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State of Art Review of Experiments on RC Exterior Beam Column Connection

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Abstract: *Beam column connections play vital role in stability of RC framed structures. Proper detailing of reinforcement provides much required rigidity to the connections. In quest of understanding behavior of connections, many researchers have done extensive experimental work on prototype and scaled down specimen. Some researchers have sought to different detailing strategies and have tried to study impact of the same on performance of connections. This work is an attempt to summarize experimental work of a few experiments done during year 2004 to year 2018.*

Keywords: *beam column connections, cyclic loading, ductile detailing, experiment, reversed cyclic, scaled model.*

I.INTRODUCTION

RC framed structure as we build it derives its stability through the rigidity of beam column connections. Connections can be classified based on their location in structures as exterior, corner and interior connections as shown in Fig.1.1

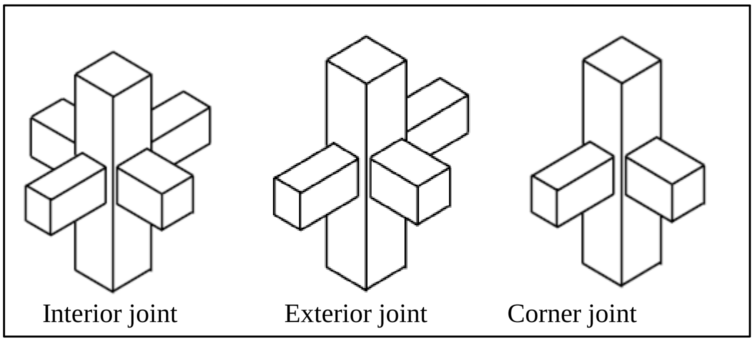

Fig.1.1 Connection Types

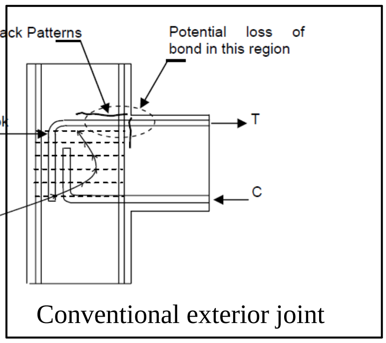

Fig. 1.2

Proper detailing of connections is very vital. Improperly detailed connections perform poorly during the earthquake. Researchers have done extensive experimental work on performance of connections with variety of detailing and loading. This study focuses on review of experimental work done on exterior joints as shown in Fig.1.2

Haung et.al[8] studied shear strength of joints in relation to hoop reinforcement. G. M. S. Alva et.al.[2] studied the behavior of fully ductile detailed RC connections under reverse cyclic loading. Bindhu K. R. et. al.[1], studied behavior of columns and ductile derailed exterior joints under seismic loading. Siva Chidambaram K.R. et. al.[7] studied ductility capacity, energy dissipation capacity and load deformation behavior of exterior beam column joints constructed with an external anchorage system by providing small projection beyond column face. Thomas H. K. Kang et.al.[9] studied Cyclic testing for seismic design guide of beam column joints with closely spaced headed bars. Mohammadamin Azimi et.al.[3] studied seismic performance of beam column connections with continuous rectangular spiral transverse reinforcements for low ductility. S. Rajagopal et.al.[5] studied seismic behavior of exterior beam column joint using mechanical anchorage under reversal loading. Salim Barbhuiya et. al.[6] studied the size effect on RC beam column connections under reverse cyclic loading. V. R. Pawar et.al.[10] studied behavior of cyclic loading of exterior beam column joint with threaded headed reinforcement. Roy Y. C. Huang et.al[4], studied behavior of shear strength of exterior wide beam column joint with different beam reinforcement ratios. This study is a state of art summary of various experiments done by researchers during last decade. This study will help understanding performance of variously detailed connections subjected to a verity of loading.

II.CHRONOLOGICALLY ARRANGED LITERATURE REVIEW

Shyh-Jiann Hwang, Hung-Jen Lee et.al. (2004)[8], studied the effect of joint hoops on the shear strength of exterior beam column connections. Six exterior beam column sub assemblages with different reinforcement detailing as shown in Fig.2.1 were tested under reverse cyclic loading. A simplified SST (Softened Strut and Tie model) approach for analysis of joints was proposed. Tests concluded that lesser hoop reinforcement, especially in case of moderate axial loads provides adequate joint shear strength. In case of reversed cyclic loading adequate shear reinforcement design and ensuring the hoops to remain in elastic range was found to be important.

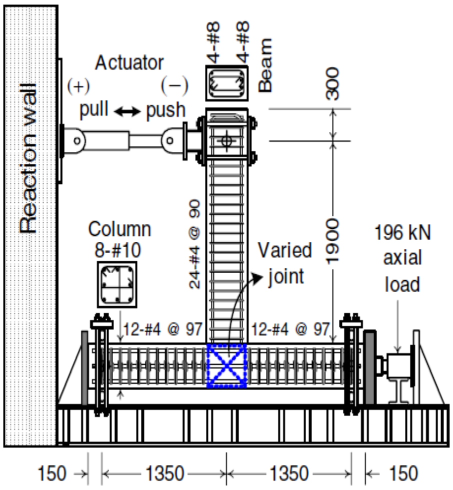

Fig 2.1 Reinforcement Details

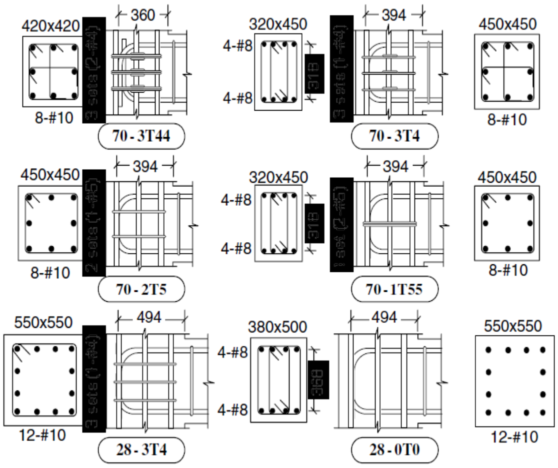

Fig.2.2 Beam Column Joint Detail

G. M. S. Alva, A. L. H. De Cresce El Debs et.al.(2007)[2], studied the behaviour of fully ductile detailed RC connections under reverse cyclic loading. Four specimens with different reinforcement detailing as shown in Fig 3 were tested under reverse cyclic loading. Instead of 3Dia hook as per IS 456 a 7.5D hook was used. Tests concluded that shear capacity of the joint increased with the increase in the hoop reinforcement. Shear capacity and behaviour of the joint depends on amount and nature of hoop reinforcement. It was also observed that F_{CK} has great influence on joint behaviour at service loads.

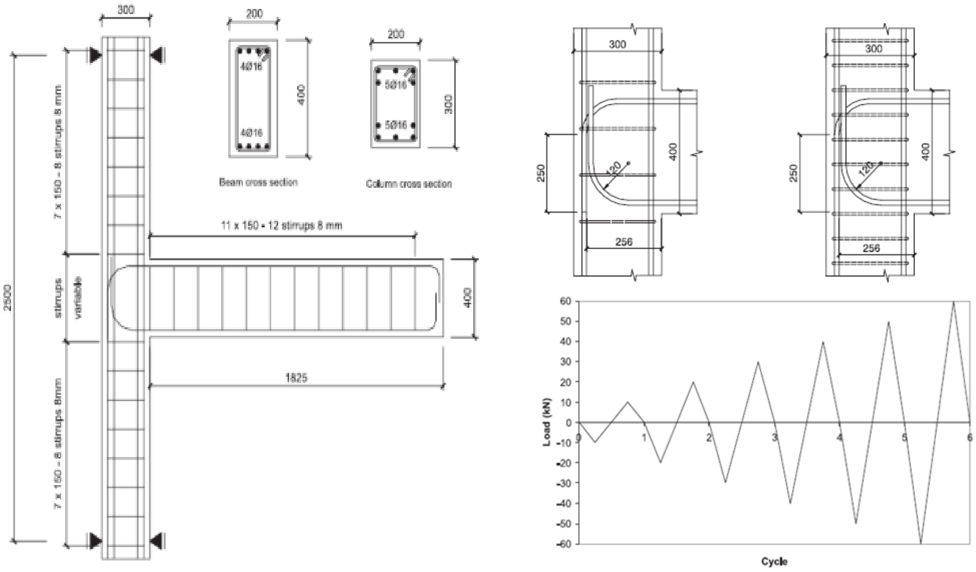

Fig. 3 Reinforcement details of joint with Loading history

Bindhu K. R. (2009)[1], studied behaviour of columns and ductile derailed exterior joints under seismic loading. In this study four specimens were provided cross inclined bars as a replacement of ties in joint as per IS 13920:1993 shown in Fig 4.2 and four specimens had hoops and additional inclined bars in the joint as shown in Fig 4.3. Eight specimens of one third scaled model were tested under reversed cyclic loading. Provision of special confining reinforcement showed improvement in ductility and energy absorption capacity. Non conventional distribution of confining reinforcement Fig 4.1 showed higher ultimate strength with reduced cracking of columns. Provision of inclined bars Fig 4.2 along with hairpin bends were found to improve ultimate strength of connections.

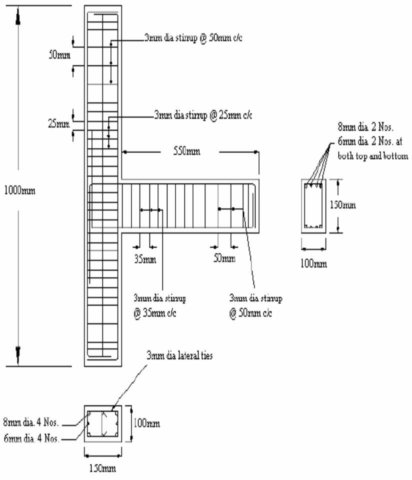

Fig 4.1 Special Confinement

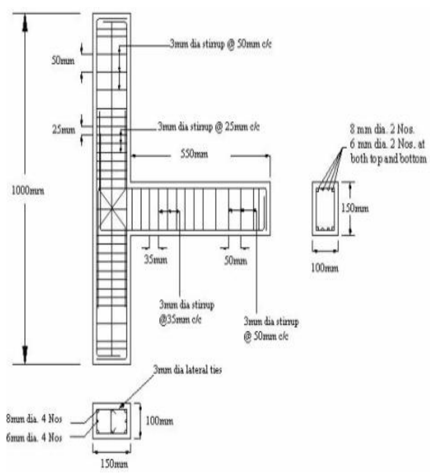

Fig 4.2 inclined bars in joint

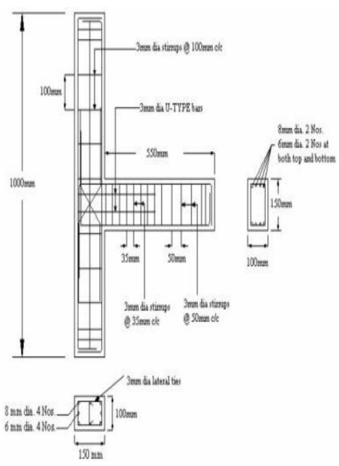

Fig 4.3 inclined bars with hoops

Siva Chidambaram K.R., Thirugnanam G.S. (2012)[7], studied ductility capacity, energy dissipation capacity and load deformation behaviour of exterior beam column joints constructed with an external anchorage system by providing small projection beyond column face. Two one fifth scaled beam column joint (Fig.5.1 and 5.2) specimens were tested under quasi-static cyclic loading. Experiments revealed that cracking load for modified reinforcement detailing was 45 % more than that for conventional detailing. Resilience and ductility was also found to increase by 4 times and 2 times respectively as compared to control specimen.

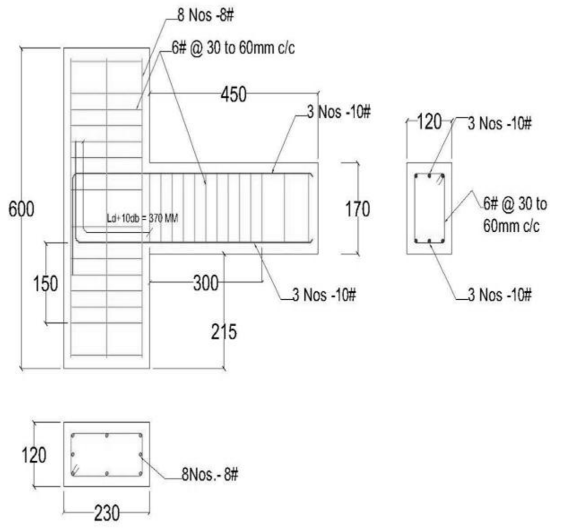

Fig 5.1 Detailing of joint as per IS 13920

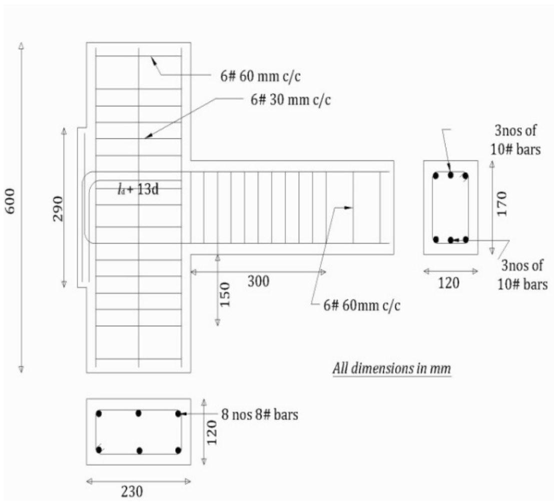

Fig. 5.2 Detailing of Special Anchorage joint

Thomas H. K. Kang, Woosuk Kim et.al.(2012)[9], concluded that headed bar arrangement ensured beam hinging with no unfavourable mechanism formation, limiting drift ratios as per ACI were satisfied by all specimen (Fig. 6). Double layered rebar distribution showed higher resilience and secant stiffness. It was concluded that rebar spacing of 2Db or use of double layered headed bars improved overall earthquake performance of the connection.

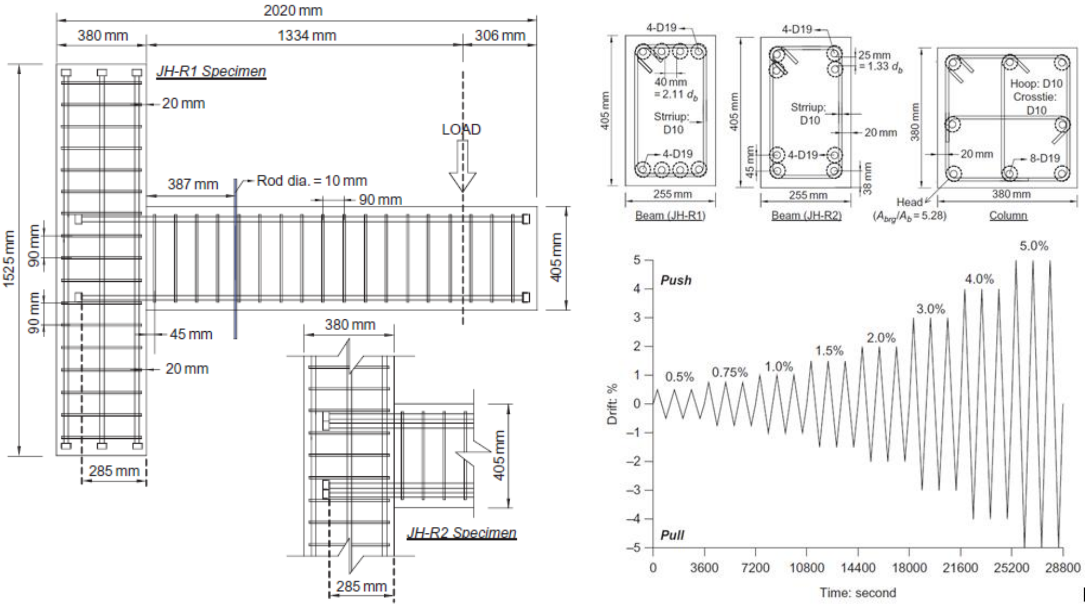

Fig 6.Reinforcement details of joint with loading history

Mohammadamin Azimi, Azlan Bin Adnan et.al.(2014)[3], studied seismic performance of beam column connections with continuous rectangular spiral transverse reinforcements for low ductility. In this study new proposed detail for joint introduced as "twisted opposing rectangular spiral" was experimentally and numerically investigated and seismic performance was compared against normal rectangular spiral and conventional shear reinforcement systems. Three full scale size beam column connections specimens were formed and tested by quasi-static cyclic loading. Finally results shows that new proposed connection could improve the ultimate lateral resistance, ductility and energy dissipation capacity. The nonductile formation of spiral hoops perform to meet seismic requirements.double spiral hoops show higher resilience as compared to single spiral system.

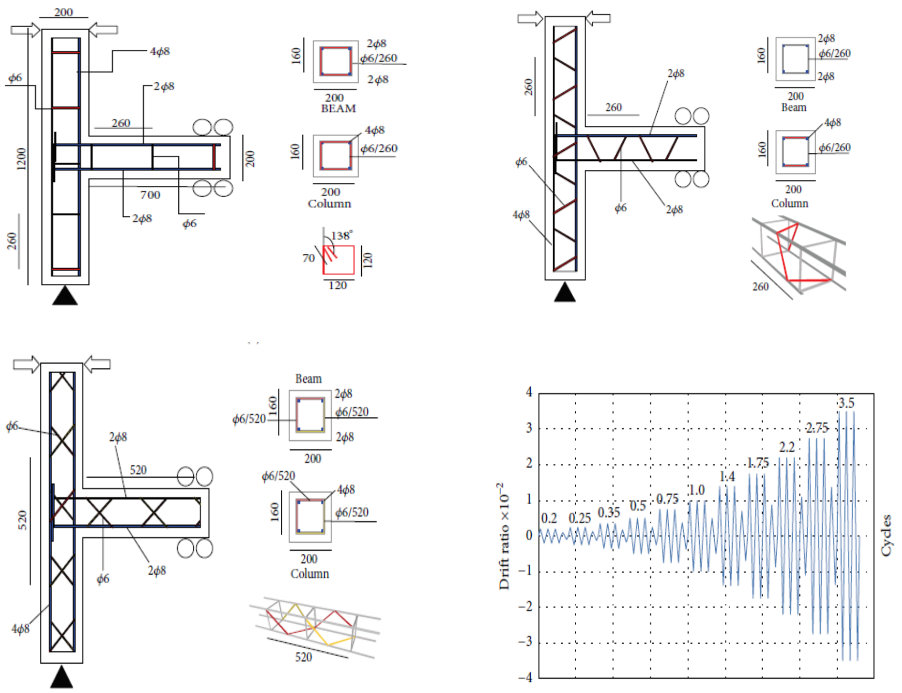

Fig. 7 Reinforcement details of Spiral hoops with loading history

S. Rajagopal, S. Prabavarthy (2014)[5], studied seismic behaviour of exterior beam column joint using mechanical anchorage under reversal loading. The joints are detailed for higher seismic prone areas as per ACI- 352 (Mechanical Anchorage) (Fig.8.1), ACI-318 (Conventional Hooks Bent) (Fig 8.2) and IS-456 (Full Anchorage Hooks Bent) (Fig 8.3) along with confinement as per IS-13920 and X-cross plus hair clip bar joint reinforcement (Fig8.4). Half scale specimen for all the conditions were tested. It was observed that provision of headed bars improved overall performance including ductility as compared to those with 90^0 hooks. headed bars reduced conjestion improving quality of concrete at joint. Headed bars with x cross bars reduced cracks improving seismic performance and ductility

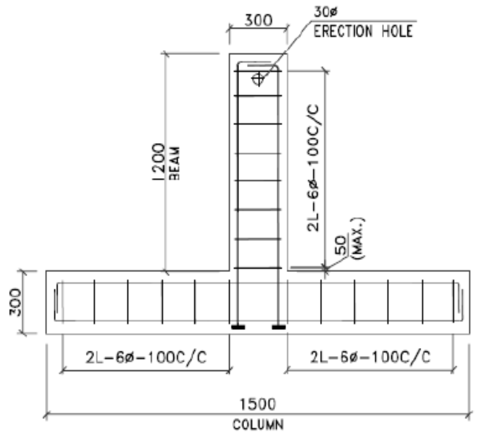

Fig 8.1 Mechanical Anchorage

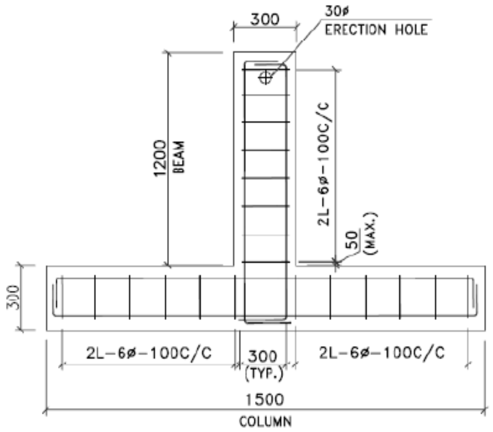

Fig 8.2 Conventional Hook Bent

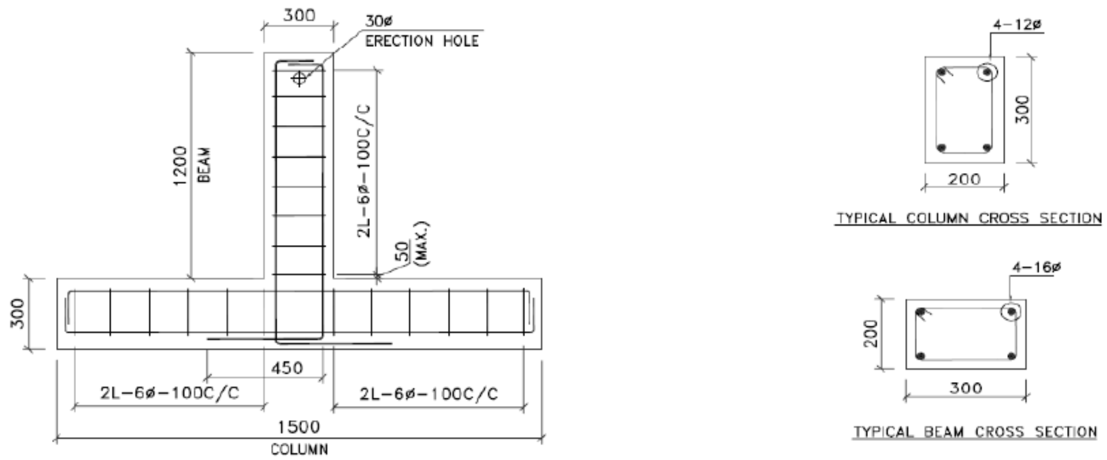

Fig 8.3 Full Anchorage Hook Bent with section details

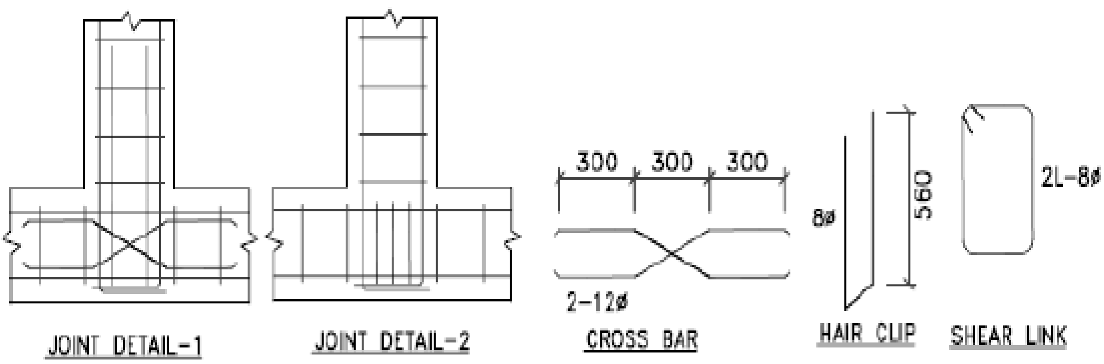

Fig. 8.4 X cross plus hair pin joint

Salim Barbhuiya, Abdul Munim Choudhury (2015)[6], studied the size effect on RC beam column connections under reverse cyclic loading. In this study full scaled (Fig. 9.1), two third scaled (Fig 9.2) and one third scaled (Fig. 9.3) models were tested. Size effect became more pronounced with increase in brittleness of the specimen. Energy dissipation of specimens per unit volume as well as variation of stress with relative deflection indicated the existence of size effect.

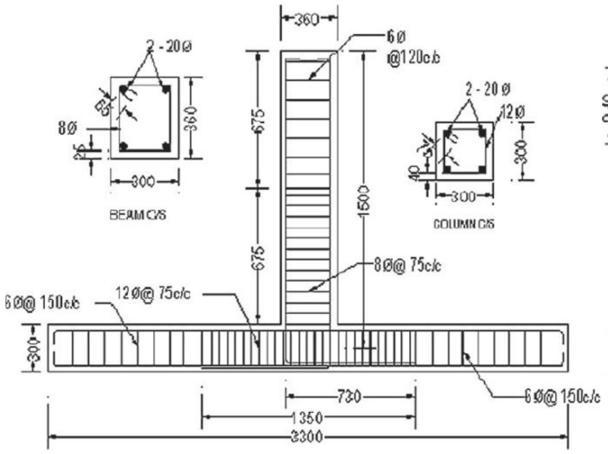

Fig. 9.1 Full scaled model

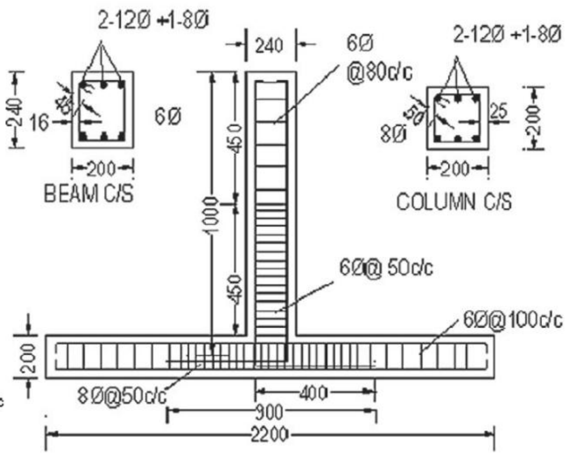

Fig 9.2 Two third scaled model

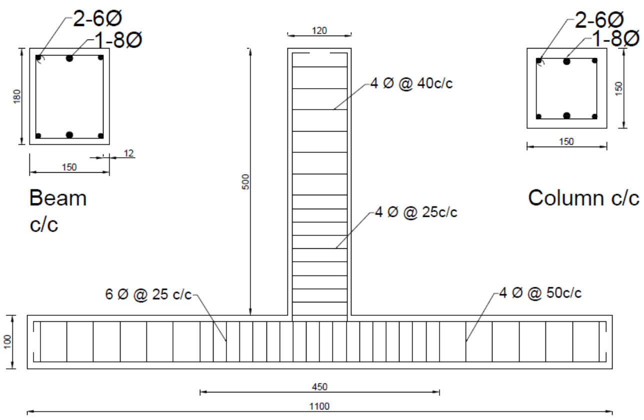

Fig 9.3 One third scaled model

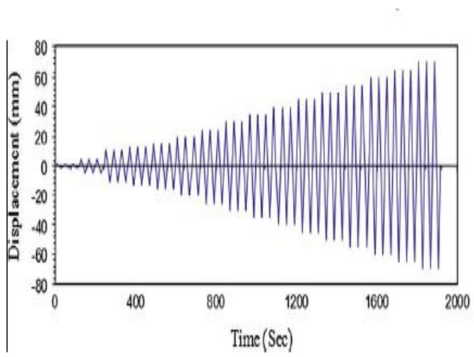

Fig 9.4 Loading history

V. R. Pawar, Dr. Y D. Patil et.al. (2017)[10], studied behaviour of cyclic loading of exterior beam column joint with threaded headed reinforcement. The specimens were constructed and tested to assess the anchorage strength of headed bars under cyclic loading. This type of anchorage exhibited significant improvement in seismic performance. Brittle failure of concrete was not observed for any specimen. Welded and threaded headed bars had similar performance. Larger heads showed better performance than smaller heads.

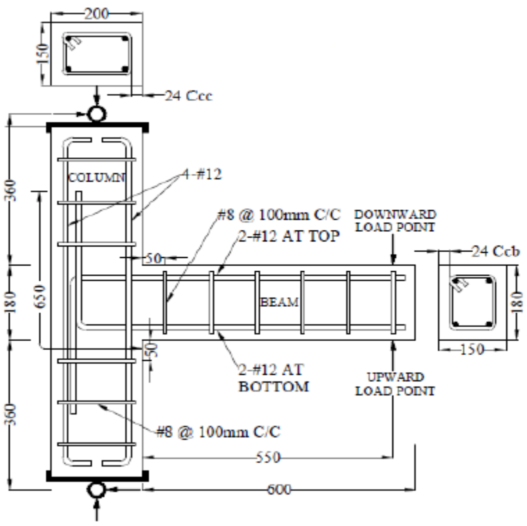

Fig 10.1 IS 13920: 1993 (No Confinement)

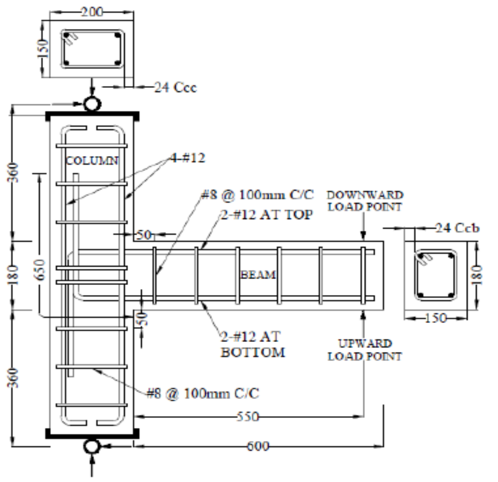

Fig 10.2 IS 13920 : 1993 (With Confinement)

Roy Y. C. Huang, J. S. Kuang et.al.(2018)[4], studied behavior of shear strength of exterior wide beam column joint with different beam reinforcement ratios. Full scale RC wide beam column joints with beam reinforcement ratios of 0.84%, 1.07% and 1.28% were tested under reversed cyclic loading (Fig.11). It was observed that beam reinforcement ratios of 0.84% show typical flexural failure. Joint shear failure after beam yielding was seen in rebar ratios 1.07% and 1.28%. As beam reinforcement ratio increases, failure modes of wide beam column joint change.

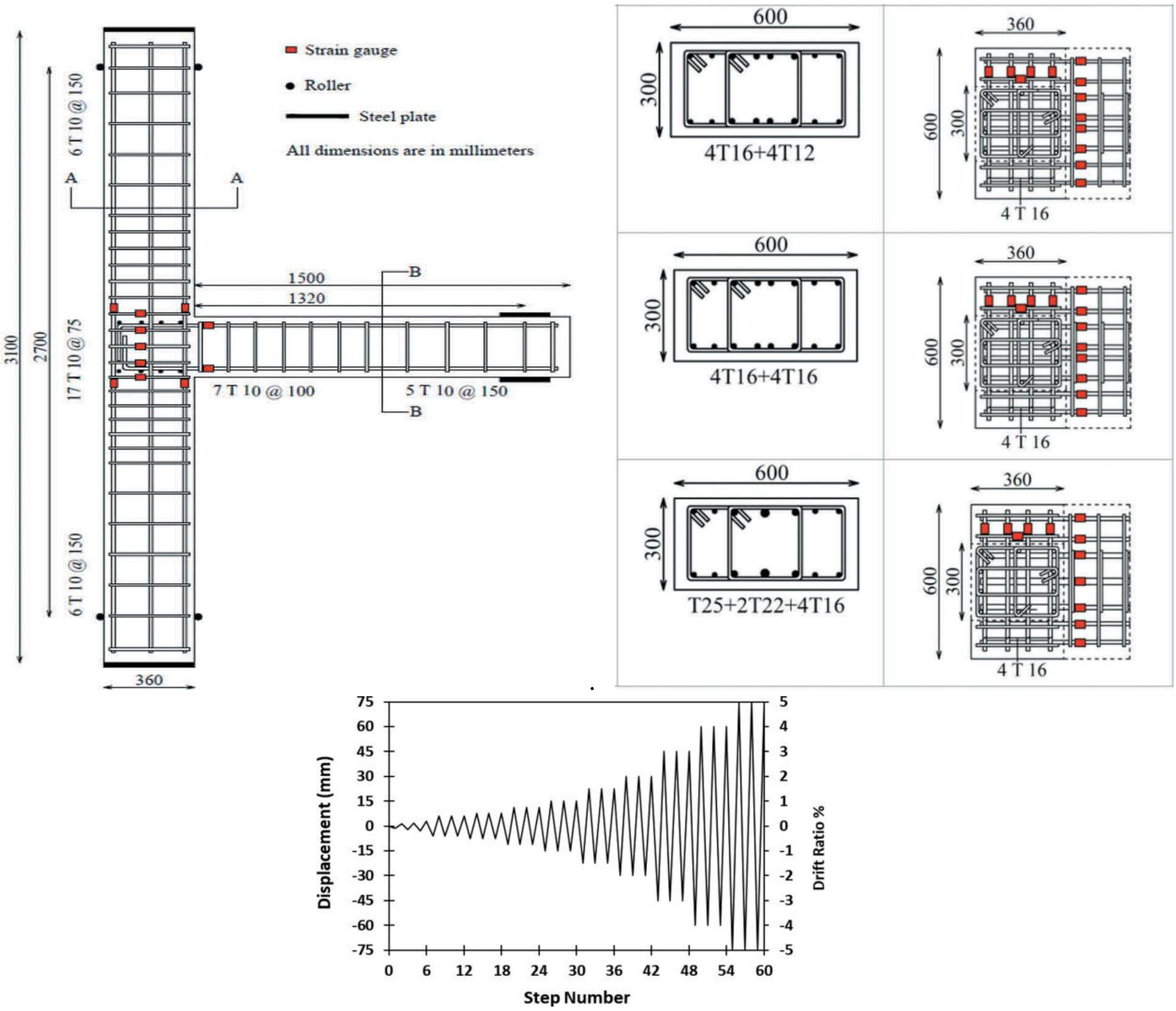

Fig 11. Reinforcement details with loading history

III.CONCLUSION

Literature review revels that beam column connections require careful attention with respect to detailing. The major source of failure is the lack of shear capacity. Many researchers have suggested new techniques and methods. They have experimented on those techniques and compared results with that of conventional detailing of beam column joint. Experimental investigation reveals that proposed methodologies have better performance in comparison to the conventional beam column joint.

This study gives an insight on various methods to study and improve performance of connections. Behaviour of connection varies with quality of concrete, rebar and workmanship available. This study will help to carry out experiments; on connection specimen, manufactured from locally available construction material, sourced at site conditions.

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