IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

5th National Conference on Science, Technology and Communication Skills – NCSTCS 2K22

Narula Institute of Technology, Agarpara, Kolkata, India

Vol. 9, Special Issue 2, September 2022

Non-Linear Finite Element Analysis of Exterior Beam Column Joints to Predict the Effect of Seismic Excitation

Suraj Pal[1] and Abhishek Hazra[2]

Student, Civil Engineering, Narula Institute of Technology, Kolkata, India[1]

Assistant Professor, Civil Engineering, Narula Institute of Technology, Kolkata, India[2]

Abstract: This paper presents a non - linear 3D (three- dimensional) finite element analysis of three different exterior beam column joints performed under seismic load by Abaqus 6.14 structural simulation software. The three corresponding experimental works of similar beam-column joints has been considered to simulate and validate the work data by comparing the load deflection curve, joint deformation and joint failure pattern. Beam and column parts kept as 3D solid homogeneous section where the reinforcing bars has been modeled as 3D truss element. Concrete damage plasticity model has been used to assess the concrete characteristics under inelastic range of loading. Stirrups and reinforcing bars were embedded within concrete using embedded region property. The analytical result was well described the joint crack with the experimental work, displacement at the beam end and at the joint region were also similar to the test results. In the load deflection curve a clear difference has been observed between two works has been observed. However, in terms of energy dissipation the values are quite similar but significant amount of deviation in load-displacement curve pattern has been observed. The comparison between experimental and analytical results clearly indicates that the analytical model is capable to simulate the performance of beam column joint as well as the joint failure pattern fairly well. Hence, realizing the capability of the analytical solution this paper concluded that the methodology can be used for performance analysis of beam column jointunder seismic loading condition which may be beneficial for scientific and engineering fraternity.

I. INTRODUCTION

In recent years, due to earthquakes' suddenness and destructiveness, large casualties and economic losses have been suffered by countries all over the world. In civil engineering perspective these losses and casualties have shown us our limitation and scope of improvement. So many researchers have went through it and concluded that a structure may collapse due to many reasons like inadequate material property, poor designing, lack of knowledge regarding seismic force, etc. But beside all of that they all agreed in one thing, that design of earthquake resisting building work required more precision in some critical areas. Beam-column joint is one of them. This is due to its construction difficulty and its complex design procedure.

Researchers have discovered four types of failures that can take place at joint i.e., shear failure in the joint, slippage of the beam main reinforcement bars, yielding of the beam main reinforcement and yielding of the column longitudinal bars. Many researchers had studied and gave their views about these failures. Like Constantin E. et al numerically investigated RC beam column joint under cyclic loading where reinforcements were given in cross direction. They tested 26 types of specimens with combinations of number of stirrups and vertical bars. They compare their data with 6 experimental studies with a satisfactory result. Chris G Karayannis et al investigated the performance of a RC beam with rectangular spiral reinforcement as a tie bar under a quasi-static type loading. They prepared 8 beams in which 2 of them have no shear reinforcement. Four beams have continuous steel spiral. The results indicate that continuous rectangular spiral bars improved bearing capacity and shear capacity of the beam up to 15%. J. S. Kaung and h. F. Wong studied the effect of horizontal stirrups at the joint under reverse cyclic load. They concluded that joint stirrups improve the seismic behaviour and joint shear strength. De-Cheng Feng et al analysed the beam-column joint to understand the bond-slip effect under cyclic loading. The precast and post cast concrete interface in joint area is considered. They theoretically evaluate the anchorage slip of the bar and validate it with a pull-out test. From that result the modified their work by considering an equivalent strain to surround the bar strain and slip.

Therefore, this research proposed to study the structural behaviour of exterior beam-column joint under seismic excitation by using enhanced computational method. To validate the outcomes by comparison with conventional numerical method and available experimental data. This research also aims to enhance the overall performance of the joint, by providing suitable design criteria.
In this analytical work the finite element analysis is used to simulate the exterior beam column joint model behaviour. Through FEA failure pattern, cracking types, concrete strength, effect of column axial load, gravity force effect, beam top displacement can be learnt. Hence FEA is an adequate solution to achieve the desired result.

IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

5th National Conference on Science, Technology and Communication Skills – NCSTCS 2K22

Narula Institute of Technology, Agarpara, Kolkata, India

Vol. 9, Special Issue 2, September 2022

II. EXPERIMENTAL RESULTS CONSIDERED

From the pastdecades earthquake set the toughest questions for the engineers. This is due to its complex loading pattern, demolishing effect and unexpected occurrence. That is why engineers always should keep this problem in a top most priority. During an earthquake it hits the structure rapidly and hence loading pattern in every individual reference should take into consideration. In natural loading or static loading, the inertia effect doesn't have any role, but in dynamic loading inertia always have some values that is sum of all forces = mass * acceleration. In static loading acceleration is zero hence inertia becomes zero., In past many researchers have done with quasi static approach to analyse, in which it is also static at a given time, and the load is applied very slowly that acceleration as well as inertia effect is very negligible.

On the other hand, in dynamic load it forced the structure to vibrate. In abaqus, dynamic explicit approach is the best way to simulate a dynamic loading but it requires too much time to complete a job and so why many prefers quasi static type, In this study twoexperimental work papers were considered which is done by K.R. Bindhu, P.M. Sukumar and K.P. Jaya [14] and other one is done by Minakshi Vaghani, Dr. S.A. Vasanwala, Dr. A.K. Desai [16]. The objective of first two paper was to compare the behaviour of exterior beam column joint designed and detailed as per IS 456 and IS 13920.

A six-storey building, situated in zone 3 was considered. An exterior beam column joint from an intermediate storey wasenumerated for design and tested under reverse cyclic (seismic type) loading. They followed two types of design consideration, one is designed and detailed according to IS 456 (Fig -1) which included with additional U-bar as per SP 34 and other was detailed as per IS 13920 (Fig- 2). The third specimen was also designed as per IS 456 (Fig- 3) in which they considered a 4 storey RC school building frame which is designed in STADD. PRO. Based on analysis data, critical region the exterior joint is considered for analysis.

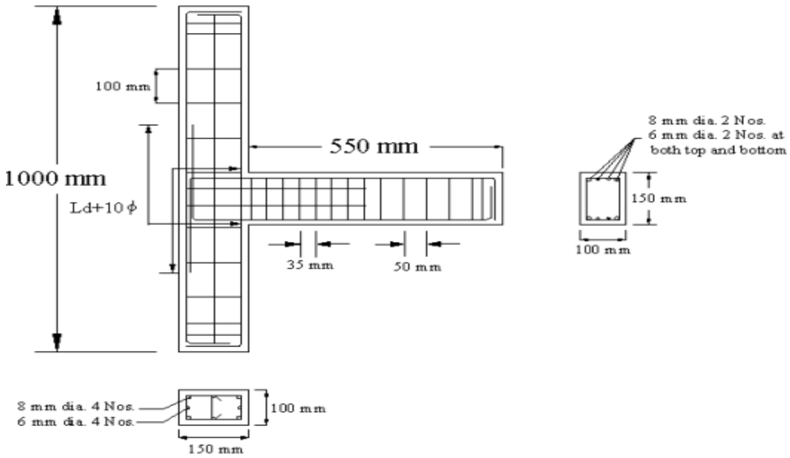

Fig. 1 Reinforcement details of the exterior beam column joint as per IS 456 (BIS, 2000)

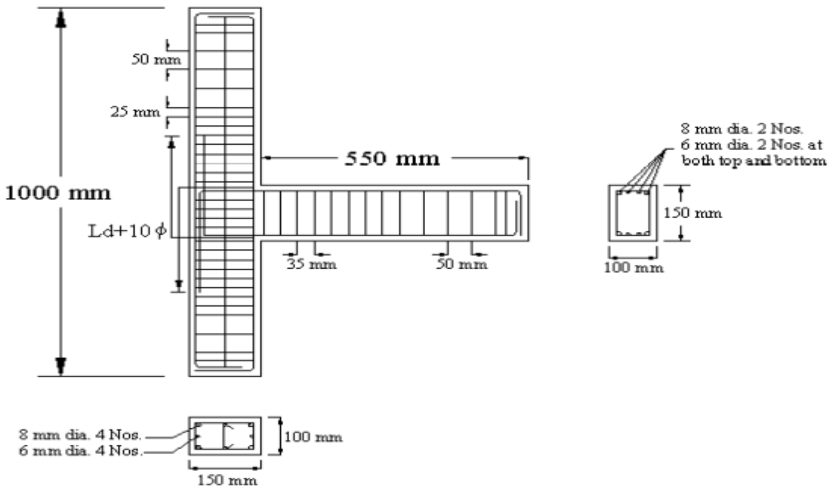

Fig. 2 Reinforcement details of the exterior beam column joint as per IS 13920 (BIS, 1993)

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

5th National Conference on Science, Technology and Communication Skills – NCSTCS 2K22

Narula Institute of Technology, Agarpara, Kolkata, India

Vol. 9, Special Issue 2, September 2022

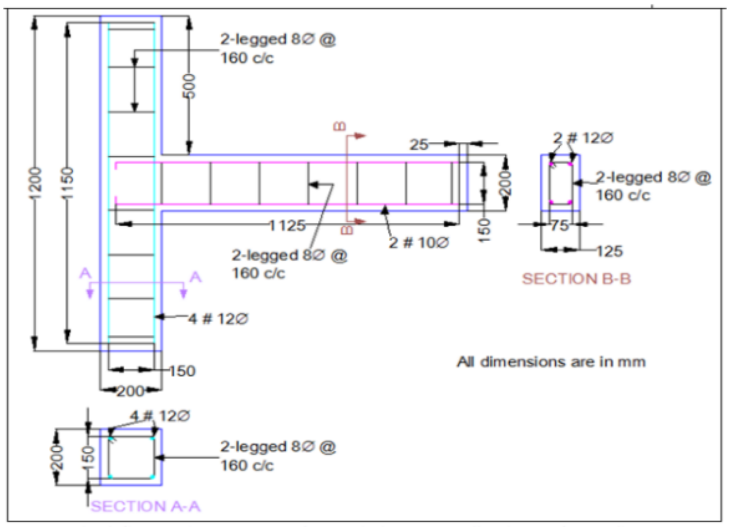

Fig. 3 Building frame consider for this study from Minakshi Vaghani, Dr. S.A. Vasanwala, Dr. A.K. Desai (Performance of RC Beam Column Connections Subjected to Cyclic Loading.

III. MATERIAL PROPERTIES AND MODELING

In the model specimen the material properties were followed as per the experimental set up. In the first specimen the height of column is 1000 mm. Cross section of the column was 150 mm x 100 mm. It had four 8 mm dia bar and four 6 mm dia bar both top and bottom. Dia of column stirrups bars were 3 mm @ 100 mm c/c. Length of the beam was 550 mm long with a cross sectional area of 150 mm x 100 mm. Beam has two 8 mm dia bar and two 6 mm dia bar both top and bottom. The stirrups dia were 3 mm @ 35 mm c/c up to 270 mm from the joint and @ 50 mm c/c for the remaining length. Total 11 stirrups at column and 14 stirrups in beam were present. Additional U- bar with extended length up to the beam core was given as per SP 34, there is no joint stirrups present.

In the 2nd specimen all the parameters were same as specimen 1 but column stirrups are situated @ 25 mm c/c for a distance of a 230 mm c/c from either side of the joint and 50 mm c/c for the remaining portion. Total 30 stirrups were provided at column and 14 stirrups for beam. The additional U- bars are not used in this specimen. M 30 grade concrete and Fe- 415 grade steel were used in both the specimens. After prepared the model dynamic implicit step was used to run the programme with total step time of 1 sec, with time increment of 0.1. Loads are given as per the experimental setup and bottom end of the column was kept pinned support and other was roller support.

In the third specimen the length of the column is 1200 mm. The cross-sectional area of the column was 200 mm * 200 mm. 4 numbers of column longitudinal bars and 8mm dia stirrups @ 160 mm c/c from top to bottom were given. Beam length is 1025 mm from the joint and it is situated 500 mm below from the column top. Cross sectional area of the beam was 125 mm * 200 mm. 2 numbers of longitudinal bars were given both top and bottom.

Beside all these material properties, there are some default parameters required to run a job in abaqus. The beam and column part were made using solid and homogeneous section. Stirrups and reinforcing bar were modelled using truss element of beam section in abaqus. Stirrups and bars were embedded within beam and column using embedded region property.Ties were given between beam and column to perfectly placed the joint. Two types of elements used for this work. A Linear hexahedron C3D8R element type was approached for beam and column part and T3D2 element type was approached for beam stirrups, column stirrups and reinforcing bars. Other parameters used in these models are given below. As these parameters were used only for analytical work, hence all the parameters were kept same for the given specimens.

TABLE I MATERIAL PROPERTIES FOR CONCRETE

Density	2400kg/m3
Young's modulas	2.8GPA
Poison ratio	0.2

IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

5th National Conference on Science, Technology and Communication Skills – NCSTCS 2K22

Narula Institute of Technology, Agarpara, Kolkata, India

Vol. 9, Special Issue 2, September 2022

TABLE 2 CONCRETE DAMAGE PLASTICITY PARAMETER

Dilation angle (β)	Eccentricity	fb0 / fc0	K	Viscosity parameter
30	0.1	1.1	0.667	1e-005

TABLE 3 MATERIAL PROPERTIES OF STEEL

Density	7850kg/m3
Young's modulas	210GPA
Poisson's ratio	0.3

IV. LOADING AND BOUNDARY CONDOTION

Loads are given as per the experimental setup. In experiment, reverse cyclic loading is applied with constantly increasing load up to its failurein order to perform seismic excitation at the end of the beam. One end of column was given hinge support and other is roller support. The axial load applied in the first specimen designed according to IS 456 and SP 34 was 15.92 KN which was 3 % of its capacity. In the second specimen detailed as per IS 13920 axial load was 53.06 KN which was 10 % of its capacity. Total 5 cycles were applied to observe the cracking pattern, damage in joint, load deflection curve. After applying all this loads and boundary conditions in the model (Fig. 2) the dynamic implicit step was used to run the programme with total step time of 1 secwith a time increment of 0.1. 100 KN of static load also applied at beam end. (Fig-5)

In the third experiment the axial load of 75 KN which was 40 % of the column capacity was applied at column top.Total step time chosen was 1.1 sec with time increment of 0.1. Columns was pinned support and beam had a displacement of 5 mm at the end. The 5 mm displacements mean 5 mm positive as well as 5 mm negative displacement.

Along with this load a gravity load of 9.81 KN also applied on these three models. There was no mention about gravity data in those 3 papers hence few analytical papers and some online resources helped to get gravity load data.

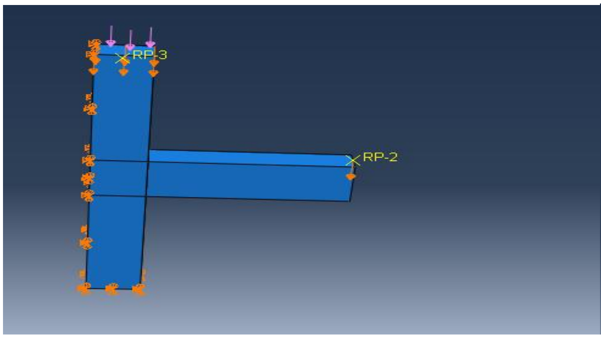

Fig.6 Load and boundary condition of the specimen 1&2

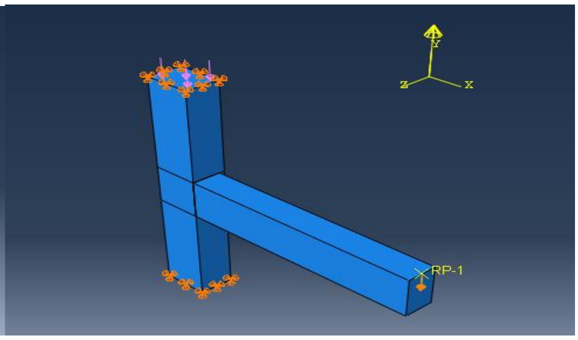

Fig.7 Loading and boundary condition of the specimen 3

V. RESULTS AND DISCUSSIONS

In experimental studies they evaluate many parameters like failure pattern, deformation, energy dissipation, tensile stresses, stiffness degradation, load deflection curve. But this study mainly focused on load deflection curve at beam and failure pattern at joint Beam tip displacement datahad been put it in X-axis and load in Y-axis to get force displacement curve for all the three cases.In abaqus at first displacement vs time and force vs time data was collected then combined them to get force vs displacement data. Joint deflections and joint stress results were also given to understand the joint behaviour.

IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

5th National Conference on Science, Technology and Communication Skills – NCSTCS 2K22

Narula Institute of Technology, Agarpara, Kolkata, India

Vol. 9, Special Issue 2, September 2022

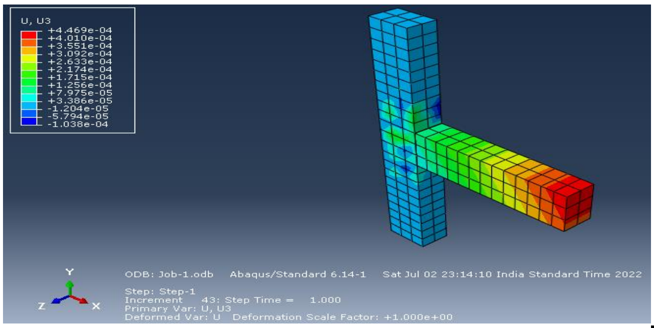

Fig.7 Joint deformation of specimen- 1

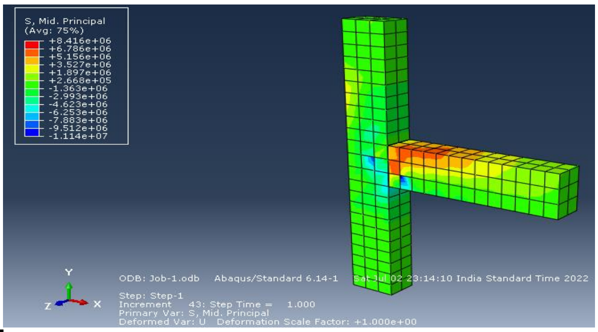

Fig. 8 Joint stress of specimen- 1

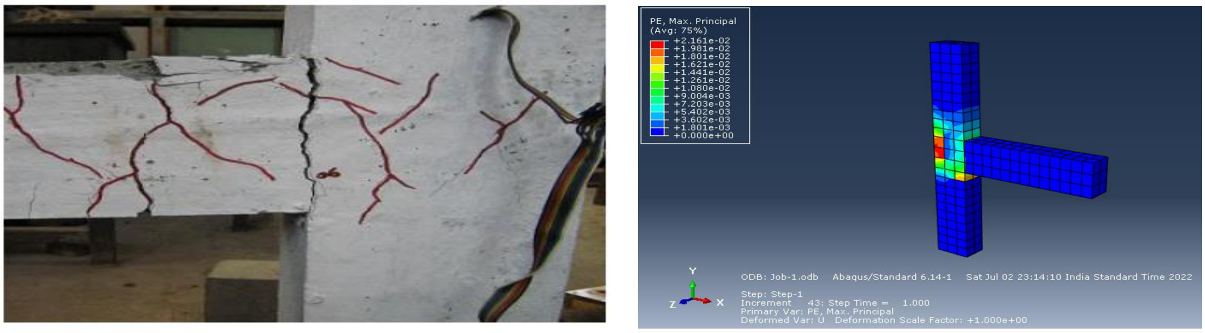

Fig. 9 Comparison of joint failure between A) Test specimen and B) Simulated model of specimen -1

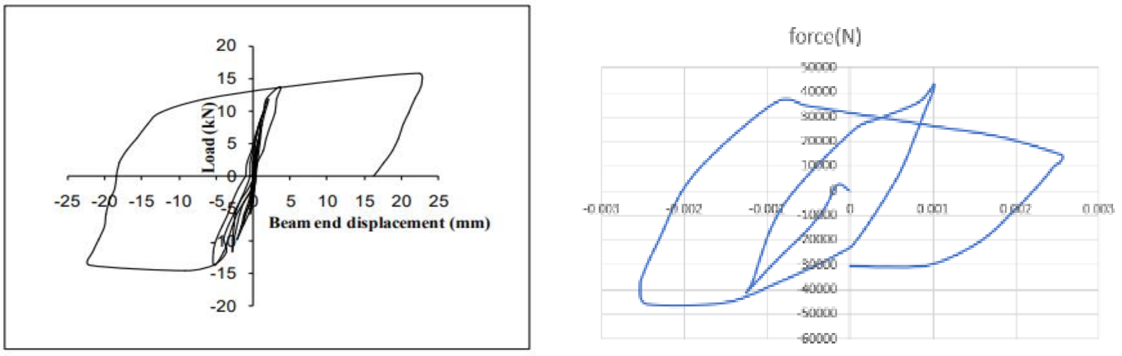

Fig. 10 Comparison of load deflection curve of A) Test specimen and B) Simulated model of specimen- 1

Displacement results clearly shows that beam end had maximum displacement value as the cyclic amplitude for beam load was given in that zone. That is why maximum stress occurred at joint region to hold the beam tight. There were no additional stirrups at the joint region for specimen- 1, but a pair of U- bar was used to provide additional support and counteract this stress and it was proved beneficial. Development length also well distribute the stress coming from the beam to the column.From the force deflection curve it is observed that, maximum deflection occoured in beam portion, which is nearly 2.5 mm in +ve direction and 2 mm in -ve direction in specimen 1, where as maximum reaction force in that same area to counteract the deflections were +38 KN and -42 KN. In experimental work the upward and downward deflections were +25 mm and -18 mm respectively.Where as maximum load offered by the column were +12 KN and -13 KN in upward and downward direction respectively. Hence the values nearly matches to each other. Max stress observed at joint region was 5.36e+06 N/ mm2 at 0.72 sec

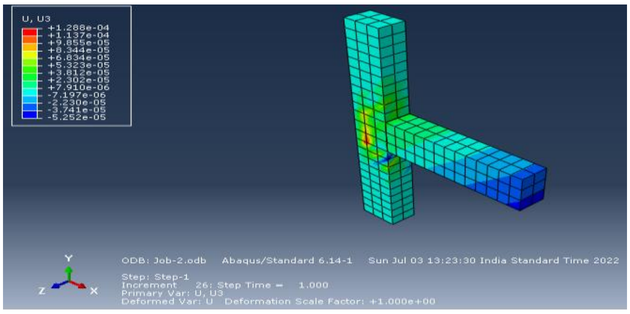

Fig. 11 Joint deformation of specimen- 2

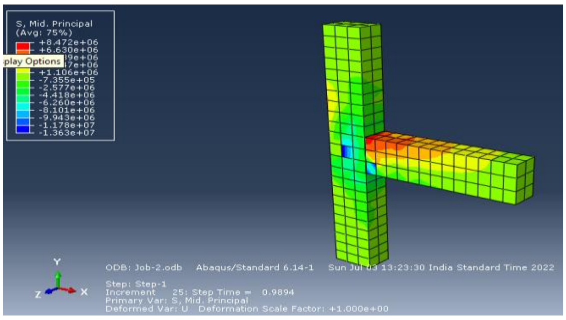

Fig. 12 Joint stress of specimen- 2

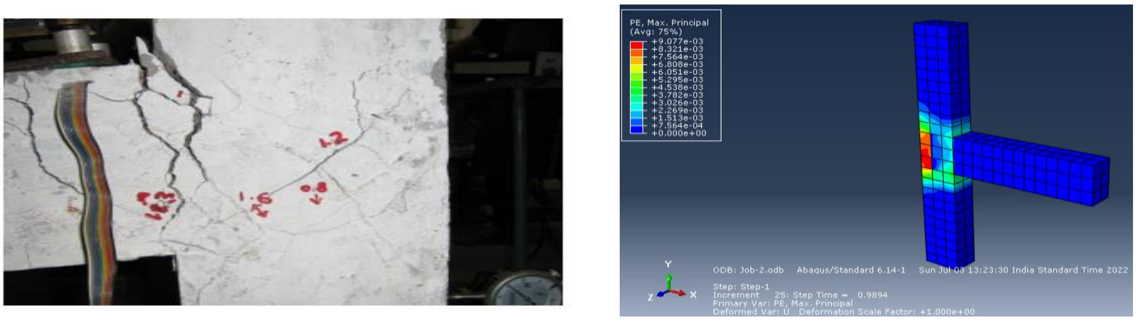

Fig. 13 Comparison of joint failure between A) Test specimen and B) Simulated model of specimen -2

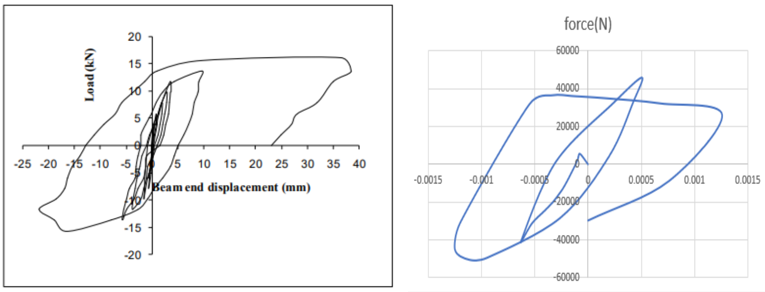

Fig. 14 Comparison of load deflection curve of A) Test specimen and B) Simulated model of specimen- 2

Specimen 2 also showed similar types results like previous one. But here additional stirrups were provided instead of U- bar.Similar cracks were also observed at same region for two results. In the experimental results it was totally collapsed but model result had minor effect comparatively. It showed that experimental work had more demolishing effect than analytical work. The load deflection curve and joint beahviour shows that even seismic design consideration is not sufficient to counteract the deformation. The type of load used in specimen 1 and specimen 2 it showed that column felt maximum stress earlier than beam and also reaction force is more in column. But beam deformed heavily due to the repeated load on beam top in the both the specimens. Here force vs displacement comparision was done at beam top (similar to experimental work) for all the specimen.

In specimen 2 the upward and downward defelctions were +1.3 mm and -1.4 mm respectively and the forces were +40 KN and -42 KN whereas in the experimental work the maximum deflections were +40 mm and -15 mm with maximum reaction force of 15 KN and -14 KN in upward and downward respectively. Maximum stress developed at joint was 9.31e+06 N/ mm2 at 1 sec. The force displacement curve was almost identical with experimental result.

IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

5th National Conference on Science, Technology and Communication Skills – NCSTCS 2K22

Narula Institute of Technology, Agarpara, Kolkata, India

Vol. 9, Special Issue 2, September 2022

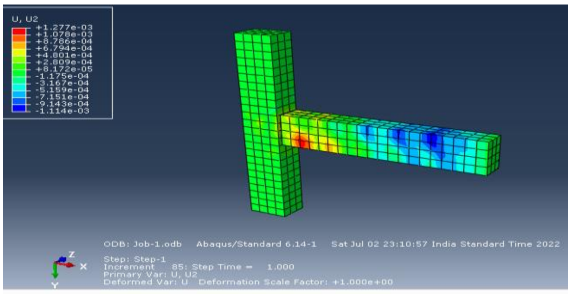

Fig. 15 Joint deformation of specimen- 3

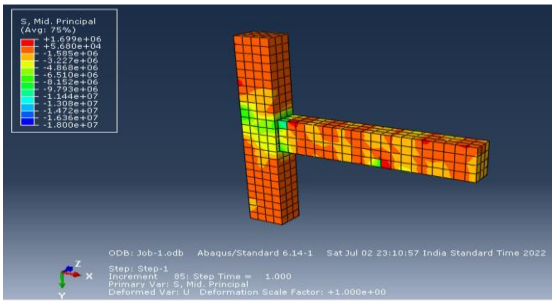

Fig. 16 Joint stress of specimen- 3

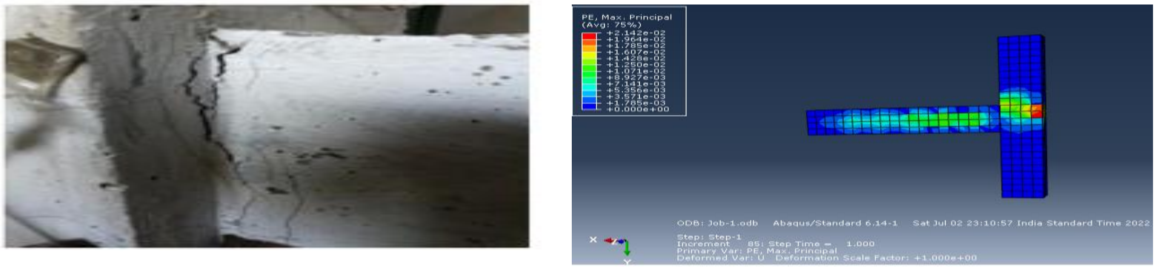

Fig. 17 Comparison of joint failure between A) Test specimen and B) Simulated model of specimen -3

Fig. 18 Compression of load deflection curve of A) Test specimen B) Simulated model of specimen 3

In the 3rd specimen the analytical result showed that the model was well deformed at the joint area, also maximum stress recorded in that zone to beam. Failure zone was exactly similar to the experimental work as clear cracks were found at the joint for both the specimens. Force displacement curve pattern were also same. Maximum and minimum force recorded in model were +27 KN and -25 KN, where as in experimental model it were +40 KN and -30 KN. Maximum and minimum displacements at beam end were 6mm in positive and negative direction both and in the experimental work it was +50 mm and -52 mm. Maximum stress at the joint section was 1.67e+06.

Therefore, the results suggest that this 3D model is well capable of justify the experimental work as well as their results. Though there were some basic parameters taken from other experimental works, which needs to be given in the original work and hence there were some differences observed in results data.

VI. CONCLUSIONS

The purpose of this paper is to prepare a model identical with an experimental work, to understand that how well we can simulate any model and also the comparative behaviour of the outcomes. There are other softwires available but Abaqus had the best reviews in academics and there were many large problems were solved through it. That is why it is chosen. Though there were identical results observed in failure pattern but in case of load displacement curve some differences was observed in all three cases. It can be clearly observed that numberof datawas considerably less whereas the pattern of curve was almost same.

There were few reasons for all these partially different results, such as the material properties were not exactly same as lab work. The type of cement, sand and other ingredients used were completely different with analytical work where this type of things kept in a default manner which provided by the software only. In laboratory they might mixed up other material like plasticizer, catalyst or other reactive material which influence the test results. Also, the quality of cements, sand, aggregate, water cement ratio were the key factors for varied results.

Spacings used in beam and column were not clearly mentioned, force displacement data used under the beam load and displacement, also for gravity load were not specified. Still the analytical works tried to present a satisfactory result which nearly matched the experimental work and in future surely there will be more development on this work observed.

REFERENCES

[1] Ahmed G. Asran, Hassan H. EL-Esnawi, Sabryfayed Numerical Investigationof RC Exterior Beam Colum Connections underMonotonic Loads. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 13, Issue 1 Ver. VI (Jan- Feb. 2016), PP 60-67
[2] BIS (1987a). ―IS 12269: 1987—Indian Standard Specification for 53 Grade Ordinary Portland Cement‖, Bureau of Indian Standards, New Delhi.
[3] BIS (1987b). ―SP 34: 1987—Handbook on Concrete Reinforcement and Detailing‖, Bureau of Indian Standards, New Delhi.
[4] BIS (1993). ―IS 13920: 1993—Indian Standard Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces—Code of Practice‖, Bureau of Indian Standards, New Delhi.
[5] BIS (2000). ―IS 456: 2000—Indian Standard Plain and Reinforced Concrete—Code of Practice (Fourth Revision) ‖, Bureau of Indian Standards, New Delhi.
[6] BIS (2002). ―IS 1893 (Part 1): 2002—Indian Standard Criteria for Earthquake Resistant Design of Structures, Part 1: General Provisions and Buildings (Fifth Revision) ‖, Bureau of Indian Standards, New Delhi
[7] Chalioris, C.E., Favvata, M.J. and Karayannis, C.G. (2008). ―Reinforced Concrete Beam-Column Joints with Crossed Inclined Bars under Cyclic Deformations‖, Earthquake Engineering & Structural Dynamics, Vol. 37, No. 6, pp. 881–897.
[8] Clyde, C., Pantelides, C.P., Reaveley R.D. (2000). Performance based evaluation of exterior reinforced concrete building joints for seismic excitation. PEER Report 2000/05 Pacific Earthquake Research Center, College of Engineering University of California, Berkele
[9] Dr.S.R.Uma Prof. A. Meher Prasad Seismic Behavior of Beam Column Joints in Reinforced Concrete Moment Resisting Frames ITK-GSDMA-EQ31-V1.0 A - Earthquake Codes IITK-GSDMA Project on Building Codes.
[10] El-Amoury, T. and Ghobarah, A. (2002). ―Seismic Rehabilitation of Beam-Column Joint Using GFRP Sheets‖, Engineering Structures, Vol. 24, No. 11, pp. 1397–1407.
[11] J. S. Kaung and h. F. Wong Effectiveness of Horizontal Stirrups in Joint Core for Exterior Beam-Column Joints with Nonseismic Design. The Twelfth East Asia-Pacific Conference on Structural Engineering and Construction
[12] Karayannis, C., Sirkelis, G. and Mavroeidis, P. (2005). ―Improvement of Seismic Capacity of External Beam-Column Joints Using Rectangular Spiral Shear Reinforcement‖, Proceedings of the Fifth World Conference on Earthquake Resistant Engineering Structures (ERES V), Skiathos, Greece, pp. 147–156.
[13] Kiran, R., and Genesio, G., (2014), "A case study on pre 1970sConstructed concrete exterior beam-column joints", Case Studies inStructural Engineering, Vol.1, pp. 20–25
[14] K.R. Bindhu, P.M. Sukumar and K.P. Jaya Performance Of Exterior Beam-Column Joints Under Seismic Type Loading. ISET Journal of Earthquake Technology, Paper No. 503, Vol. 46, No. 2, June 2009, pp. 47–64
[15] M.A. Najafgholipour, S.M. Dehghan, Amin Dooshabi, Arsalan Niroomandi Finite Element Analysis of Reinforced Concrete Beam-Column Connections with Governing Joint Shear Failure Mode. Latin American Journal of Solids and Structures 14 (2017) 1200-1225.
[16] Minakshi Vaghani, Dr. S.A. Vasanwala, Dr. A.K. Desai Performance of RC Beam Column Connections Subjected to Cyclic Loading IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 12, Issue 2 Ver. VII (Mar - Apr. 2015), PP 48-53
[17] Mohamed H. Mahmoud, Hamdy M. Afefy , Nesreen M. Kassem,Tarek M. Fawzy "Strengthening of defected beam–column joints usingCFRP" Cairo University, Journal of Advanced Research, Vol.5, P:67-77, 2014.
[18] Recommendations for Design of Beam-Column Connections in Monolithic Reinforced Concrete Structures Reported by Joint ACI-ASCE Committee 352 and ACI 318-02 for seismic design
[19] Said M. Allam, Hazem M.F. Elbakry, Israa S.E. Arab Exterior reinforced concrete beam column joint subjected to monotonic loading Alexandria Engineering Journal (2018) 57 4133- 4144.
[20] S. S. Patil, S. S. Manekari Analysis of Reinforced Beam-Column Joint Subjected to Monotonic Loading ISSN: 2277-3754 ISO 9001:2008 Certified International Journal of Engineering and Innovative Technology (IJEIT) Volume 2, Issue 10, April 2013.
[21] S.V.Chaudhari, K.A.Mukane and M.A.Chakrabarti Comparative study on Exterior RCC Beam Column Joint Subjected to Monotonic Loading International Journal of Computer Applications (0975 – 8887) Volume 102– No.3, September 2014.