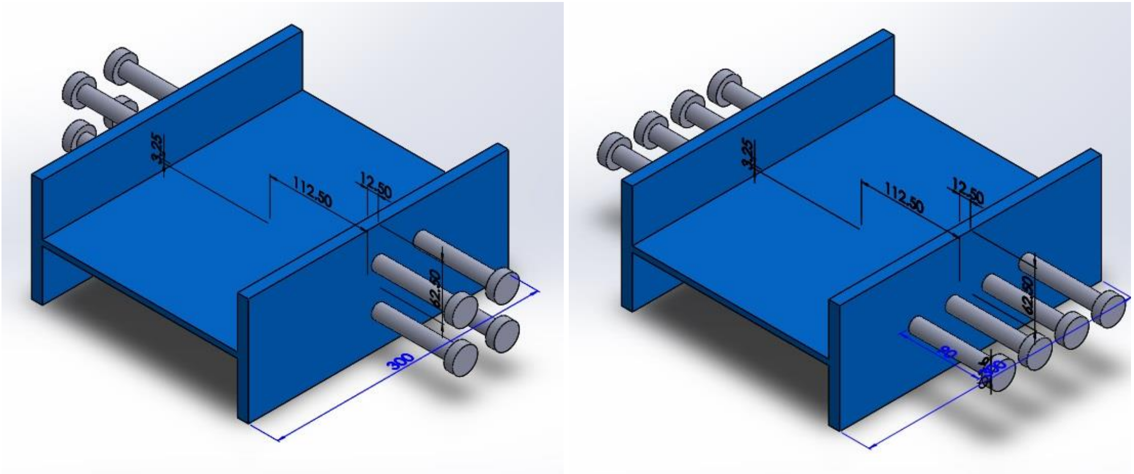

Figure 1: Arrangements of Studs on Flange portion Of I-Beam Using Solid-Works

F. Material Specification:

Table II: MATERIAL SPECIFICATION

S.NO	*MATERIAL TYPE*	*YOUNG'S MODULUS(E) (Gpa)*	*POISSON'S RATIO(μ)*	*DENSITY(ρ) (Kg/m³)*
1	Steel	200	0.3	7850
2	Concrete	30	0.18	2500
3	Mild steel	210	0.3	7850

G. Element Type:

SOLID 65 elements were used to model the concrete. ***BEAM 188 elements*** was used in reinforcements for RC Block. ***SOLID 186 elements*** were used for steel I-beam.

H. Modeling And Meshing In Ansys:

Three type of arrangement of shear studs are to be considered for the study. They are connected with steel I section and concrete slab to form a composite member. The composite member is created in SOLID WORKS and then imported to ANSYS.

III. LOADING AND BOUNDARY CONDITIONS

Before applying load on the composite member boundary conditions are need to be provided, the bottom end of the both concrete slab attached to the flange of the steel I beam are fixed. Then the load is applied on the face of web.

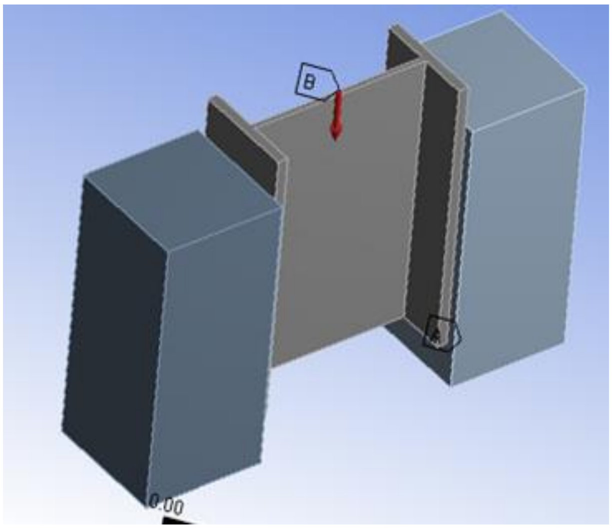

Figure 2: Loading and Boundary Conditions

IV. BEHAVIOR OF SINGLE STUD SHEAR CONNECTOR

The figure-3 shows the total deformation of single stud Push-Out Model in ANSYS. Load is applied at central portion of the web. Deformation of push-out model can be identified by contours as shown in figure. Red portion on the web indicates the maximum deformation at centre and gradually it goes down towards the depth of the I-section. Due to transmission of load from I-beam to concrete through stud connectors, concrete portion attached to the flange part of I-beam gets damaged.

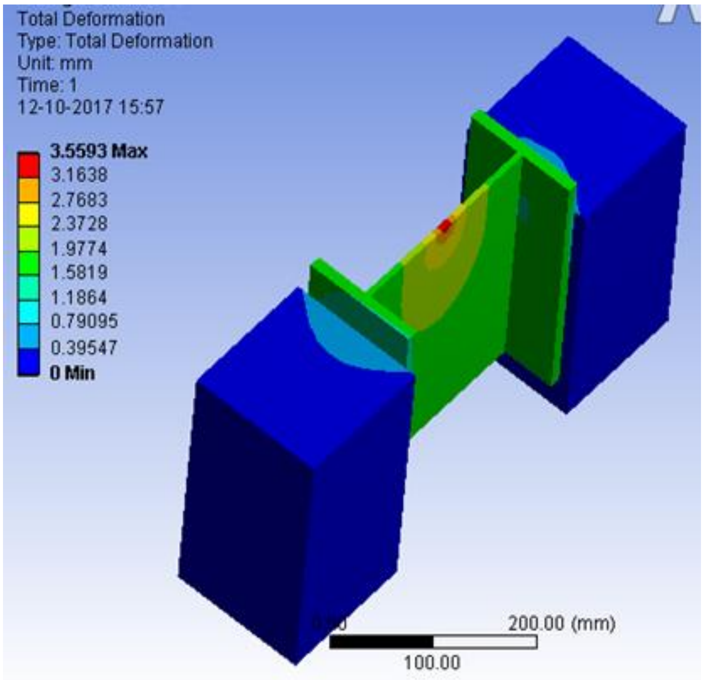

Figure 3: Total Deformation of Single Stud (Push-Out Model)

A. Stress And Strain Distribution:

The figure-4 shows the Equivalent Von-mises Stress and Strain distribution. The stress and strain seems to be maximum (positive) at the point of application of load and gradually goes down towards the direction of load. It is clear that if internal resistance is more there will be minimum (negative) stress in the member.

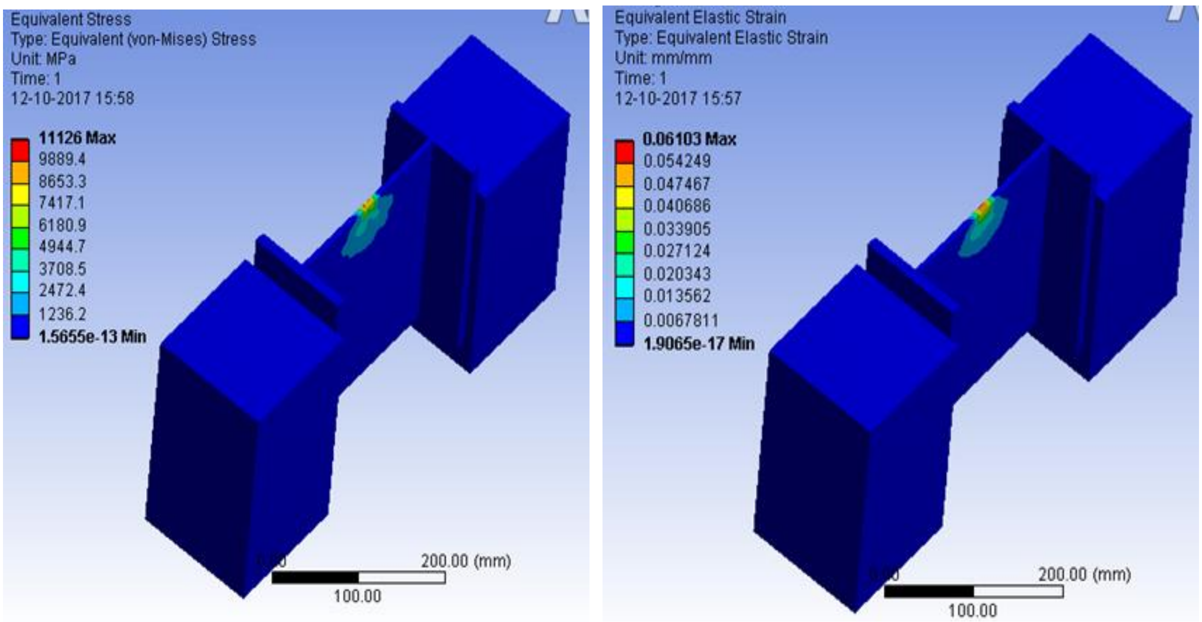

Figure 4: Stress And Strain Distribution of Single Stud (Push-Out Model)

B. Deformation Of Single Stud Shear Connector:

Figure 5 and 6 represents the behavior of single stud shear connector in composite member with respect to loading. The maximum stud bending deformation and shear stress is at the stud root and it is gradually decreased towards the head portion of the stud. If higher the resistance, then lower will be the stress (inversely proportional).

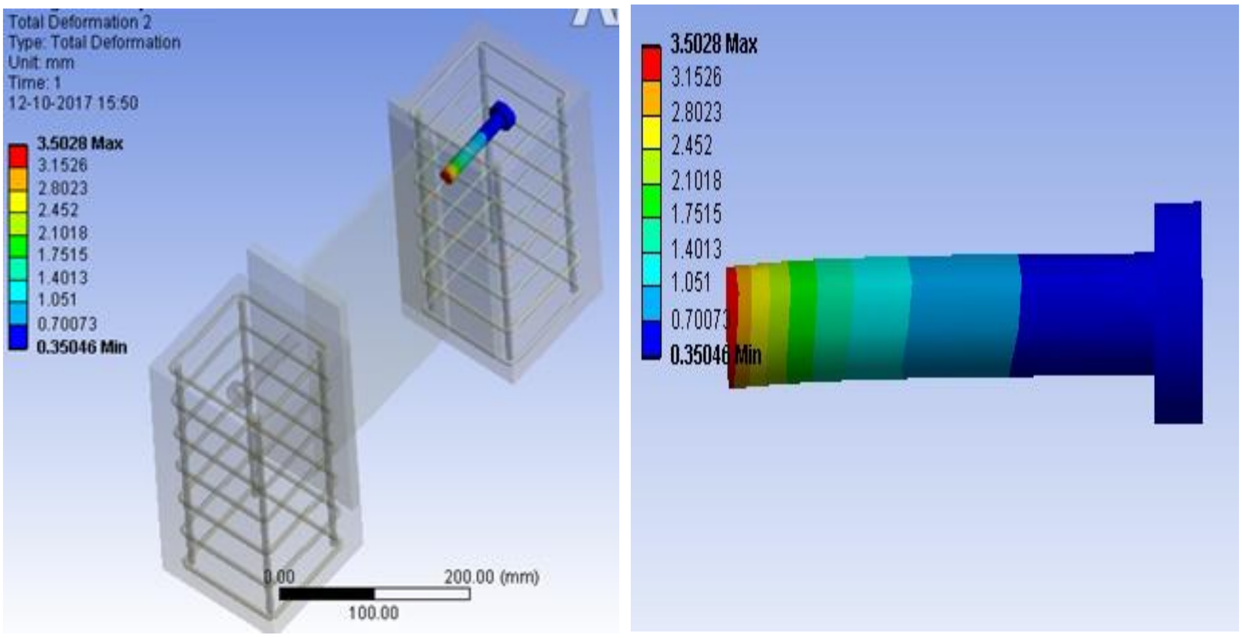

Figure 5: Deformation of Single Stud Shear Connector

C. Shear Stress Distribution Of Single Stud Shear Connector:

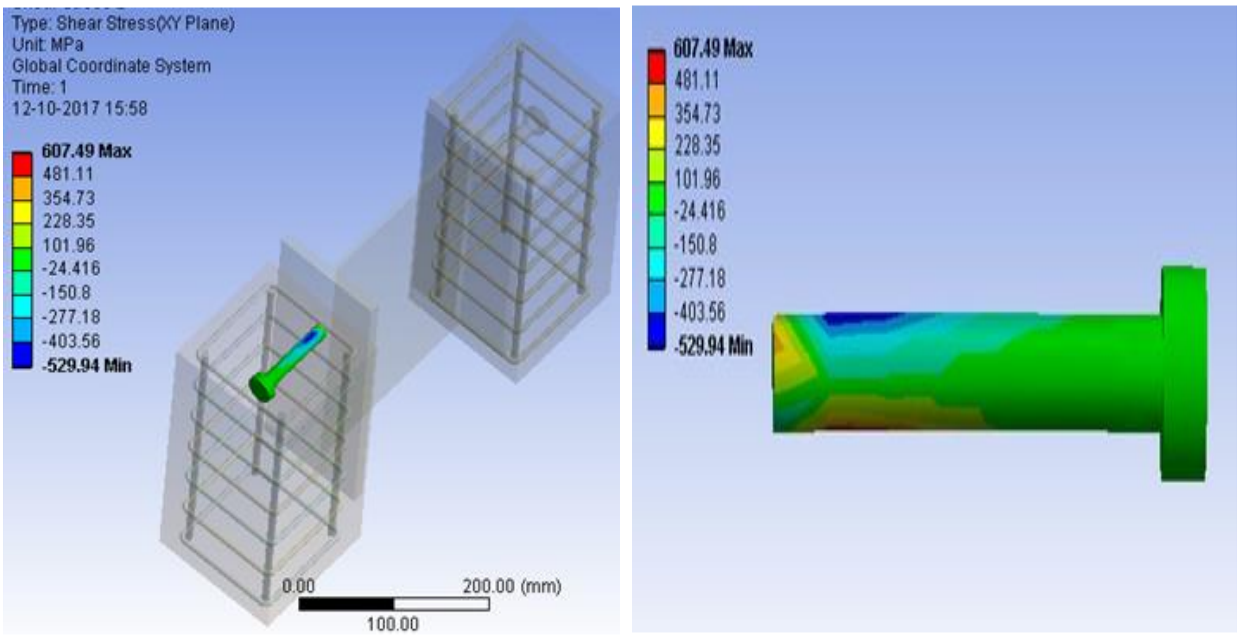

Figure 6: Shear Stress Distribution of Single Stud Shear Connector

V. BEHAVIOR OF SQUARE ARRANGEMENT OF STUD SHEAR CONNECTORS

The figure-7 shows the total deformation of square arrangement of studs (Push-Out Model) in ANSYS. Load is applied at central portion of the web. Deformation of push-out model can be identified by contours as shown in figure. Red portion on the web indicates the maximum deformation at centre and gradually it goes down towards the depth of the I-section. The total deformation seems to be lesser compared to single stud push-out model. Due to transmission of load from I-beam to concrete through stud connectors, concrete portion attached to the flange part of I-beam gets damaged.

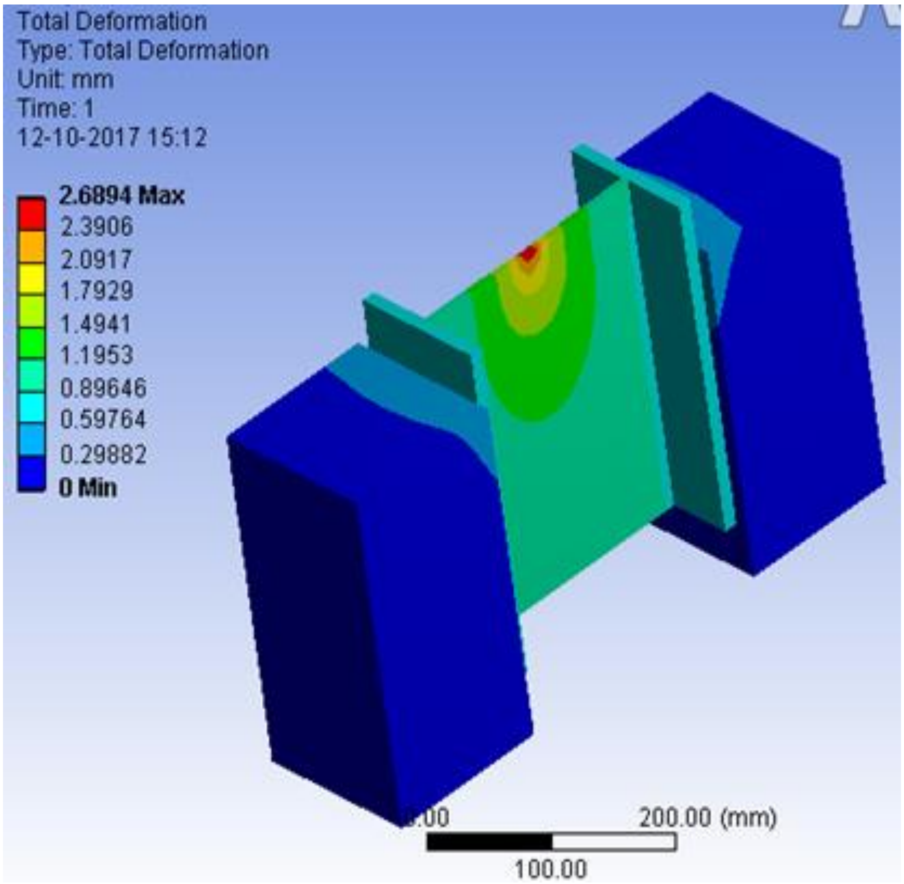

Figure 7: Total Deformation of Square Arrangement of Studs (Push-Out Model)

A. Stress And Strain Distribution

The figure-8 shows the Equivalent Von-mises Stress and Strain distribution. The stress and strain seems to be maximum (positive) at the point of application of load and gradually goes down towards the direction of load. It is clear that if internal resistance is more there will be minimum (negative) stress in the member.

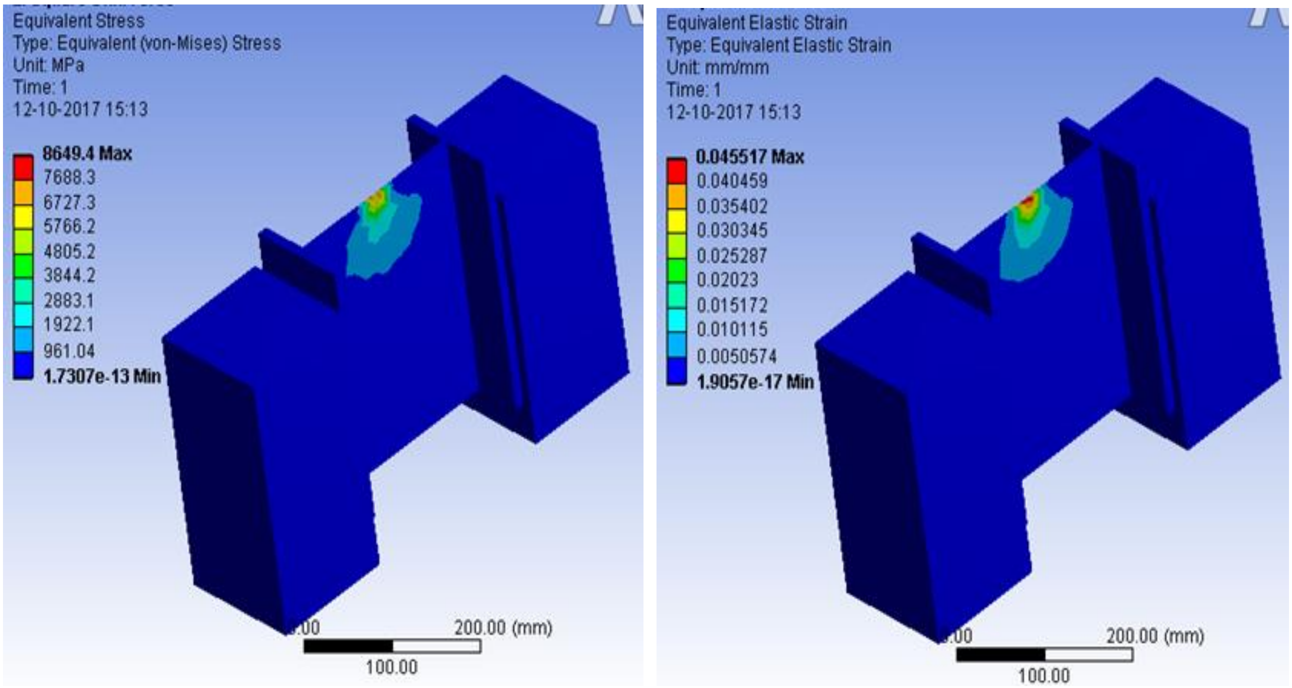

Figure 8: Stress And Strain Distribution of Square Arrangement of Studs (Push-Out Model)

B. Deformation Of Square Arrangement Of Shear Studs:

Figure 9 and 10 represents the behavior of square arrangement of stud shear connectors in composite member with respect to loading. Stud bending deformation and shear stress values are seems to be high at the stud root and it is gradually decreased towards the head portion of the stud. Deformation and shear stress values are minimum compared to single stud arrangement.

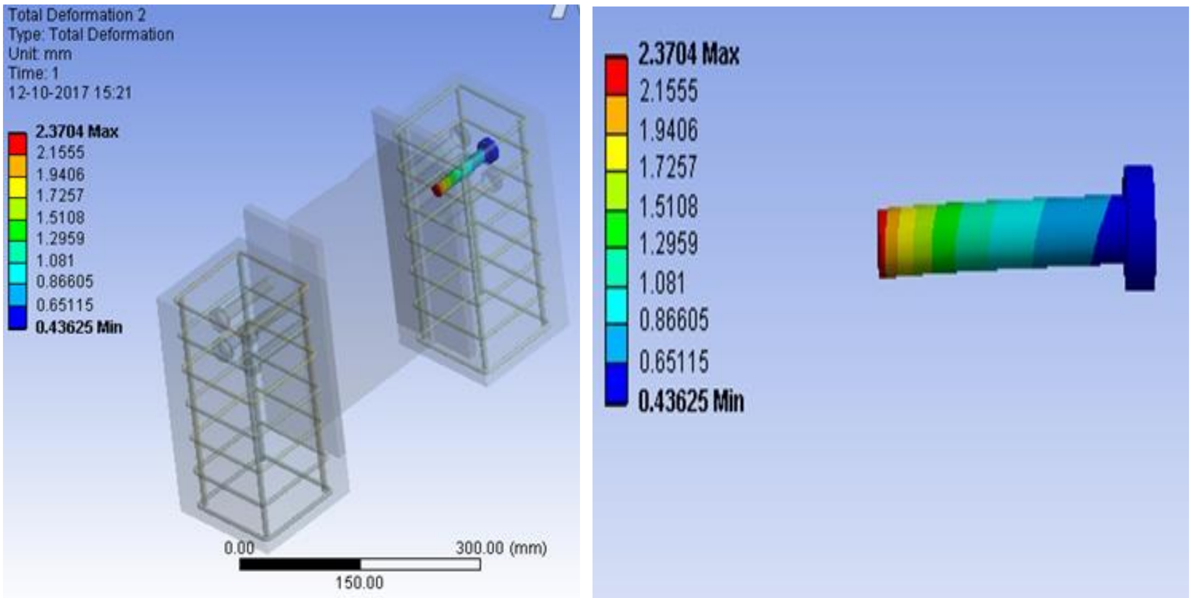

Figure 9: Deformation of Square Arrangement of Shear Studs

C. Shear Stress Distribution Of Square Arrangement Of Shear Studs:

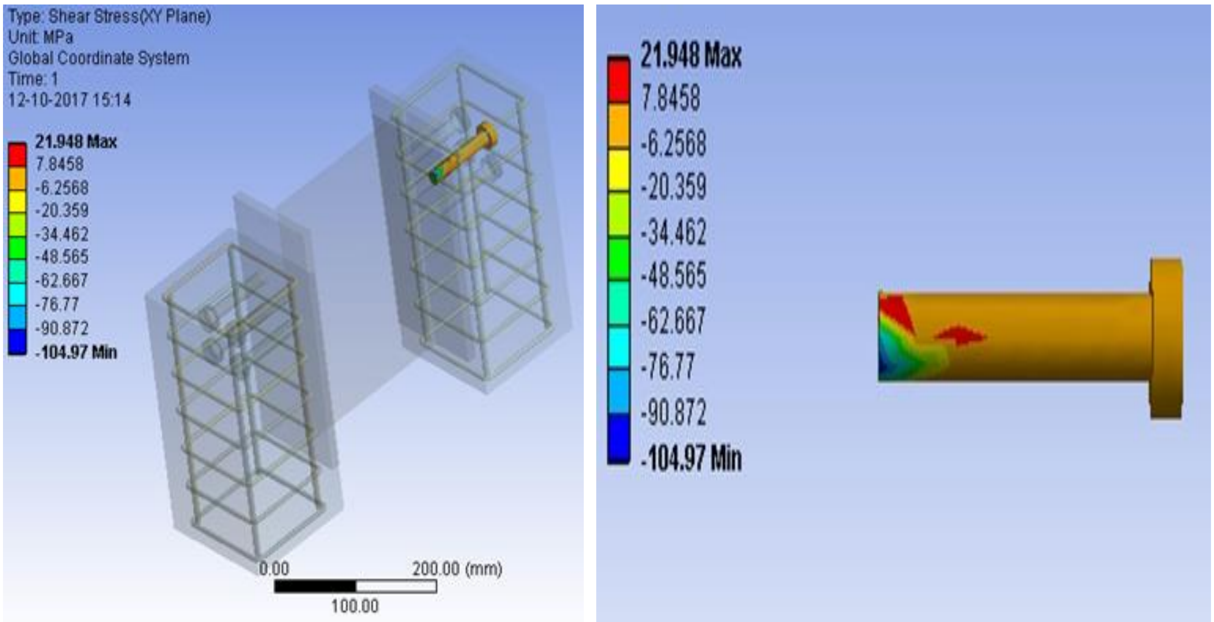

Figure 10: Shear Stress Distribution of Square Arrangement of Shear Studs

VI. BEHAVIOR OF LINEAR ARRANGEMENT OF STUD SHEAR CONNECTORS

Figure-11 shows the total deformation of square arrangement of studs (Push-Out Model) in ANSYS. Load is applied at central portion of the web. Deformation of push-out model can be identified by contours as shown in figure. Red portion on the web indicates the maximum deformation at centre and gradually it goes down towards the depth of the I-section. The total deformation of linear arrangement of studs seems to be slightly lesser compared to square arrangement of studs due to influence of stud spacing.

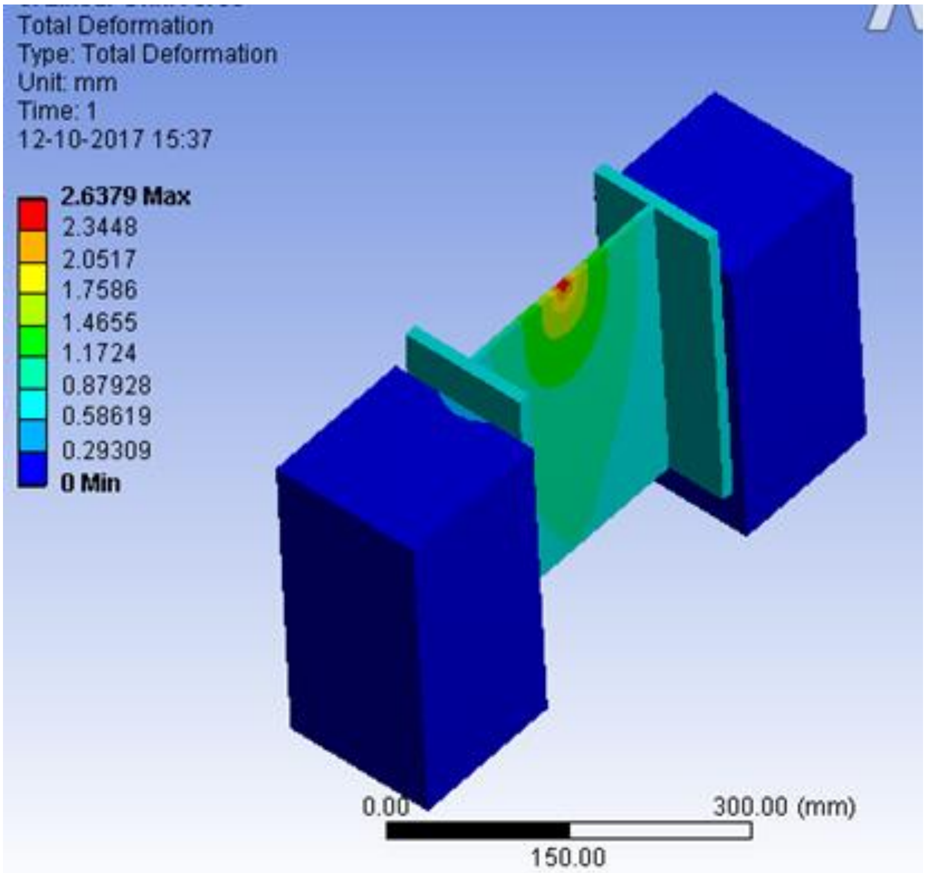

Figure 11: Total Deformation of Linear Arrangement of Studs (Push-Out Model)

A. Stress And Strain Distribution:

The figure-12 shows the Equivalent Von-mises Stress and Strain distribution. The stress and strain seems to be maximum (positive) at the point of application of load and gradually goes down towards the direction of load. It is clear that if internal resistance is more there will be minimum (negative) stress in the member.

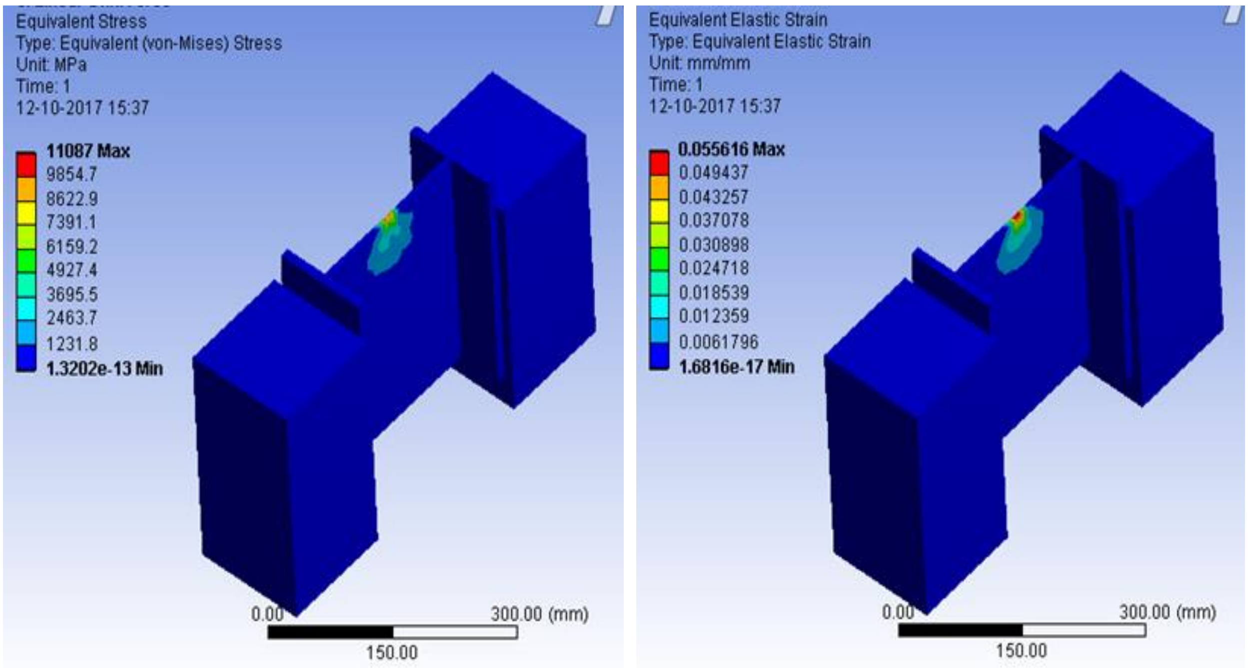

Figure 12: Stress And Strain Distribution of Square Arrangement of Studs (Push-Out Model)

B. Deformation Of Linear Arrangement Of Shear Studs:

Figure 13 and 14 represents the behavior of linear arrangement of stud shear connectors in composite member with respect to loading. The maximum stud bending deformation and shear stress is at the stud root and it is gradually decreased towards the head portion of the stud. Compare to single stud, here deformation and stress are minimum, it depends on number of studs and stud spacing used.

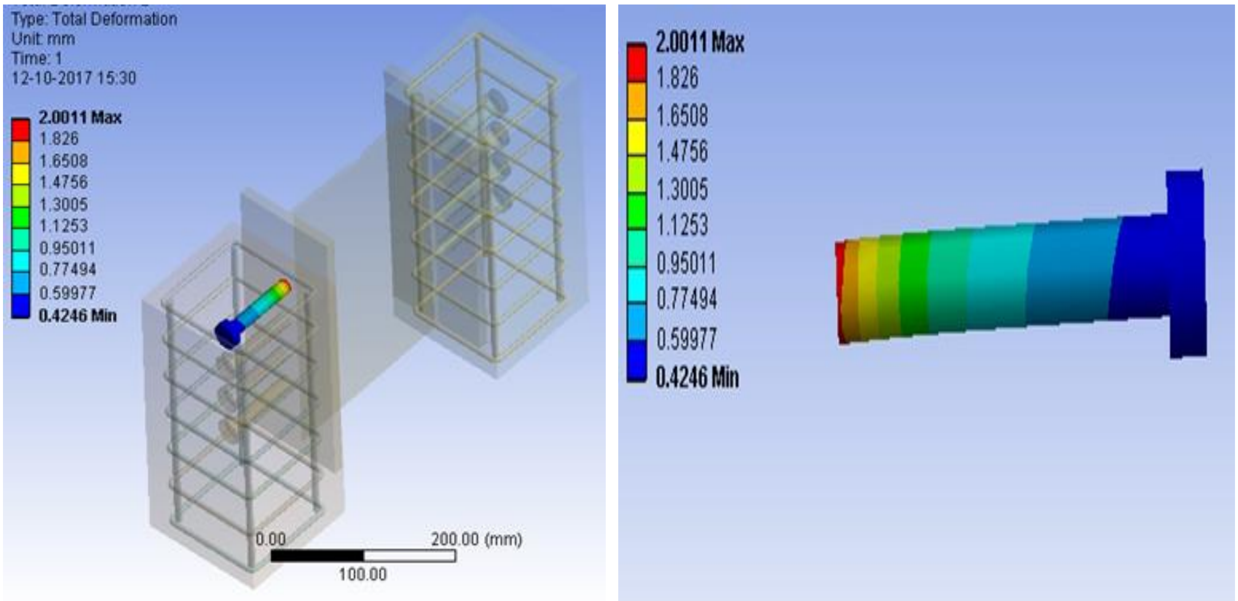

Figure 13: Deformation of Linear Arrangement of Shear Studs

C. Shear Stress Distribution Of Linear Arrangement Of Shear Studs:

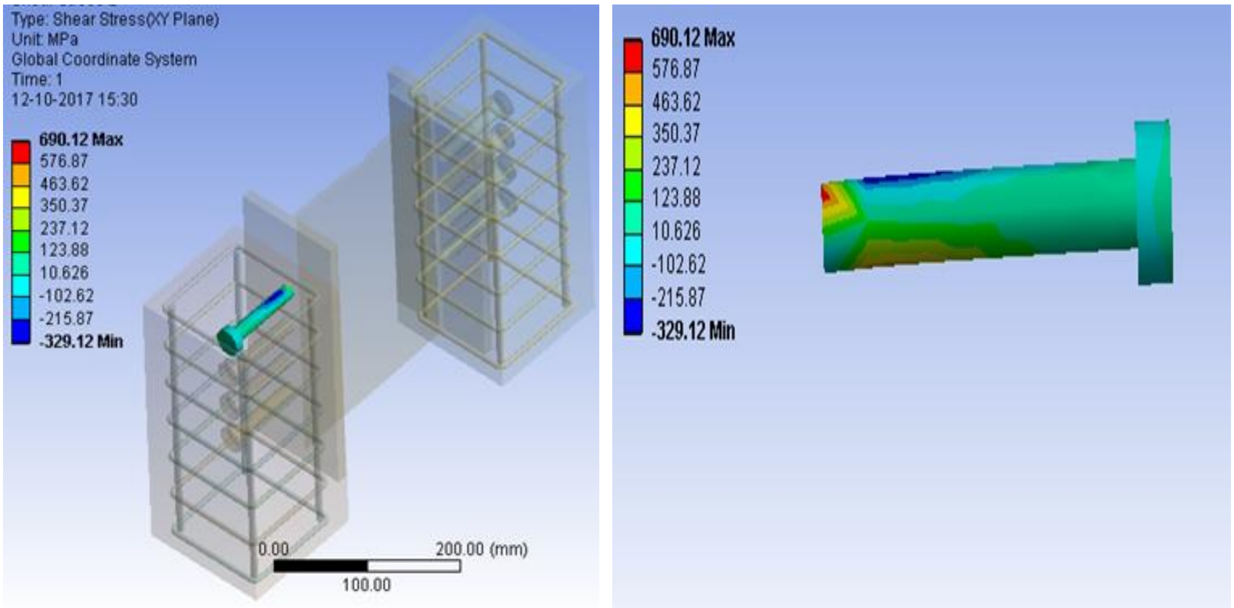

Figure 14: Shear Stress Distribution of Square Arrangement of Shear Studs

VII. RESULTS AND DISCUSSION

When comparing the analytical results of single stud and multi-stud shear connectors, multi-stud shear connectors gives better results. From the table III, it is clear that the multi-stud shear connectors have more load carrying capacity when compared to the single stud shear connectors. Among the two different arrangements of multi-stud shear connectors, linear arrangement of studs with 2.5d spacing have more load carrying capacity than square arrangement of studs with 3d spacing.

Table III. ANALYTICAL RESULTS OF SINGLE STUD AND MULTI-STUD SHEAR CONNECTORS

S.NO	STUD SHEAR CONNECTORS		MAXIMUM LOAD CARRYING CAPACITY IN KN	SLIP IN Mm
1	SINGLE STUD		344.68	3.56
2	MULITI-STUD	SQUARE ARRANGEMENT	420	2.68
		LINEAR ARRANGEMENT	425.38	2.63

The above table represents the results obtained by analyzing the composite member with single and multi-stud shear connectors. It is documented to compare with experimental results in future.

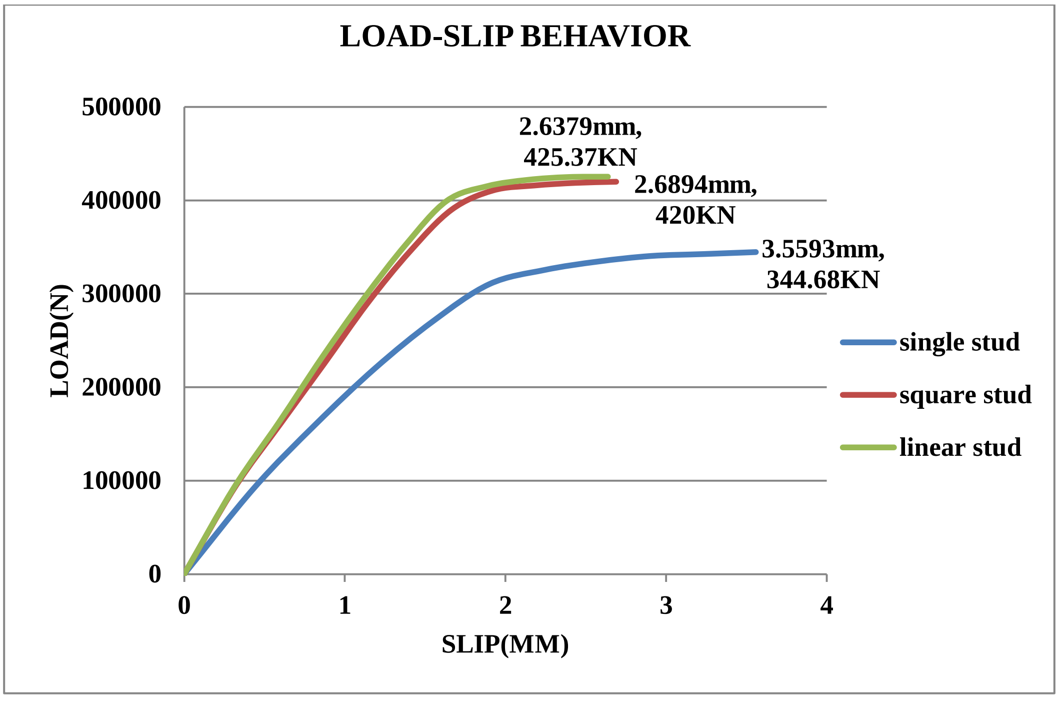

Figure 15: Comparison Chart of Analytical Results of Single Stud and Multi-Stud Shear Connectors

The above chart shows the comparison of load slip behavior, it represents how single and multi-stud shear connectors behave with respect to loading.

A. Load-Slip Curves And Stiffness:

As the load is applied on the push-out specimens, slip b/w the steel and concrete occur. The static behavior of stud shear connectors can be explained through load-slip curves. It consists of three different parts. First part is the elastic part in which it reaches almost 50% of the maximum load value. The slip is very small and the shows large shear stiffness. Second part is the plastic part in which the curves show a new branch with a softer slope with increasing load. The slip increases rapidly while load increases slowly and the stud shear stiffness reduces continuously. After the maximum load is reached, the specimens fail suddenly and the load-slip curves do not show an evident descending part.

B. Ductility:

As per BS EN 1994-2 that all headed studs ranging from 16mm to 25mm in diameter, with the height in excess of 4d, are classified as ductile headed studs. As given in the paper, a group of four headed studs 16mm in diameter can be considered ductile if the headed stud height exceeds 6.25d (100mm). Now it is clear that the ductile behavior of connection can be achieved with an adequate height of headed studs.

C. Shear Resistance:

According to IS: 11384-1985 and BS EN 1994-2, the stud shear resistance is defined as a function of the headed stud diameter, stud height, properties of headed stud material, and compressive strength of concrete. For this study, the stud shear resistance will be calculated in future.

VIII. CONCLUSION

Two multi-stud and one single-stud push-out tests were carried out and the following conclusions can be made based on the tests and analysis.

- The load-slip curves show an initial almost linear relationship, and then the curves develop a new branch with a softer slope. After the maximum load is reached, the specimens fail suddenly and the load-slip curves do not show an evident descending part.
- The ultimate strength of multi-stud specimens is higher than that of single stud specimen. The ultimate strength of multi-stud is about 18% larger than single stud.
- The slip of single stud specimen is about 25% larger than multi-stud specimens. These results may be useful in the design of steel-concrete composite bridges.
- The single-stud and multi-stud specimens have varying stiffness, and the spacing of studs has little influence in the stiffness in the multi-stud specimens.
- Normally, decreasing stud spacing resulted in lower ultimate strength. For that we provided confined reinforcements that enhance the shear strength of the shear connection.
- Behavior, ductility and shear resistance of the connection realized with a group of headed studs depends on the height of headed studs in the group.

IX. FUTURE WORK

For better acceptance, further researches in experimental investigation of multi-stud shear connectors, has to be conduct. The results from the experimental investigation have to be compared with analytical investigation. For further understanding the shear resistance of studs will be found in future. From that, we will conclude which arrangement of multi-stud shear connectors is suitable for composite bridges.

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