Mechanical Properties of Strengthened RC Beams using Steel Plates

P. Oliver Jayaprakash, P.Sudarshan, C.Hemalatha

Abstract: The focus of this analysis is the review of steel plate strengthened RC beams using Single row and Stagger row bolt arrangements and to compare the bonding behaviour of different bolts arrangement under flexure. Also, to investigate the behaviour, load bearing capacity and the deflection for control and steel plate bonded beams. This research is constrained by FEM analysis utilizing ANSYS to the actions of standard RC Beam and RC beam steel plate associated.

Keywords: FEM, ANSYS.

I. INTRODUCTION

Various researchers studied the actions of the bolting mechanism on a stainless steel sheet reinforced concrete beams. This analysis is limited in the conduct of standard RC beam and steel plate bonded metal RC beam from FEM. The performance evaluation of reinforced reinforced concrete (RC) beams subject to flexural loading, Esmaeel Esmaeli et al (2015), was examined. The tests were conducted by the experiment Ashraf A. Alfeeha (2014), has linked the exterior plate with the epoxy and mechanical beams. W.H. Siu et al(2010) analyzed the dominant impact on beam's ductility efficiency as two significant structural parameters for structure subjected to gravity stress, both in relation to post-elastic strength change. The configuration of "Strong bolt-weak plate can contribute to a system that can attain both strength and ductility. Everything leads to a deterioration and unnecessary loss. BSP beams are controlled by the weakest component in strength and ductility. The beam of different plating lines examined by G. Arslan et al (2008) verified the likelihood of the ultimate bearing capacities of the weakened RC beams that were externally bonded continuous steel plates. The experimental research to increase the shear ability of beams in reinforced concrete with a different technique, Bimal Babu Adhikary et al(2006) investigated the beams collapse in ductile flexural mode to prevent a delicate shear fracture. The externally epoxy bonded steel plates, vertical bands and externally attached strips have been reported to increase the overall shear strength of the strengthened cement beams and shift the failure mode from brittle shear to bending.

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Masashi Sano et al (2006) performed an experimental analysis to determine the utility of web-bonded steel plate for the shear reinforcement of internal stirrup RC beams. As the load in the current system rises, the load power to support weight should be improved. The stability, power and ductility of the coupling beams discussed by RKL Su et al. (2005) have a major influence on the overall structural behavior of coupling walls in seismic attack. Local failure of the coupling beams will lead to a global failure of the entire building lateral load resisting system. The beam is supported with fixed exterior steel plates on the sides of the beams and the other serve as a monitoring device without the reinforcement of the frame. The stainless steel plates used in this test helps to boost the beam by holding the steel plate on the beam soffit by two separate bolt configurations and observing the mechanical properties by analyzing experimental and measurement results.

II. PROPOSED METHODOLOGY

Under static loading conditions, six beams were casted and tested on RC. The beams were strengthened by steel plates. The size of the control beam is 1000 mm x 150mm x 200mm and the size of the beam S1and Z1 is 1000 mm x 150 mm x 204 mm (since thickness of steel plate is 4mm). All three beams C1, S1 and Z1 were reinforced with 2 nos. of 12mm rebar in tension and 2 nos. 10 mm rebar in compression side with stirrups provided at 100mm c/c. Clear cover for stirrups is 50 mm from the cross section. A clear cover of 25 mm is maintained all around for compression & tension reinforcement. Table 1 shows the detailed description of three different types of beam.

Table 1: Specimen details

Beam ID	Depth (mm)	Steel plate thickness (mm)	Description
C1	200	-	Control Beam
S1	200	4	RC beam with steel plate connected using single row bolted connections
Z1	200	4	RC beam with steel plate connected using stagger row bolted connections

Fig. 1 shows the reinforcement details of beam specimen. Bolts of size length 150 mm and 10 mm diameter are fixed to the plates with spacing 100 mm c/c in two configurations, single row and stagger row. In both types, the bolts were placed inside the reinforcement cage as shown in Fig. 2 & Fig. 3.

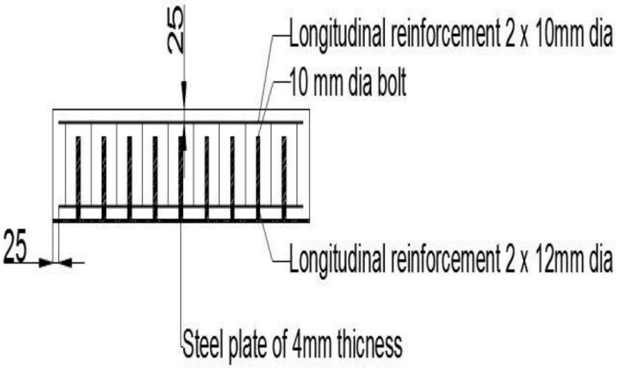

Fig. 1: Longitudinal section of the beam

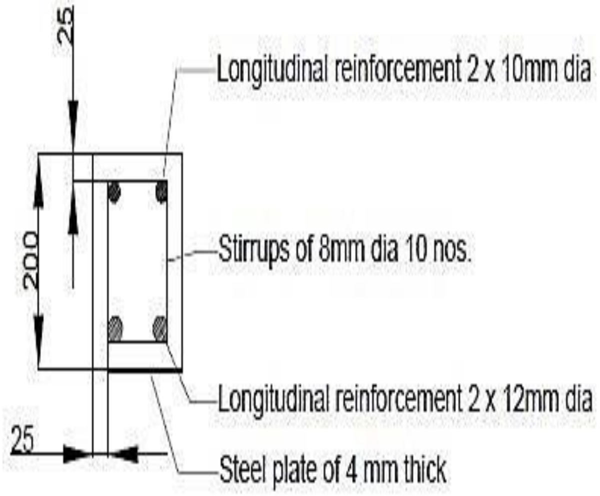

Fig. 2: Cross section of the beam

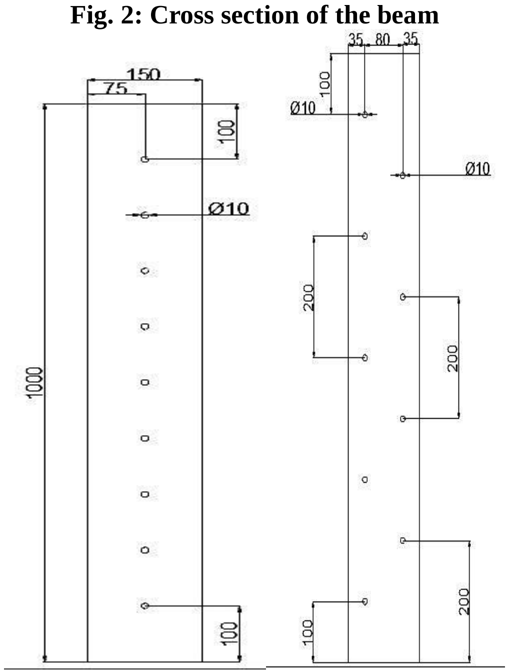

Fig. 3: Detailing of bolt arrangements

Fig. 4: Single row bolt arrangements with steel plate having reinforcement cage

Fig. 5: Stagger row bolt arrangements with steel plate having reinforcement cage

A waterproof wooden mould was prepared where it's inner dimensions are 1000mm x 150mm x 200mm.The reinforcement cage is kept inside the mould by allowing proper clear cover all around the reinforcement. Then the fresh concrete is poured inside in layers and compacted well using 16 mm compacting rod. The top surface of beam specimen is perfectly levelled using trowel. After 24 hours, the specimen was demoulded and subjected to moist curing for 28 days by wrapping in gunny jute bags before testing. Fig. 5 represent the steps involved in casting of beam specimens. Fig. 6 shows the specimen after the wooden mould was removed.

Fig. 6: Stages involved in casting of beam specimen.

Fig 7: Demoulded specimen

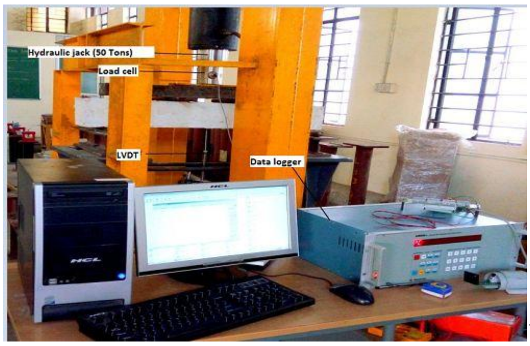

Fig. 8: Test setup

All the beams were tested in a loading frame of 100 tons capacity. Linear variable differential transducer (LVDT) have been placed on the tension face at the middle of the beam to measure deflections. The load was brought over to the beam by way of a load cell size of 50 tonnes, with an hydraulic jack of 100 tonnes. Load cell and LVDT were connected to a data acquisition system. Loading were applied gradually by two-point load method and the readings were being recorded through the computer by means of data logger. The test parameters such as ultimate load, deflection, crack pattern, failure mode was observed during the test. At different stages of loading that were marked on the specimens he crack pattern and the crack growth are analyzed.

III. FINITE ELEMENT MODELLING

Finite element modeling of the reinforced concrete beam modelled and studied in order to study the behavior of the static load acting on steel plate bonded RC beam with the help of ANSYS software. A beam was modeled with 150 mm X 200 mm cross section and the steel plate is about 100 mm width and 4 mm in thickness is placed on the soffit of the beam using bolts. A finite element model of the beam is being modeled and the loading procedure has been carried out.

The steps involved in the FEA are as follows,

Specimen Testing:

- Element types
- Real constants
- Material properties
- Modeling
- Meshing
- Boundary conditions and loading
- Analysis and results

Description of element types

Table 2: Element types for RC beam and steel plate

Material type	ANSYS element type
Concrete	Solid 65
Reinforcement	Link 180
Steel plate	Solid 46

For 3-D simulation of solids with or without reinforcing bars (rebar) the SOLID 65 is used. The solid is capable of tension cracking and compression crushing. Eight nodes with three degrees of freedom at each node determines the element: translations at the x, y and z directions of nodals. There can be specified up to 3 separate rebar requirements. The figure below shows the geometry of SOLID65

Fig.9: SOLID 65 Geometry

For 3-D rendering of concrete objects, SOLID 46 is used. Eight nodes with a freedom of three degrees at each node are described as the element: translations in the directionx, Y and Z nodes. The element has plasticity, weakening, swelling, stress intensification, wide swinging and comprehensive strain potential. A reduced hourglass control interface option is available. The real constant of RC beam with steel plate is described in Table 3.

Table 3: Real constants for RC beam with Steel plate

Real constant set	Element type	Cross sectional area (mm^2)	Initial strain / thickness (mm)
1	Solid 65	30000	-
2	Link 180	113.09	-
3	Solid 46	600	6

IV. MATERIAL PROPERTIES

Table 4 states the material properties used for RC beam mod eling using steel sheet are shown in for link 180. The table shows the material properties used to bui ld RC beam with a steel plate for SOLID65. Table 6 shows the material properties for SOLID 46 used for modeling of RC beam with steel plate

Table 4:: Material properties for SOLID 65

Material model number	Type	Properties	
Linear properties			
1	Linear Isotropic	EX	27386
		PRXY	0.2
Non-linear properties			
1	Concrete	Open shear transfer coef	0.3
		Closed shear transfer coef	1
		Uniaxial cracking stress	3.5
		Uniaxial crushing stress	-1

Table 5: :Material properties for link 180

Material model number	Type	Properties	
Linear properties			
1	Linear Isotropic	EX	$2x10^5$
		PRXY	0.3
Non-linear properties			
2	Bilinear Isotropic	Yield stress	250
		Tang. Mod	20

Table 6: Material properties for SOLID 46

Material model number	Type	Properties	
Linear properties			
3	Linear Orthotropic	EX	62000
		EY	48000
		EZ	48000
		PRXY	0.22
		PRYZ	0.22
		PRXZ	0.30
		GXY	3270
		GYZ	3270
		GXZ	1860

The model of steel plate fitted with different bolt connections had done and it is shown in Fig. 10 and Fig. 11. The full-fledged model was done in ANSYS and it is shown in Fig. 12. The model beam was simply supported and it was given two-point loading as shown in Fig. 13.

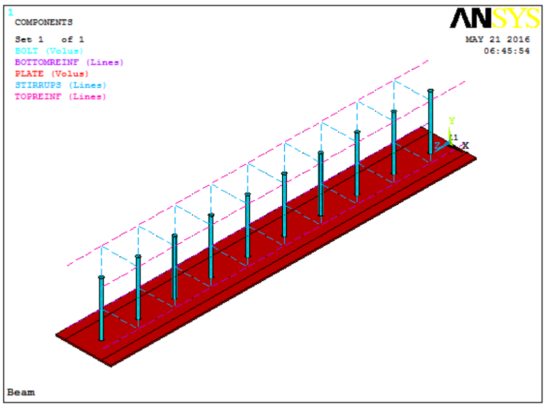

Fig. 10: Steel plate bolted by single row bolt arrangements

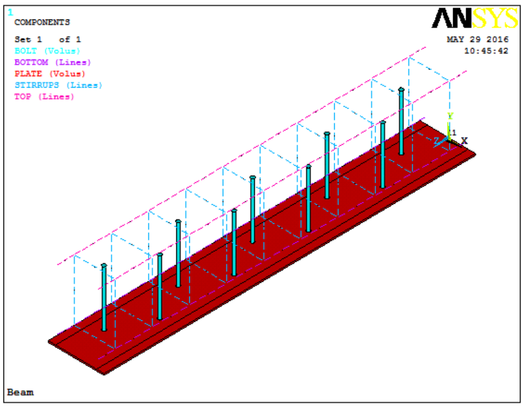

Fig. 11: Steel plate bolted by stagger row bolt arrangements

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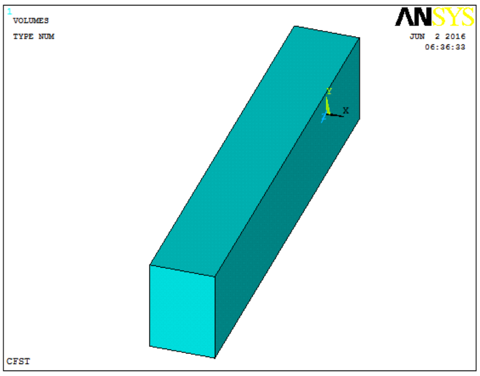

Fig. 12: Model done through ANSYS

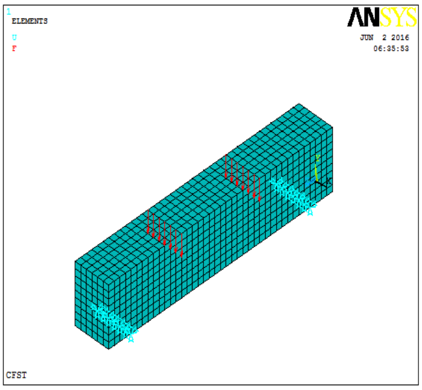

Fig. 13: Analytical model

V. RESULTS AND DISCUSSION

In this section, results for the control beam and the steel plate reinforced beams are presented experimentally and analytically. Six beams, including two control beams were cast, two are reinforced reinforced beam of steel with a single row bolt arrangement and the other two are reinforced beam of reinforced steel beam with stagger row bolt arrangements. Experimental and analytical results are compared for Ultimate load, deflection, and crack pattern. Modes of failure were observed during the test. After the application of static loading, the results were observed at various stages and the values are being shown in Table 7.

Table 7:: Observations on Flexure Strength Test

S.NO	Beam ID	First crack load (KN)	Deflection at First crack load (mm)	Mode of failure	Failure region
1.	C1	269.76	1.6	Shear Crack	1/3rd distance from both ends of the beam at tension zone
2.	S1	348.76	1.17	Flexural - Shear Crack	45º diagonal crack propagating from two loading point on either side
3.	Z1	420	0.96	Flexural -Shear Crack	45º diagonal crack propagating from central loading point on either side

Table 8:: Observations on Flexure Strength Test

Beam ID	Initial crack load (KN)	Yield load (KN)	Ultimate load (KN)
C1	269.76	347.54	439.79
S1	348.76	437.89	600
Z1	420	449.78	630

It is observed that from table 7 and 8, the cracks pattern for the specimens S1 and Z1 were unchanged and the first crack occurred relatively at the same deflection. The first crack load for the specimen S1 was perceived as 66% more than the conventional one and for the specimen Z1 it was perceived as 80% more than the conventional beam. The crack occurred in the control beam was shear crack. For the S1 and Z1, flexural- shear cracks were followed on static two-point loading condition.

Effect of steel plate on load bearing capacity

It was found that the steel late strengthened RC beams with single row and stagger row bolted connections has an increase in load carrying of 36.43% and 43. 62 % more than the control beam respectively. Thus it has been established that the RC beam reinforced by a steel plate with a stagger bolted attachment significantly increases the beam load capacity in relation to other beams..

Effect of steel plate on deflection

For various stages of loading, deflections were observed and noted down as shown in table 6. From the test, the RC-beam with bolted single row attachment improved steel plate has a 3.83 mm deflection for 600 KN and 3.8 mm for the load 630 KN for the stagger row. The control beam was deflected to 4 mm for a load 439.79 KN which is comparatively less than the S1 and Z1 specimen. These results indicate that the deflection was restrained by the steel plate fitted at the soffit of the RC beam.

Table 9: Observation on yield and ultimate deflection respect

Beam ID	Yield deflection (mm)	Ultimate deflection (mm)
C1	2.67	4
S1	2.1	3.83
Z1	1.89	3.8

Load deflection behaviour

Load and deflections for three beam forms were specifically identified using the load cell and LVDT connected to the acquisition network of Data Logger. According to the results observed, RC beam with steel plate connected using stagger row bolted connections behaves better than the other two beams since these beams had higher load bearing capacity comparing to the control beam and the beam with steel plate connected using single row bolted connections. In the deflection part, the beam with steel plate connected by stagger row bolted connections shows lesser deflection than the other two beams but the single row bolted connection beam results are mere to the stagger row bolted beam.

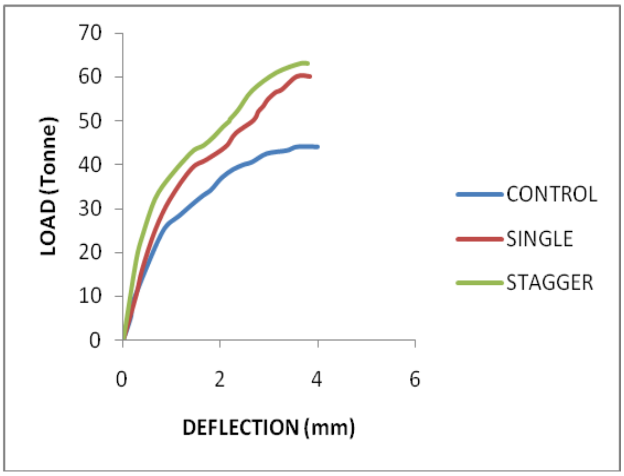

Fig. 14: Load vs Deflection curve for C1, S1, and Z1

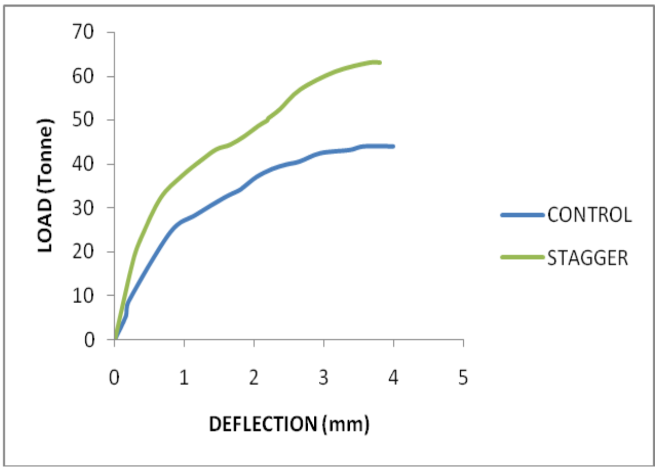

Fig.16: Load vs Deflection curve for C1 and Z1

Fig 15 shows the load deflection behaviour control and beam with steel plate connected by stagger row bolted connections. The rigidity of the planned beam is found to be greater than the reference beam. The initial performance was started at 420 kN with a value of 270 kN as for the control

The load deflection behaviour is shown in Fig. 14 Shows the behaviour of control beam and S1and Z1 beams based on load- deflection . It is clear that the deflection gradually decreases as the pressure grows. It is clearly noted that the linear behaviour exists linear up to 270 KN for control beams and for the beam with single row bolt arrangements it is 350 KN and for the beam with stagger row bolt arrangements is 420 KN.

After attaining these loads, yielding of steel occurred as it can be seen clearly through the fig. 6. Fig 72 shows the load deflection behaviour control and beam with steel plate connected by single row bolted connections.

It is observed the stiffness of the S1 is more than the control beam. The initial yielding of S1 was started at 350 KN where as in the control beam it is 270 KN. The post peak deflection for the control beam begins at 439.79 KN and the single row bolt beam is 600 KN.

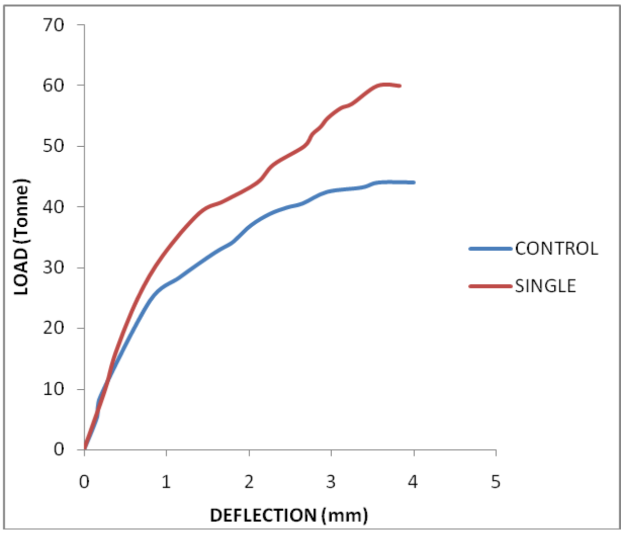

Fig. 15: Load vs Deflection curve for C1 and S1

beam The post-peak deflection for the control beam ends after 439.79 KN and the beam is 630 KN in stagger row bolt arrangements.

Effect of steel plate on ductility

For any structural element or structure itself in particular in seismic regions, ductility is an important factor. For the refurbishments in the RC systems, the ductile properties of the concrete are very smaller. The figure shows the utility of C1, S1 and Z1 and ultimate deflexion. The ductile conduct of the RC beam is more comparable with the RC beam when the steel plate is applied to the soffit of the RC beam. Since the plate is at the soffit of the RC beam, it will yield relatively for the loads applied on the RC beam. Even after the failure of concrete member the steel plate will not let the concrete to fall due to bonding of plate and bolts connected to the RC beam.

Table 6.4 shows the deflection ductility and ductility ratio of beams. The ductility ratio is in an appreciable range.

Table 10:Ductility of C1, S1 and Z1 specimen

Beam ID	Deflection ductility	Ductility ratio
C1	2.17	2.18
S1	2.64	3.4
Z1	2.84	3.96

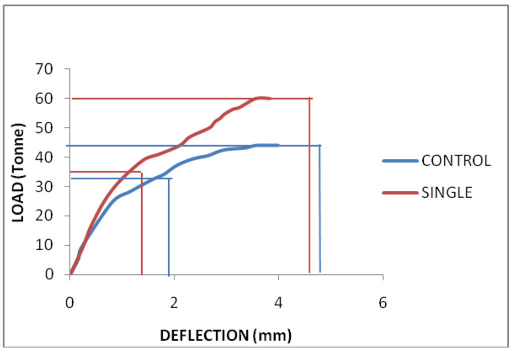

Fig. 17: Yield and ultimate deflection of C1 and S1

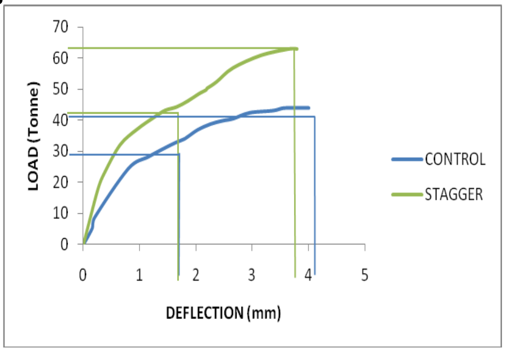

Fig. 18: Yield and ultimate deflection of C1 and Z1

VI. FAILURE MODE AND CRACK PATTERN

Figure shown are the failure mode and the crack pattern for control and RC beams strengthened by the stainless steel board. With the rise in load, there were old cracks and new cracks. The splits in the reinforced beams is identical to the control beams. The failure mode of the strengthened beams was close to that of the control beam. Beam failure occurs by steel yield, accompanied by concrete crushing.

Fig. 19: Initial and Final Cracks at specimen C1

Fig. 20:Initial and Final cracks at specimen S1

Fig. 21: Initial and Final cracks at specimen Z1

VII. ANALYTICAL RESULTS

Load-deflection behaviour

From the ANSYS, results for ultimate load, deflection and crack pattern for the beams were found and it is explained below.Load-deflection results from ANSYS for control beam and steel plate strengthened beam for different bolt arrangements is shown in table 11

Table 11 Ultimate load and deflection obtained through analytical results

Beam ID	Ultimate load (KN)	Deflection (mm)
C1	479.78	2.887
S1	615.49	2.453
Z1	680	2.356

In the analytical results it is found that the ultimate load for the control beam is 479.78 KN and for the single row bolted connection beam it is 615.49 and for the stagger row bolted connection beam it is 680 KN as shown in table 11. These results are marginal to the experimental results obtained. Considering the deflection part, the differences between experimental and analytical results are minimal.

Fig. 22 shows the load deflection behaviour control and beam with steel plate connected by single row bolted connections. It is observed the stiffness of the S1 beam is more than the control beam. The post- peak deflection starts after 479.78 KN for the control beam and the beam with single row bolt arrangements is 615.49 KN.

Fig. 6.11 shows the load deflection behaviour control and beam with steel plate connected by stagger row bolted connections. It is observed the stiffness of the Z1 beam is more than the control beam. The post- peak deflection starts after 680 KN for Z1 beam.

Failure mode and crack pattern

The deflection and crack pattern for C1 was obtained through finite element modelling is shown in Fig. 25 and 26. The deflection and crack pattern for S1 was obtained through finite element modelling is shown in Fig. 2 and 26. The deflection and crack pattern for S1 was obtained through finite element modelling is shown in Fig. 27 and 28

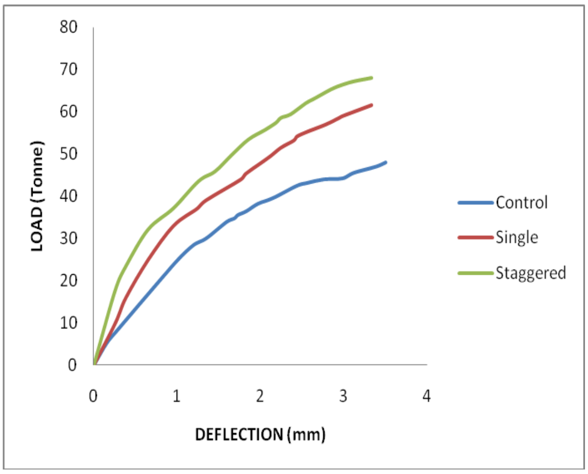

Fig. 22: Load vs Deflection curve for C1, S1, and Z1

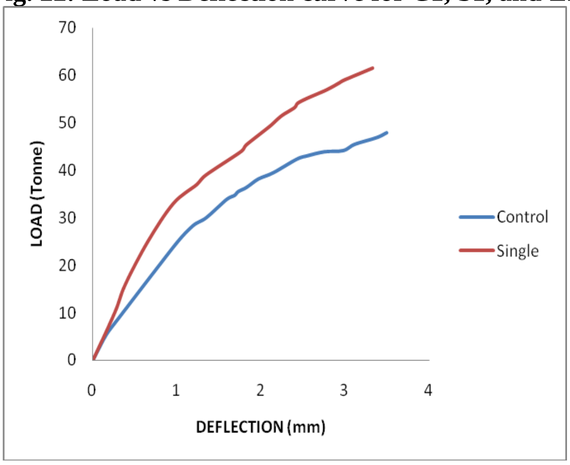

Fig. 23: Load vs Deflection curve for C1 and S1

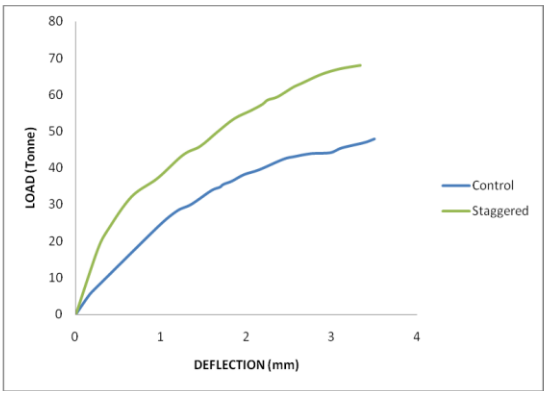

Fig. 24: Load vs Defl ection curve for C1 and Z1

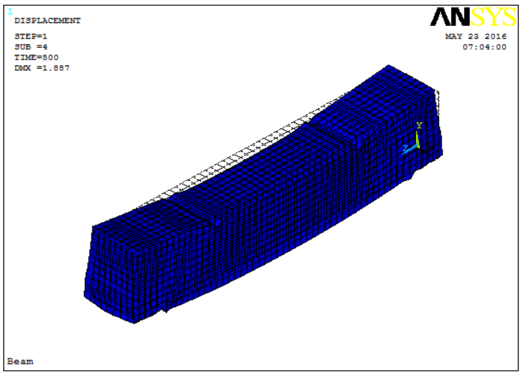

Fig. 25: Deflection occurred on beam C1

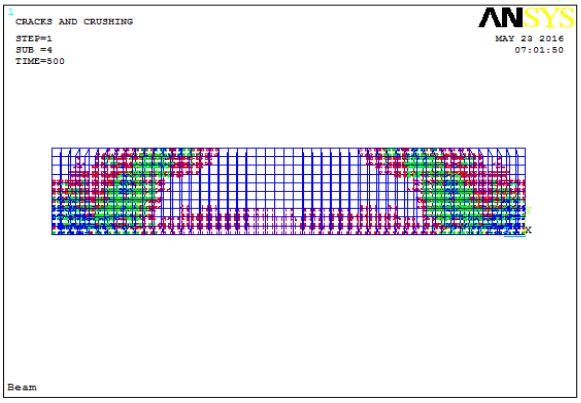

Fig. 26: Crack pattern for beam C1

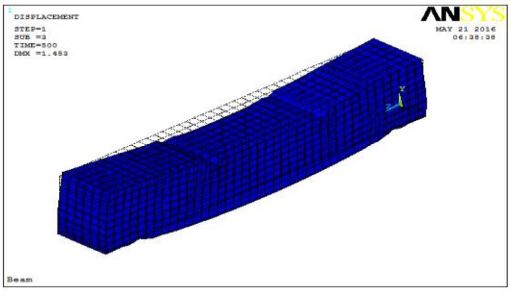

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Fig. 27: Deflection occurred on beam S1

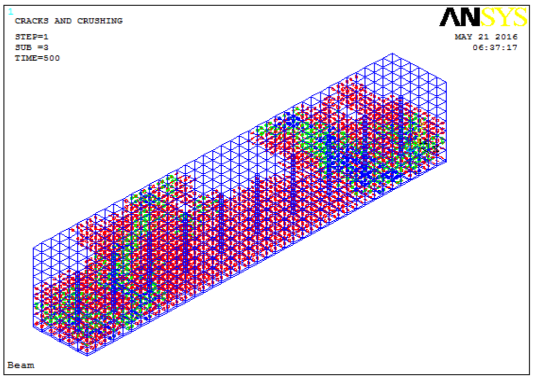

Fig. 28: Crack pattern for beam S1

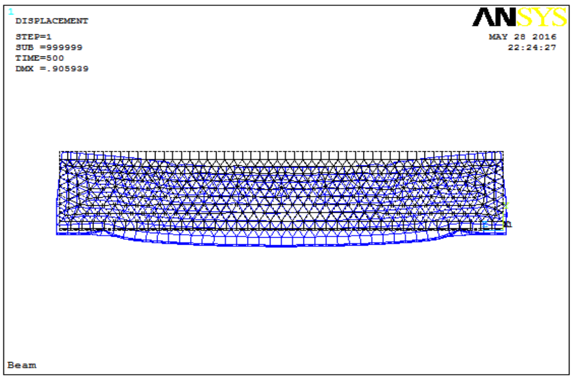

Fig. 29: Deflection occurred on beam Z1

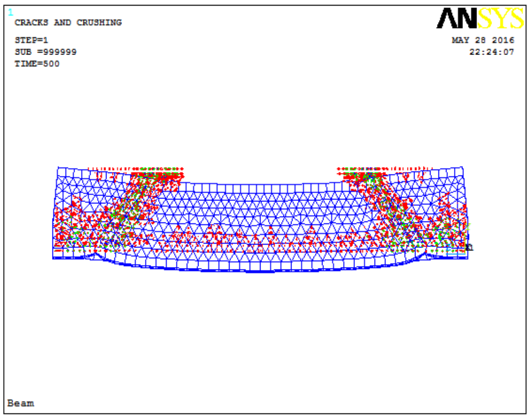

Fig. 30: Crack pattern for beam Z1

VIII. EXPERIMENTAL RESULTS WITH ANSYS

Experimental results were compared with numerical results obtained by ANSYS results shows that good agreement with numerical result obtained through ANSYS, load-deflection curve obtained through experimentally coincide with numerical load-deflection curve. So, it is clear that the experimental and analytical results obtained are relative to each other. ANSYS and test results for the ultimate load were tabulated in table 12 and 6.6 for determining the accurate difference of FEA software.

Table 12 Comparison of experimental and analytical results

Specimen ID	Ultimate load (kN)		Difference (%)
	By experimental	By analytical	
C1	439.79	479.78	9.09
S1	600	615.49	2.58
Z1	631.67	680	7.65

The results obtained were insignificant in studies and analysis. The results showed an increased load carrying capacity, a rise in ductility behavior, and a higher yield of reinforced concrete beams from the steel plates were more than the control experiment. The impact of reinforced concrete beams was strengthened. The overall performance of the beam with a stragger row bolted connection found to be marginally more than the beam with a bolted single row connection of these improved reinforced concrete beams.

IX. CONCLUSIONS

The following results were taken from the experimental and theoretical findings,

1) In contrast to the control beam the reinforced concrete beams supported by steel plate attached through different bolts have proven highly effective in load carrying capacity and deflection.
2) Steel plates strengthened by the beam for reinforced concrete bolts and the base of the stagger row bolts demonstrated a substantial increase in load carrying over the control beam by 36.43 percent and by 43.62 percent.
3) Deflection ductility indicated an increase of 21.7 % for single row bolted connection beam and 30.87 % for stagger row bolted connection beam.
4) From the analytical results it was found that the ultimate load carrying capacity for control beam, steel plate strengthened concrete beam for single row bolted connection and stagger row bolted connection has a difference of 9.09, 2.58 and 7.65 when compared with the experimental results.
5) From the analytical results it was found that the deflection capacity for control beam, steel plate strengthened concrete beam for single row bolted connection and stagger row bolted connection had a difference of 38%, 56% and 61% when compared with the experimental results.
6) Failure mode and crack characteristics of strengthened beams are identical to control beams.

In the case of strengthened beams reinforcement and a steel plate at the beam soffit contributed to the failure.

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