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Effect of Flexural Strength Ratio at Beam-Column Joint Section to Seismic Response

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Abstract
The vulnerability of RC structures to earthquake remains the challenge still in the modern days. We can never avoid the consequences rather we can only understand the extent of the damages and minimize the risk with the proper designing and planning. The major structural part in the building that is the most vulnerable is the beam column joint. So the variation of flexural strength in the beam column joint is studied in terms of seismic capacity and response. The minimum requirement of flexural strength ratio in the beam column joint is provided by different international codes. These values from different codes contradict with each other. The studies on this particular area was only done for 2-D structures in the past so this research is intended for a 3-D structure. Three sets of models were prepared where the ratio of flexural capacity at B/C joint ranging from less than 1.2 to more than 1.4. The static pushover analysis was performed on the building models. The ratio of flexural capacity more than 1.4 at B/C joint is sufficient for strong column and weak beam philosophy according to our study for buildings up to 5 storey but for buildings above 8 storey more than 1.2 is enough.

Keywords
Beam-Column Joint, Non-Linear, Pushover, SAP2000

1. Introduction

Earthquake is the major disaster that has claimed the lives of millions of people and besides that it has caused damage in the larger part of economy. Our country is located geologically in one of the most seismically active region of the earth, we are so much vulnerable to the earthquake and the study of earthquake and earthquake related area is necessary. The structural systems of most structures includes beams, columns, walls foundations, slabs, etc. among these the area which plays the great role in the absorption and dissipation of the seismic loads is the seismic strength of beams and columns joint. "strong column and weak beam" is the philosophy and the phrase that is so common in our field of expertise but also the most important phrase for the structure to be perfect in the seismic design. By perfect, we designers mean perfect in dissipating the seismic and overall loads in a safer way.

Upon the study of certain literatures it is found that the flexural strength ratio at the beam column joint does of course plays part in the energy dissipation process and the seismic capacity of the whole structure. And those research are majorly based on the 2-D structures so in this research we are focused on the more realistic models 3-D structures. It is observed that increase in column to beam moment capacity ratio (C/B ratio) increases lateral strength and displacement capacity of structures in 2-D frames (Bhandari, 2017). It was found through the study that the codal provisions for C/B ratio for buildings was not adequate, specially for tall buildings (Nabapallab, 2014). (Kadid & Boumrkik, 2008), presents the study using nonlinear static analysis program SAP 2000 which concluded that the causes of failure of reinforced concrete during the Boumerdes earthquake may be attributed to the quality of the materials of the used and also to the fact that most of buildings constructed in Algeria are of strong beam and weak column type.

Through this research work we intend to be more realistic so we will be analyzing our models in their non-linear states. The members will be assigned with appropriate hinges so that we can study the ways the hinges yield and through those results we can make our judgements about whether the structure has dissipated the lateral loads in the proper way as to insure the safety. In the study the lateral loads are provided as pushover loads and conclusions are made based upon the results.

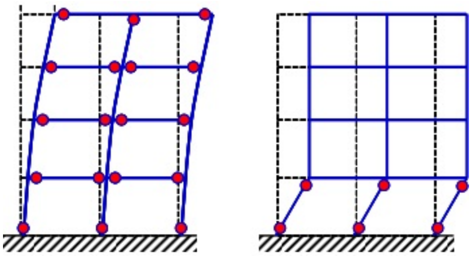

Figure 1: Beam failure and column failure in 2-D frame respectively.

The first of the figure shows the failure in beams also known as global failure which insures the safety in comparison to the local failure in second figure where the failure is localized in columns. As in the first figure the energy dissipation is proper and we don't expect failure as in the second figure

2. Objective of the study

Based on the study of literatures and codes the objective of the research was set follows:

1. To determine seismic resistance of frames and their failure patterns.
2. To evaluate the column to beam flexural strength ratio for a proper failure mechanism during earthquake loads.

3. Methodology

At the start of this research different literatures on design codes, journals, research articles, thesis works and design guidelines were studied. As the literature on beam column flexural capacity ratio was studied the lack of study on 3-D structure was observed which inspired this research work. Apart from this, the variation of the acceptable ratio of flexural strength in different international codes gave the idea about the modeling for this research. The value of required flexural strength ratio at joint manipulates the design reinforcement in seismic design by increasing or decreasing the amount of reinforcement of any structure so this research is important. Three, five and eight storey 3-D RC framed structures (which represents a residential buildings) are designed using commercial software SAP 2000. Plan of all the models are kept same to keep the symmetry on the building. Reinforcement in columns of the frames is increased to attain required codal column to beam moment capacity ratio(MCR). Nonlinear static (pushover) analysis is done to determine the failure pattern of the structure and to evaluate the hinges in the context of energy distribution. The non-linear analysis was assisted by (Prestandard And Commentary For The Seismic Rehabilitation Of Buildings." FEMA 356, 2000) and (Seismic Evaluation and Retrofit of Concrete Buildings; Vol 1 ATC-40, 1996). The results from the analysis are discussed and interpreted which made us to decide the final conclusion of this research.

4. Modelling of Structure

Keeping in mind the symmetry and general typical plan used in construction of buildings in Kathmandu valley and major cities areas in Nepal, our model for the thesis was choosed. In our research three 3-D bare frames are taken and emphasis is given to the beam column joint. The flexural strength ratio in the joint of beam and column is adjusted in certain ranges. The practicality of the sections choosed during modeling was taken into due consideration so the moment capacity ratio values are adjusted only in three categories as less than 1.2, 1.2 to 1.4 and more than 1.4

Table 1: Frame Models used in the research

Building frame	Beam section	Column section	CBMCR value
3 Storey	250*400	350*350	<1.2
			1.2 – 1.4
			>1.4
5 Storey	250*450	350*350	<1.2
			1.2 – 1.4
			>1.4
8 Storey	300*450	400*400	<1.2
			1.2 – 1.4
			>1.4

Plan of the models were made symmetrical with three bays each 4 meters in both directions and storey height 3 meters. The structural properties used for the design and analysis were taken from relevant Indian code (Indian Standard Plain And Reinforced Code of Practice IS 456:2000) and Nepalese code (Seismic Design Of Buildings; NBC 105: 2020, 2020). During modeling the hinges with non-linear properties were assigned to the structural members so as to examine the pattern of failure during static and dynamic nonlinear analysis. Beam and column on our model are the linear elements. Fixity of the models was assumed to be at the base. The staircase and lifts are not modeled. The effect of infill wall was ignored and only the load from infill was considered. The interaction between foundation and soil was not taken into account. For the modeling and analysis of our models software SAP 2000 was used.

Table 2: Performance point and ductility

	C/B ratio	perf. pt (KN)	yield disp.(m)	ultimate disp. (m)	disp. ductility
3 Storey	<1.2	1675.99	0.0333	0.1080	3.243
	1.2 – 1.4	1831.30	0.0353	0.1100	3.116
	>1.4	1878.42	0.0363	0.1137	3.132
5 Storey	<1.2	1840.37	0.0515	0.1780	3.456
	1.2 – 1.4	1868.40	0.0500	0.1780	3.560
	>1.4	1970.85	0.0510	0.1800	3.529
8 Storey	<1.2	2224.66	0.0686	0.2520	3.673
	1.2 – 1.4	2226.26	0.0706	0.2520	3.569
	>1.4	2231.07	0.0637	0.2520	3.956

5. Results and Discussion

Static pushover is the process of pushing a structure horizontally with a prescribed structural loading increased with a predefined pattern until a structure reaches a limit state (Seismic Evaluation and Retrofit of Concrete Buildings; Vol 1 ATC-40, 1996). Non-linear static analysis (pushover analysis) was done on our models and certain results were observed in the first phase of our work. The performance point of the structure for capacity spectrum is obtained from SAP which is tabulated below. It is the point at which the capacity spectrum meets the demand curve and signifies at which level the structure is performing during the lateral load is acting on the structure.

The structural ductility is calculated by dividing the ultimate displacement by yield displacement which was obtained with the help of bilinear curve obtained using FEMA 356.

The failure of the structure are categorized as beam sway failure, column sway failure and intermediate failure. In beam sway failure the beam of the structures are collapsed while columns are not affected. During column sway failure the columns of the structure are collapsed while beams are not affected. While in intermediate failure some of the beams as well as some columns are collapsed. The column sway failure and intermediate failure are not desirable.

The performance point observed for capacity spectrum

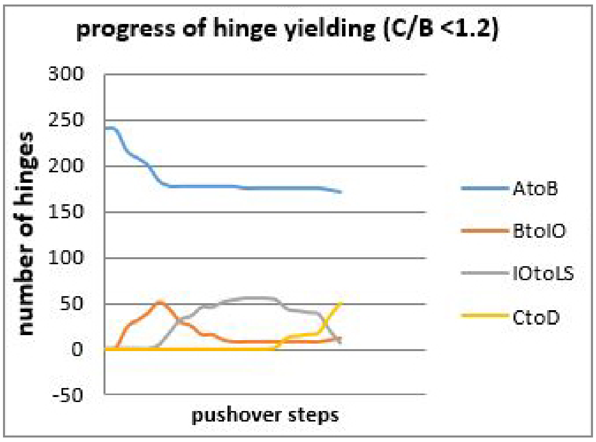

Figure 2: Hinge yielding in 3 storey RC frames for C/B less than 1.2

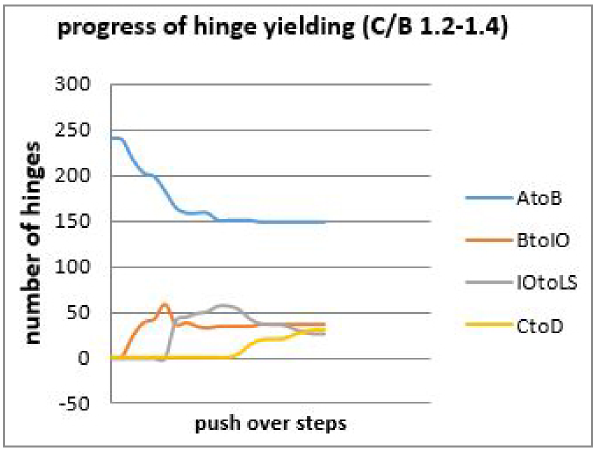

Figure 3: Hinge yielding in 3 storey RC frames for C/B between 1.2 and 1.4

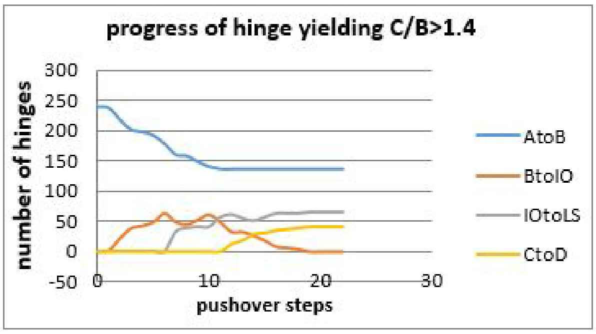

Figure 4: Hinge yielding in 3 storey RC frames for C/B greater than 1.4

ATC-40 also increased when C/B moment capacity ratio increased from less than 1.2 to more than 1.4. Also the displacement ductility which was calculated using the bilinear curve using FEMA 356 increased for moment capacity ratio of less than 1.2 to more than 1.4. Both performance point and displacement ductility was increased with increase in storey height.

The hinges were provided at both the ends of beams and columns of our structure during pushover analysis. The placement of hinges was chosen where the maximum stress is expected and where the probability of yielding is likely to take place. During the pushover analysis the yielding of column or beams is indicated by the formation of hinges in our model and its development and its state is also indicated by change in color. The maximum number of hinges yielding, indicates the proper distribution of energy during failure due to any lateral loads. The pattern of hinges development is observed closely and is shown in the graphs.

For the 3-storey 3-D RC frame with C/B capacity ratio of less than 1.2 the starting of yielding was started through beams which was indicated by appearance of hinges in our model during pushover analysis and with further steps of pushover analysis more hinges started to yield in beams and even in columns. The yielding beyond collapse prevention in beam was first sighted and later at final steps of pushover analysis the yielding of columns beyond collapse prevention is observed. The frame failed through intermediate mechanism. This indicates the C/B moment capacity ratio less than 1.2 is not adequate for a proper collapse mechanism.

For the 3-storey 3-D RC frame with C/B capacity ratio between 1.2to 1.4 the starting of yielding, development of further yielding and final state was found to be similar to that of our frame with C/B capacity ratio less than 1.2. The frame failed through intermediate mechanism. This indicates the C/B moment capacity ratio more than 1.2 is not adequate for a proper collapse mechanism as well.

For the 3-storey 3-D RC frame with C/B capacity ratio of more than 1.4 the yielding of hinges were recorded during pushover analysis. The starting of yielding was observed in beam first of the lower storey and which was distributed to the upper stories in further steps. The yielding of beams was observed even in the top most storey which indicated the proper dissipation of energy during the failure process. All the beams of the first storey yielded beyond life safety and all the beams of the upper stories yielded but were within the life safety state. And none of the columns yielded which indicates the adequacy of the IS codal C/B moment capacity ratio for proper failure mechanism. But in case of 5 storey frames more positive result were found even in the flexural strength ratio range of 1.2 to 1.4 and for 8 storey RC frame the frame showed totally positive results even in the range of flexural strength ratio of 1.2 to 1.4 so the pattern of our results shows that with increasing height of our structure less value of flexural strength at joint is demanding.

6. Conclusion

The number of hinges that took part in yielding increased when the C/B moment capacity ratio was increased from less than 1.4 to more than 1.4 which indicates the proper energy dissipation during failure. The overall performance of the 3-D RC structure in terms of proper failure mechanism and ductility with C/B moment capacity ratio as specified by IS code 13920 i.e. greater than 1.4 is found to be suitable for a 3-storey RC frame. But when the storey height is increased the value required for the strong column weak beam philosophy gradually decreased. Value of flexural capacity ratio of more than 1.2 at the beam column joint is sufficient for models of 8 storeys. With the increase in storey height and value of flexural capacity at beam column joint the displacement ductility and performance point also increases.

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