Shear Capacity and Shear Reinforcement of Exterior Beam-Column Joint of RC Building

Sujan Mishra
M.Sc. Student
(Infrastructure Engineering and, Management),
Pashchimanchal Campus,
IOE, Tribhuvan University,
Pokhara, Nepal,

Sailesh Adhikari
Lecturer
Pashchimanchal Campus
IOE, Tribhuvan University,
Pokhara, Nepal,

Deepak Thapa,
Lecturer
Pashchimanchal Campus
IOE, Tribhuvan University,
Pokhara, Nepal,

***Abstract*:- In reinforcement concrete moment resisting frame joints between beams and columns are critical zones which resisted both lateral and vertical load subjected to building. Nepal is seismically active zone due to this earthquake frequently happen and failure beam column joint fail to withstand high shear force developed on joint so this study determined shear reinforcement on joint to resist shear force developed on joint to make the joint ductile. The main objective of this study was to determine shear capacity and shear reinforcement in exterior beam-column joint of RC building. For this study modelling of nine residential building was done in ETABS software. From the obtained results this study indicated that more increase in shear force, column-beam size, longitudinal and shear reinforcement on beam-column by increasing the story height and bay width of building. This study indicated that small change in shear force by changing the concrete grade and number of bays. This study used IS 13920:2016, ACI 352R.02 and NZS 3101.1:2006 codal provision to determine joint shear strength and joint shear reinforcement. NZS 3101.1:2006 codal provision showed that minimum joint shear strength. NZS gave more joint shear reinforcement in external beam-column joint whereas IS 13920:2016 gave minimum joint shear reinforcement.**

Keywords— RC Building, Exterior Beam-Column Joint, Joint Strength, Joint Shear Reinforcement

I. INTRODUCTION

Due to sideways and downward movement of the Indian plate underneath the Eurasian plate causes earthquake frequently in Nepal (Chaulagain et al., 2015). Major Purpose of constructing earthquake resisting building is prevention of failure of building in lateral load. Proper design of beam-column joint is one of the important parameters of earthquake resisting building. Joint could develop sufficient inelastic capacities to disperse seismic energy (Kadarningsih et al., 2014) . In many moment resisting RC frame failure seen beam-column joint. Design check for gravity load and live load is not critical for beam-column joint in normal design but during the earthquake or lateral force heavy distress develops due to shear in joints that lead to failure and studies of seismic effect on joints have undertaken only past three to four decades(Uma & Jain, 2006). Tiwari and Adhikari (2020) studied the behavior of building in the variation in the stiffness and mass subjected to seismic load however the results specified in the joint was not obtained. This study extends the results to the joint results.

Beam-column joint is the zone of intersection of beams and columns, which is critical zone in moment resisting reinforced concrete frame. During ground shaking large force acting on it which has influence on structure response. For considering effect of shear force developed on joint, it is assumed to be rigid fails. When shear force exceeds the limit shear failure occurs which is always brittle in nature and this failure is not an acceptable structural performance especially in seismic condition so that joints should have adequate strength and stiffness to resist the internal forces developed by the framing members(Uma & Prasad, 2015). Tiwari et. al. (2020) attempted to study different irregular low-rise buildings is considered for the modelling, linear static analysis was performed to check time period, displacement, drift and storey shear of models, but the localized joint output was not reported in the study.

Columns are constructed earlier than beam slab and less compaction on beam-column joint due to congestion of reinforcement on joint so that joint strength may be differ in same concrete grade of column, beam and slab. Load carrying capacity of joint depends upon the ductility of joint so sufficient ductility should be provided on joint. Visible damage will be seen on joint during inelastic deformation of beams and column and effect of this force is known as plastic hinge. During inelastic rotation, the ductility capacity of all members is transferred to the joint so that the damage at the joint will be substantial and should be avoided. The formation of a plastic hinge is expected, where permitted structural damage occurs. Thus, it is very important in seismic design that the damage of a plastic hinges occurs in the beam, rather than in the column. During horizontal earthquakes, moments and shear forces acting on the beams and columns of the frame building are resulting in internal-vertical and horizontal forces on the face of the joint core. The internal forces produce a resultant acting in the joint core, either a diagonal tensile or compression stress. Diagonal tensile stresses and compressive forces result in cracking and crushing of the concrete core. If the shear resistance at the joint core is insufficient, there will be failures along the diagonal of the joint core. The design of the shear beam-column joint of steel reinforced concrete (SRC) contributed much to the design of joints under seismic loads (Kadarningsih et al., 2014). According to report ACI Committee 352 by (Bonacci & Leon, 1988) beam-column joints are interior, exterior, corner, roof interior, roof external and roof corner which is shown in figure 1. In figure slabs are not shown for clarity and wide beam cases are not shown.

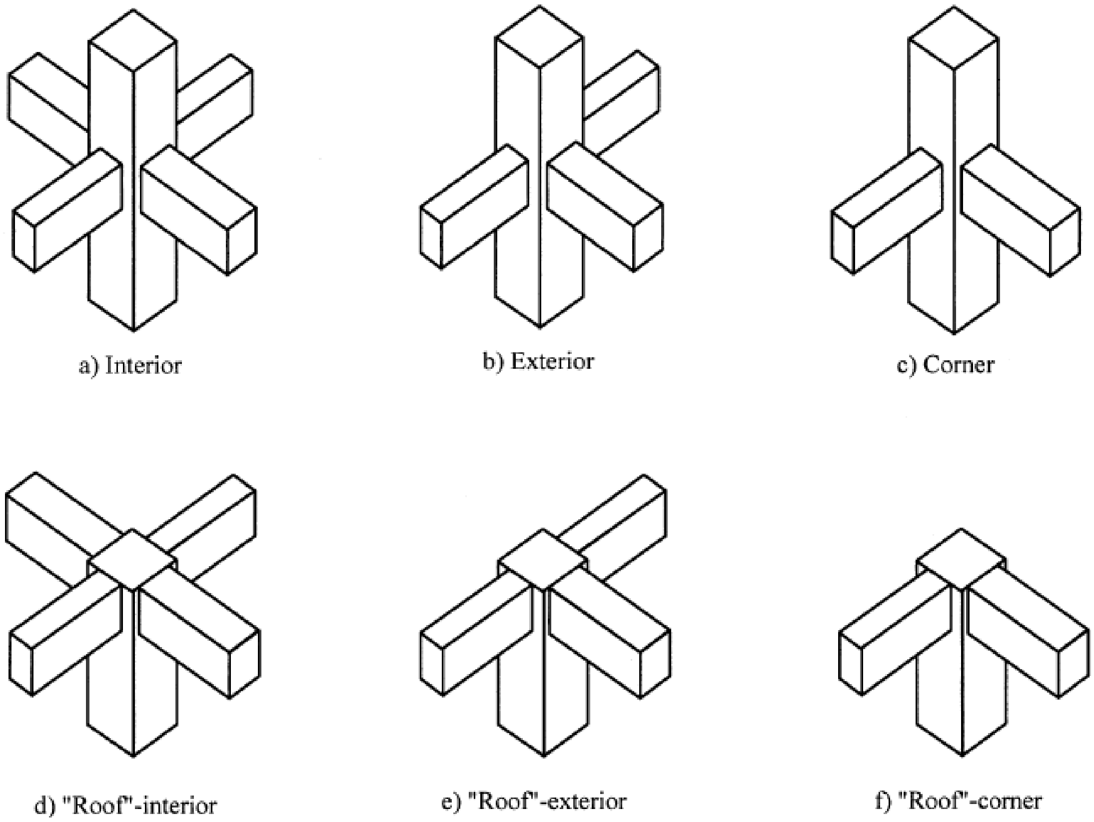

Figure 1: Typical Beam-Column Joint

Tran et al. (2018) developed formula to predict the shear strength of exterior RC beam-column joints where beam longitudinal reinforcements are anchored into the joint by headed bars and those formula based on a regression analysis which used the database collected from 30 experiments. It was shown that, concrete compressive strength, beam rebars details and joint shear reinforcement also play vital role in the joint shear strength. Pimanmas & Chaimahawan (2011) focused on joint strengthening method by expanding the joint area by experimentally with under control specimen to investigate the shear strength of specimens with expanded joint with non-ductile reinforcement details. They found that sufficiently joint enlargement is effective to reduce shear stress transmitted in the joint panel, failure mode is changed from brittle joint shear failure to moderately ductile flexural failure in beams, plastic hinge is moved from column face to the edge of enlargement and if the size of enlarged area is small, the failure mode is concrete crushing in the joint panel and expanded areas.

II. MODELLING BY ETABS

In the present study 9 different model of reinforced concrete building is modelling and analyzing in ETABS software. This study has been chosen RC building of 3 story building and variation in parameters such as building story height, bay width, number of bays, size of beam column and grade of concrete. Following parameters of building has been taken for modelling and analyzing of this study.

1. Width of the bays: 3m, 3.5m and 4m
2. Floor heights: 3m 3.5m and 4m
3. Number of the bays: 2, 3 and 4
4. Grade of the concrete: 20MPa, 25MPa and 30 MPa
5. Size of column: 300mmx300mm, 350mmx350mm
6. Size of beam: 230mmx300mm, 230mmx350mm 300mmx350mm
7. Earthquake load: Zone V, importance factor 1, response reduction factor 5, soil type II, mass source took from (IS 1893 part 1, 2002)

8. Wall load: 230mm thick brick wall of unit weight 18.85 KN/m^3 from IS 875(Part 1) reported by (IS 875 part 1, 1987)
9. Live load: 2 KN/m^2 for all room and 1.6 KN/m^2 for roof had taken from (IS 875 part 2, 1987)

From above parameter this study categorized 9 models of RC building and modelling is done by using ETABS software. In all model Fe415 reinforcement is assigned in all frame members. This study assigned square column as frame element, rectangular beam as frame element and slab as membrane element and only one parameter is changed in each model.

Model 1: M20 concrete, bay width 3m, story height 3m, 3 story, 3x3 bay building
Model 2: M25 concrete, bay width 3m, story height 3m, 3 story, 3x3 bay building
Model 3: M30 concrete, bay width 3m, story height 3m, 3 story, 3x3 bay building
Model 4: M20 concrete, bay width 3m, story height 3.5m, 3 story, 3x3 bay building
Model 5: M20 concrete, bay width 3m, story height 4m, 3 story, 3x3 bay building
Model 6: M20 concrete, bay width 3.5m, story height 3m, 3 story, 3x3 bay building
Model 7: M20 concrete, bay width 4m, story height 3m, 3 story, 3x3 bay building
Model 8: M20 concrete, bay width 3m, story height 3m, 3 story, 4x4 bay building
Model 9: M20 concrete, bay width 3m, story height 3m, 3 story, 2x2 bay building

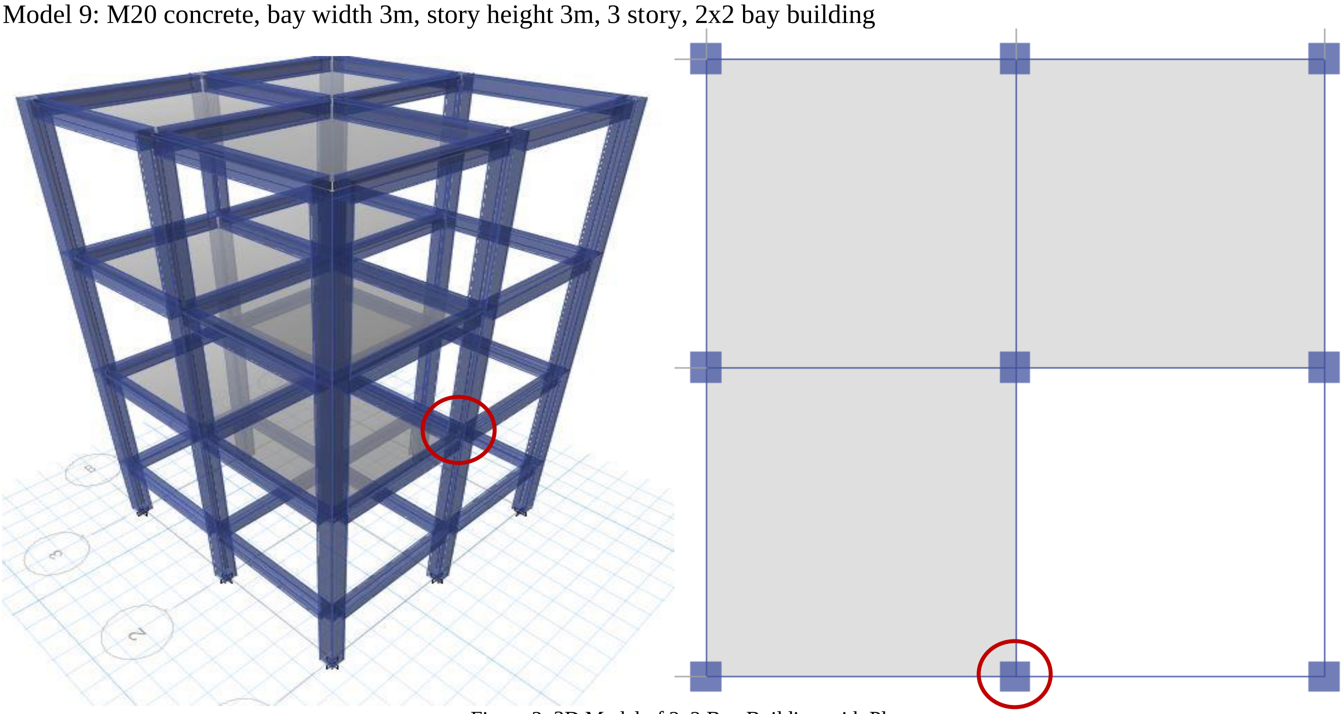

Figure 2: 3D Model of 2x2 Bay Building with Plan

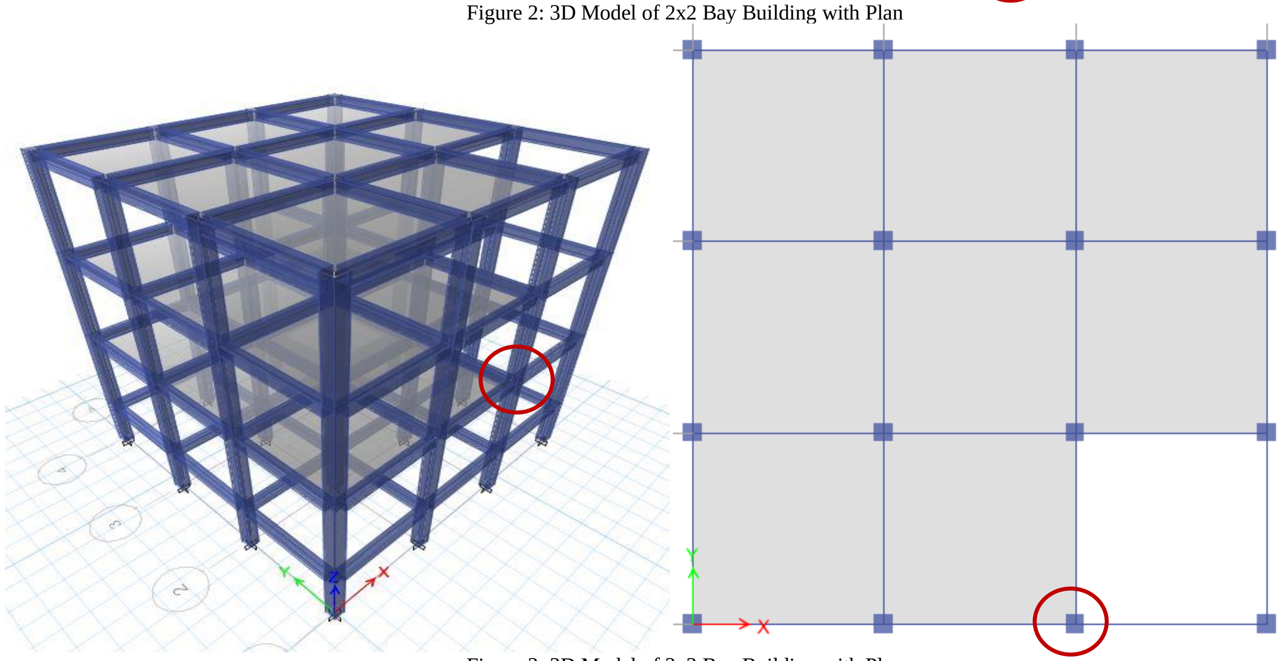

Figure 3: 3D Model of 3x3 Bay Building with Plan

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 03, March-2021

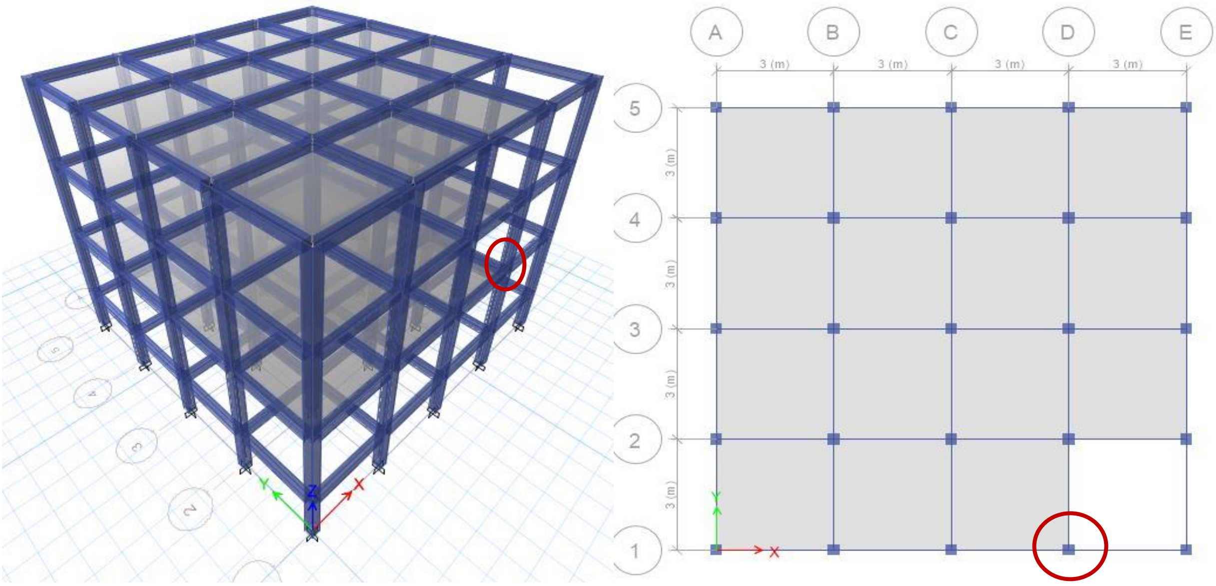

Figure 4: 3D Model of 4x4 Bay Building with Plan

III. RESULTS AND DISCUSSIONS

The nine RC building models are analyzed. This study finds exterior beam-column joint with maximum shear force on beam and column of all nine models, longitudinal and shear reinforcement of beam and column exterior joint, joint shear strength, joint shear reinforcement of exterior joint and their spacing according to IS 13920:2016, ACI 352R.02 and NZS 3101.1:2006 code provision. The results of each parameters are discussed below.

1.1. Shear force on Beam Column of exterior Joint

Maximum shear force develops in 2x2 bay building at column 4 at story 1 and beams connected to column 4 are beam 3, beam 7, beam 8 which formed an exterior beam-column joint. Maximum shear force develops in 3x3 bay building at column 9 at story 1 and beams connected to column 9 are beam 7, beam 14, beam 15 which formed an exterior beam-column joint. Maximum shear force develops in 4x4 bay building at column 16 at story 1 and beams connected to column 16 are beam 13, beam 23, beam 24 which formed an exterior beam-column joint. Maximum shear force develops in model 7 that means shear force also increases with increases in story height of building. As increases in bay width of building shear force is also increasing. There is small variation in shear force as increases in grade of concrete and number of bays.

Table 1: Shear Force on Beam and Column of Exterior Joint

	Column 9 top shear (KN)	Column 9 bottom shear (KN)	Beam 7 shear (KN)	Beam 14 shear (KN)	Beam 15 Shear (KN)
Model 1	35.46	21.90	75.07	68.35	85.67
Model 2	37.58	23.03	77.23	70.76	88.10
Model 3	38.72	24.01	79.08	72.38	88.67
Model 4	32.92	20.31	83.25	76.04	94.63
Model 5	33.15	21.78	95.65	88.48	102.78
Model 6	45.65	30.13	87.04	80.42	99.84
Model 7	61.54	40.00	104.82	99.00	114.35
Model 8	35.84	21.64	75.11	69.53	85.63
Model 9	36.59	22.23	75.31	70.23	86.02

1.2. Longitudinal and Shear Reinforcement of Exterior Beam-Column Joint

As increases in grade of concrete longitudinal reinforcement of column decreases. Similarly, as increases in bay width of building and story height of building longitudinal reinforcement in both beam and column increases more. Longitudinal reinforcement of external beam column of each model is tabulated below.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 03, March-2021

Table 2; Longitudinal Reinforcement of Exterior Beam-Column Joint

		Column 9		Beam 7		Beam 14		Beam 15
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
		(mm^2)		(mm^2)		(mm^2)		(mm^2)
Model 1	1041	1678	524	349	474	254	510	255
Model 2	1006	1575	531	364	478	268	520	260
Model 3	970	1548	538	378	486	281	518	259
Model 4	1254	4168	595	397	531	275	564	282
Model 5	2484	5920	707	470	640	360	625	313
Model 6	1246	2258	552	347	503	251	565	283
Model 7	1267	2119	731	409	682	344	729	364
Model 8	1039	1729	536	359	478	257	509	255
Model 9	1086	1745	529	349	502	277	512	256

In model 5 shear reinforcement is maximum in both column and beam. As increases in bay width and story height shear force increases so shear reinforcement is also increased. Shear reinforcement of beam and column exterior joint tabulated below.

Table 3: Shear Reinforcement of Exterior Beam-Column Joint

	Column (mm^2)/m	Beam 7 (mm^2)/m	Beam 14 (mm^2)/m	Beam 15 (mm^2)/m
Model 1	332	887	943	681
Model 2	332	915	974	700
Model 3	332	936	998	705
Model 4	332	988	1055	772
Model 5	388	1178	1241	839
Model 6	332	847	898	667
Model 7	387	1049	1094	720
Model 8	332	896	956	679
Model 9	332	923	991	687

1.3. Joint Shear Strength and Joint Shear Reinforcement of Exterior Beam-Column Joint

According to IS code shear strength of joint is proportional to the effective area of joint and grade of concrete so shear strength of exterior beam column joint of model 5 and model 7 had maximum shear strength. This study had taken 2 leg of 8mm stirrups ($100mm^2$) confining reinforcement for all nine models and spacing of these confining reinforcements calculated from clause 8.1 b and clause 8.1.c.2 and provide over length l_o which specified in clause 8.1.a of IS 13920:2016.

Table 4:Joint Shear Strength, confining reinforcement According to IS 13920:2016

	b_j (mm)	w_j (mm)	τ_{jc} (KN)	A_{sh} (mm^2)	S (mm)	A_{sh} mm^2/m	L_o (mm)
Model 1	240	240	309.11	100	75	1333	675
Model 2	240	240	345.6	100	65	1538	715
Model 3	240	240	378.58	100	55	1818	715
Model 4	240	240	309.11	100	75	1333	675
Model 5	290	290	451.33	100	85	1176	680
Model 6	240	240	309.11	100	75	1333	825
Model 7	290	290	451.33	100	85	1176	935
Model 8	240	240	309.11	100	75	1333	675
Model 9	240	240	309.11	100	75	1333	675

According to ACI code shear strength of joint is proportional to the effective area of joint and square root of grade of concrete so shear strength of exterior beam column joint of model 7 had maximum shear strength. This study had taken 2 leg of 10mm stirrups ($157mm^2$) confining reinforcement for all nine models and spacing of these confining reinforcements calculated from clause 4.2.2.2 and clause 4.2.2.3 and provide over length l_o which specified in ACI 352R.02.

Table 5:Joint Shear Strength, Confining Reinforcement According to ACI 352R.02

	b_j (mm)	h_c (mm)	τ_n (KN)	A_{sh} (mm^2)	S (mm)	A_{sh} mm^2/m	L_o (mm)
Model 1	265	240	354.11	157	75	2093	675
Model 2	265	240	395.91	157	60	2617	720
Model 3	265	240	433.69	157	50	3140	700
Model 4	265	240	354.11	157	75	2093	675
Model 5	290	290	468.25	157	80	1963	720
Model 6	265	240	354.11	157	75	2093	825
Model 7	325	290	524.76	157	80	1963	880
Model 8	265	240	354.11	157	75	2093	675
Model 9	265	240	354.11	157	75	2093	675

According to NZS 3101.1:2006 V^*_{jh} calculated by clause 15.3.4. Ø is 0.75 for not based on overstrength. A_{jh} and A_{jv} calculated by using NZS code. NZS code is provided vertical and horizontal shear stirrups over a length of effective depth of column and beam. As increasing the grade of concrete joint shear reinforcement is also increased.

Table 6:Joint Shear Strength, Confining Reinforcement According to NZS 3101.1:2006

	V_{jh} (N)	V^*_{jh} N	A_{jh} mm^2	S_h (mm)	A_{sh} mm^2/m	A_{jv} (mm^2)	S_v (mm)
Model 1	307200	230400	157	60	2617	157	80
Model 2	384000	288000	157	45	3489	157	60
Model 3	460800	345600	157	40	3925	157	60
Model 4	307200	230400	157	60	2617	157	80
Model 5	448533	336400	157	50	3140	157	70
Model 6	307200	230400	157	60	2617	157	80
Model 7	448533	336400	157	50	3140	157	60
Model 8	307200	230400	157	60	2617	157	80
Model 9	307200	230400	157	60	2617	157	80

1.4. Comparison of Shear Capacity of Exterior Beam-Column Joint

According to ACI code 352R.02 gave maximum shear strength of joint of external beam-column joint. In all these code shear capacities of joint depend upon dimension of beam-column joint and grade of concrete. Bar chart of shear capacity obtained from IS code, ACI code and NZS code shown in figure below.

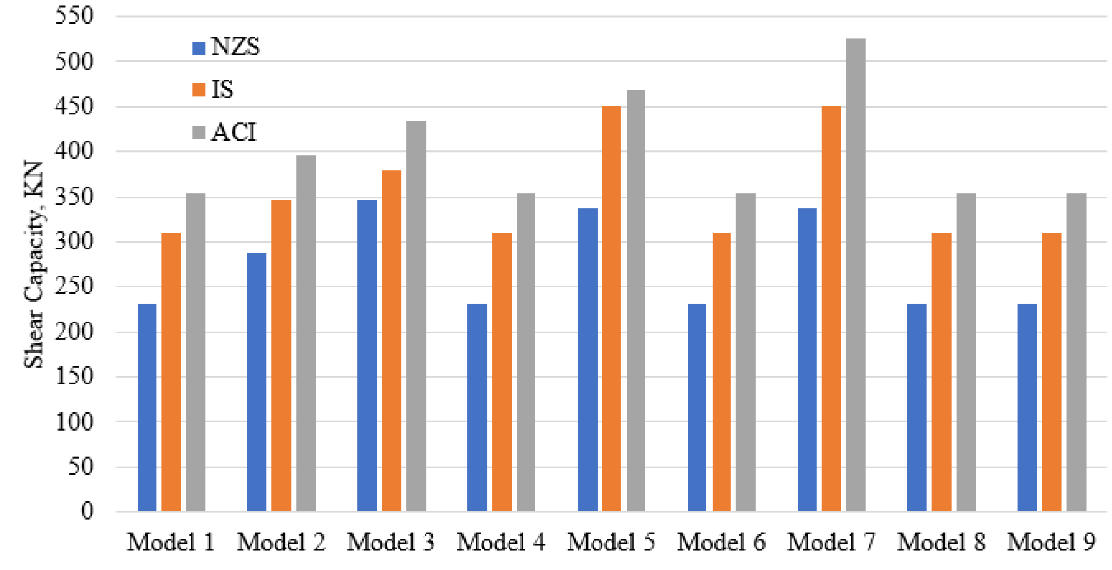

Figure 5:Shear Capacity of Exterior Beam-Column Joint

1.5. Comparison of Shear Force on Beam and Column of Exterior Joint

Shear force obtained from ETABS software presented on bar chart. Figure 6 shows that the as increase in grade of concrete there is slightly change in shear force in both beam and column. As increase in story height, there is more increase in the shear force in beam and but slightly change in column. As increase in bay width of building there is more increase of shear force in both beam and column. As increase in number of bays of building there is no such variation in of shear force in both beam and column.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 03, March-2021

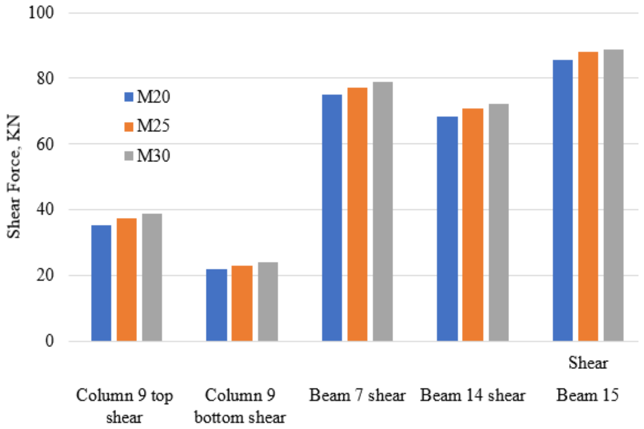

Figure 6:Shear Force due to Change of Concrete Grade

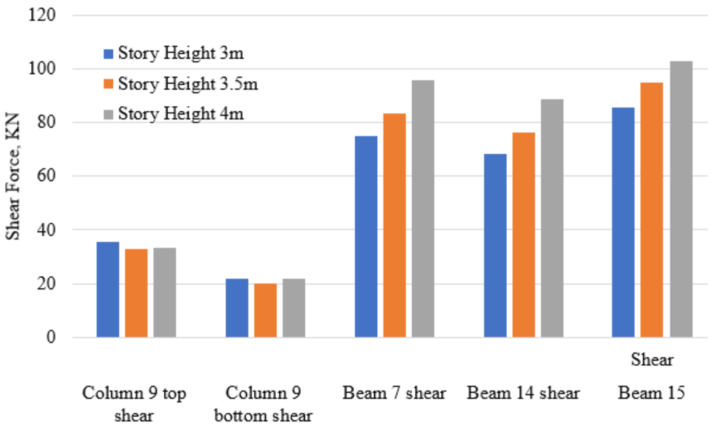

Figure 7: Shear Force due to Change in Story Height

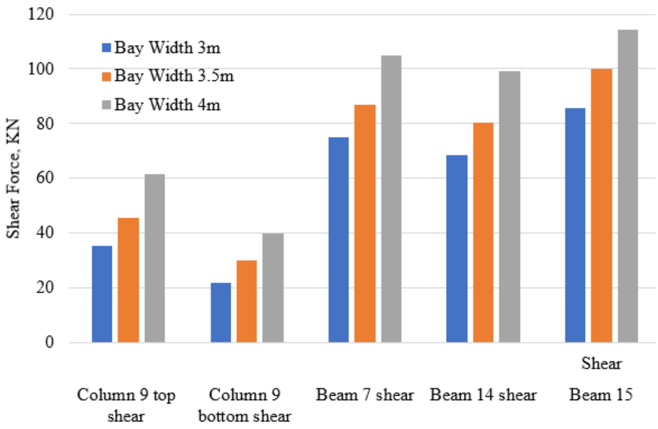

Figure 8:Shear Force due to Change in Bay Width

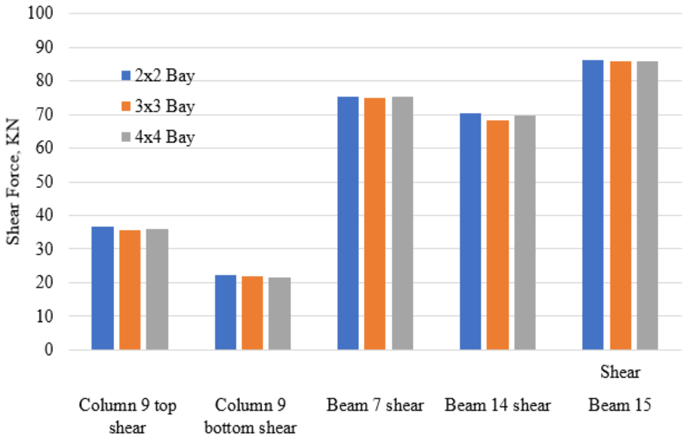

Figure 9:Shear Force due to Change in Number of Bays

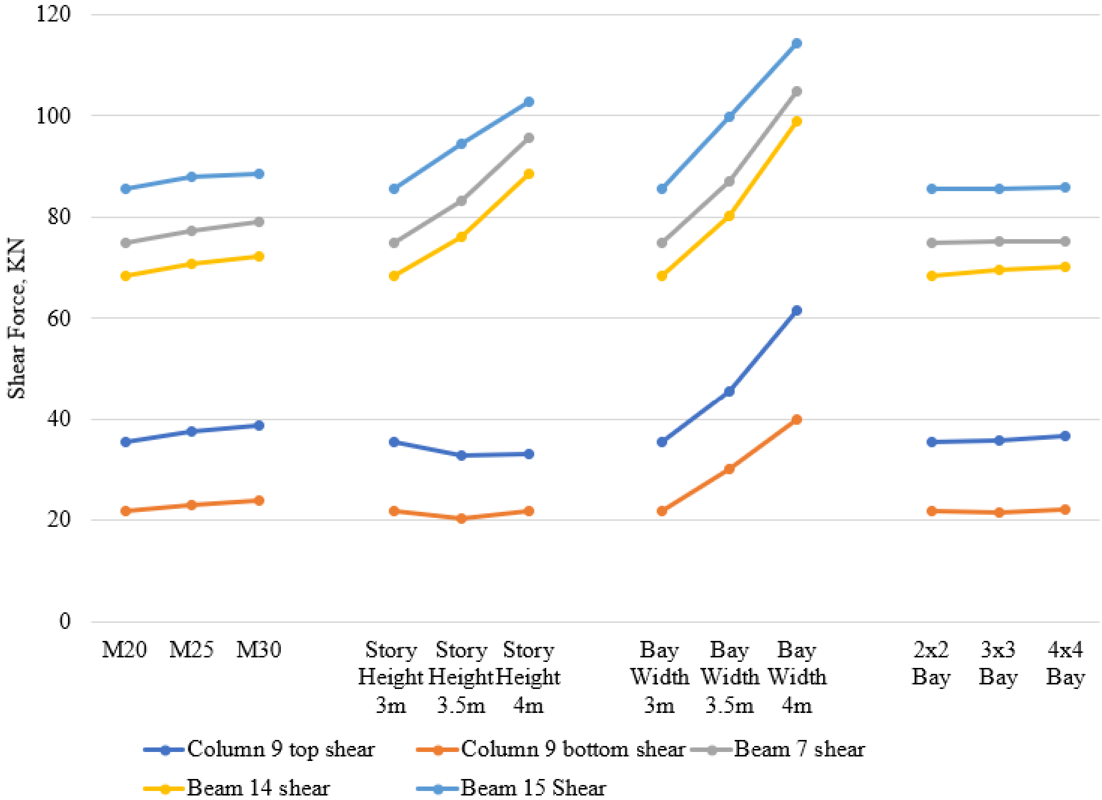

Figure 10: Shear Force on Beam and Column of Exterior Joint

1.6. Comparison of Joint Shear Reinforcement of Exterior Beam-Column Joint

As increase in grade of concrete shear reinforcement on joint increases according to IS, ACI and NZS code provision. As increase in story height and bay width column and beam size increased. As increases in beam and column size joint shear reinforcement decreased according to IS and ACI code but increased according to NZS code. As increases in number of bay joint shear reinforcement remains same for IS, ACI and NZS code which is represented in figure below.

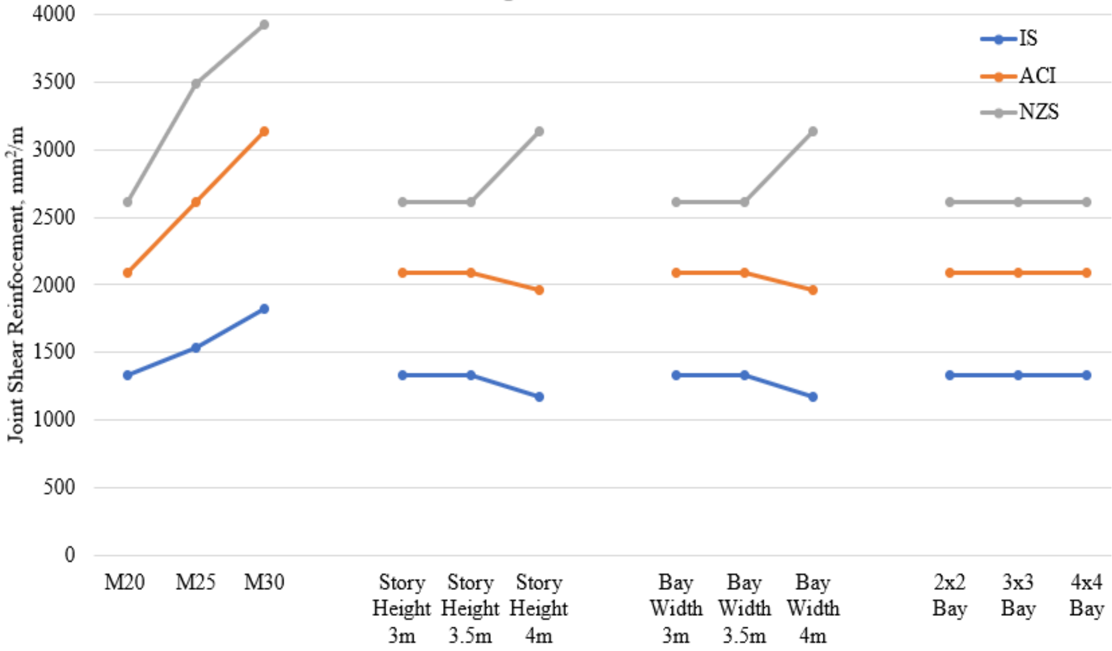

Figure 11: Joint Shear Reinforcement of Exterior Beam-Column Joint

IV.CONCLUSIONS

In the present study, modelling and analysis of 9 building of 3 story was done in ETABS software. This study examined the exterior beam-column joint of highest shear force, tabulated beam-column shear force in each model building and represented in bar chart. Longitudinal reinforcement and shear reinforcement of exterior beam-column joint obtained from ETABS software. Shear capacity, shear reinforcement and spacing of shear reinforcement of exterior beam-column joint was calculated form IS 13920:2016 code, ACI 352R.02 code and NZS 3101.1:2006 code.

1. Maximum shear force in both beam and column was developed in Model 7 of bay width 4m and maximum longitudinal and shear reinforcement of beam and column in Model 5 of story height 4m.
2. There is small change in shear force on both beam and column of exterior beam-column joint by changing the grade of concrete. There is more increase in shear force on beam but less increases in column shear by increasing the story height of building, there was more increase in shear force on both beam column by increasing the bay width of building. There is very less increment in shear force on both beam and column by increasing the number of bays of building.
3. By using the beam-column dimension of exterior joint ACI 352R.02 code gave maximum joint shear strength of exterior beam-column joint whereas NZS 3101.1:2006 code gave minimum joint shear strength with the same dimension of exterior beam-column joint. By increasing the grade of concrete shear capacity of joint increases. Similarly, shear capacity of joint increases with increase in dimension of exterior beam-column joint.
4. By using dimension of exterior beam-column joint NZS 3101.1:2006 code gave maximum joint shear reinforcement whereas IS 13920:2016 code gave minimum joint shear reinforcement with same dimension of exterior of beam-column joint.
5. With increase in grade of concrete shear reinforcement on joint increases more. As increases in number of bay joint shear reinforcement remains same. As increase in story height and bay width column and beam size increased so shear capacity of joint increased due to this joint shear reinforcement decreased according to IS 13920:2016 and ACI 352R.02 code.

REFERENCES

[1] A. Pimanmas and P. Chaimahawan, “Cyclic Shear Resistance of Expanded Beam-Column Joint,” *Procedia Engineering*, vol. 14, pp. 1292–1299, 2011.

[2] Chaulagain, H., Rodrigues, H., Silva, V., Spacone, E., & Varum, H, "Earthquake loss estimation for the Kathmandu Valley", *Bulletin of Earthquake Engineering*, vol.*14*(1), pp. 59–88, 2015

[3] M. Tran, Q. Bui, B. Sentosa, T. Duong, and O. Pl, “Sustainable RC Beam-Column Connections with Headed Bars : A Formula for Shear Strength Evaluation,” *Sustainability*, vol. 10, no. 2, pp. 401, 2018.

[4] R. Kadarningsih, I. Satyarno, and A. Triwiyono, “Proposals of beam column joint reinforcement in reinforced concrete moment resisting frame : A literature review study,” *Procedia Engineering*, vol. 95, pp. 158–171, 2014.

[5] S. R. Uma and M. Prasad, “Seismic Behaviour Of Beam Column Joints In Reinforced Concrete Moment Resisting Frames - A Review,” *Indian Institute of technology Madras, Chennai*, 2015.

[6] S. R. Uma and S. K. Jain, "Seismic design of beam-column joints in RC moment resisting frames – Review of codes," *Structural Engineering and Mechanics.*, vol. 23, no. 5, pp. 579–597, 2006.

[7] S. Tiwari, S. Adhikari, and D. Thapa, "Comprehensive Seismic Performance Assessment of Low Rise RC Buildings by Numerical Modelling," *International Journal of Advance Research, Ideas and Innovations in Technology*, vol. 6, no. 4, pp. 323–331, 2020.

[8] Saugat Tiwari and Sailesh Adhikari, "Seismic Analysis on Mass and Stiffness Variation in RC Buildings by Numerical Modelling," *International Journal of Research and Technology*, vol. 9, no. 04, pp. 123–127, 2020.

[9] T. Paulay and A. Scarpas, "THE BEHAVIOUR OF EXTERIOR BEAM-COLUMN JOINTS," *Bulletin of The New Zealand National Society For Earthquake Engineering*, vol. 14, no. 3, pp. 131–144, 1981.

[10] Z. Pan, S. Guner, and F. J. Vecchio, "Modeling of interior beam-column joints for nonlinear analysis of reinforced concrete frames," *Engineering Structures*, vol. 142, pp. 182–191, 2017.