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Seismic Response of Moment Resisting RC Frames Having Discontinuous Columns

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Discontinuous column in a structure is not desirable as it may create uneven distribution of seismic forces in the structure and variations in stiffness between adjacent stories. As a result, non-uniform floor displacement, higher storey drift, soft storey mechanism, sudden increase in column forces etc. may occur. In this paper, seismic behavior of moment resisting RC frames having discontinuous columns have been investigated. A two dimensional analysis has been conducted for frames of a typical six storied building with and without discontinuous columns and compared the seismic responses. The analysis has been carried out using a finite element software ETABS. Seismic response in terms of storey drift, storey stiffness and columns shear forces have been determined and results are compared considering discontinuity. Linear, nonlinear static and dynamic analyses have been adopted to assess the seismic behavior of the RC frames.

Keywords: Discontinuous column, storey displacement, storey drift, column shear forces.

Introduction

Now a day's construction of structures with discontinuous column are increasing day by day. Architecture is the main reason. In addition, open space requirement for parking, convention hall, assembly hall, special use such as indoor game facility etc. such columns are provided in structures. According to BNBC 2017 (draft), uniformity along the height of the building is important, since it tends to eliminate the occurrence of sensitive zones where concentrations of stress or large ductility demands might cause premature collapse. Therefore, it will weaken the structure in resisting the seismic force during earthquake and seismic demand on this structure will be higher than the regular one. A number of research studies have been performed to examine the impact of earthquakes on structure with vertical irregularities. Most of the studies on the vertical irregularity are focused on soft storey and weak storey; limited number of studies can be found dealing with the discontinuous column. Güler (1996) and Güler and Altan (2004) conducted a detailed study on the column discontinuity and focused on various seismic damages came into being due to the structural irregularity in the recent Turkish earthquakes. Kara and Celep (2012) investigated the effects of the structural irregularity which is generated by the discontinuity of a column in a plane frame subjected to seismic loads including the gravity loads. Investigation was carried out by adopting linear and nonlinear static and dynamic analyses of the structural system. They summarized that the decision on acceptance of the column discontinuity

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on an empirical rule to deal with the column discontinuity should be based on a nonlinear analysis. Aksoylu et al. (2016) conducted a set of investigations to examine the discontinuity of the vertical members using different construction models of a reinforced concrete (RC) frame structure. In cases of discontinuity of the vertical element, the variation in the internal forces and decrease of rigidity were comparatively analyzed. In this paper, a detailed investigation has been carried out to comprehend the seismic response of moment resisting frame structure having discontinuous columns. To grasp the complete seismic behavior of the structure, analyses has been done considering linear static, nonlinear static and dynamic response spectrum method. Seismic response in terms of storey displacement, storey drift, storey stiffness and columns shear forces for structures having discontinuous column at different floor level and regular structure has been determined and finally a comparative study of structural responses among these structures has been made.

Discontinuous Column in Different Seismic Codes

In order to reduce the effects of discontinuous columns, seismic codes usually impose some guidelines. The draft BNBC 2017 provides structural vertical irregularities in five categories and the discontinuous column is referred to vertical irregularity as a vertical in-plane discontinuity in vertical elements resisting lateral force. In such case, it is required to perform dynamic analysis to obtain the design seismic force. Dynamic analysis can be carried out following either response spectrum analysis method or time history analysis method. In uniform building code (UBC), the discontinuity of column in the vertical direction is referred to as the discontinuity in the plane of the vertical members showing resistance against seismic movement, and in case of such irregularity, it is required that minimum earthquake load reduction factor (R) should be taken into account. Turkish Earthquake code (TEC)-2007 describes discontinuity of vertical members in details and categorized in following four types as shown in Figure 1:

Category-(a): In the case where columns at any storey to be supported by a cantilever beam and it is not permitted.

Category-(b): In the case where a column rests on a beam which is supported at both ends and it is permitted providing all internal force components induced by the combined vertical and seismic loads in the earthquake direction considered shall be increased by 50% at all sections of the beam and at all sections of the other beams and columns adjoining to the beam.

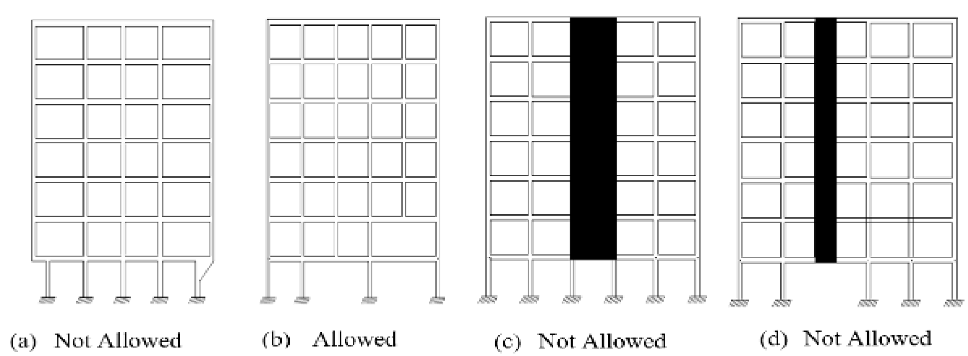

Figure 1: Vertical discontinuity in TEC-2007

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Category-(c): In the case where a shear wall rests on columns and it is not permitted.
Category-(d): In the case where a shear wall rests on beam and it is not permitted.

Frames Considered In the Present Study

To investigate the seismic behavior of structure with discontinuous column, a 6-storied moment resisting RC frame structure was selected as a base frame. Six other irregular models as shown in Figure 2 were formed considering discontinuity in column from ground floor to top floor. In the model, 3.5m was selected as a typical floor height. Span length of the beam was 5m. Out of plan grid dimension was assumed 4m. Thickness of the slab was used 0.125m. From this data, dead and live loads were found to be 24 kN/m and 8kN/m, respectively. Sizes of all columns and beams were 400x400mm and 300x400mm, respectively. Only the beams which support the discontinuous column have a cross section of 400x600 mm in order to support the load of the column which is not transferred to the column below due to the vertical column discontinuity. Concrete compressive strength and steel yield strength were considered 27.6 MPa and 414 MPa, respectively. The structures were modeled using a finite element analysis software ETABS version 2016.

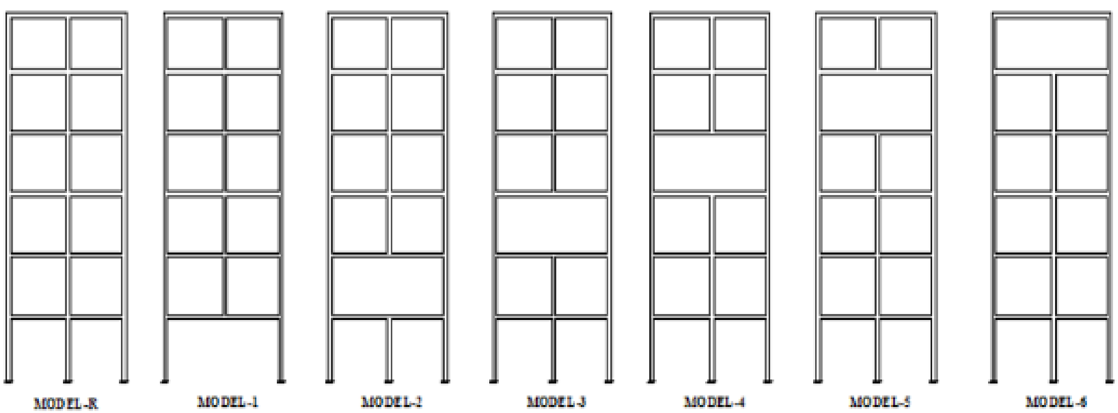

Figure 2: Base frame and different irregular models

It was considered that the structure was located in zone-2 which is medium seismic intensity zone according to draft BNBC 2017. Considering this data, C_s vs. T (sec) graph, spectral acceleration (S_a) vs. period (T) graph was generated as shown in Figure 4. From the figure 3, peak ground acceleration was found to be 0.21g.

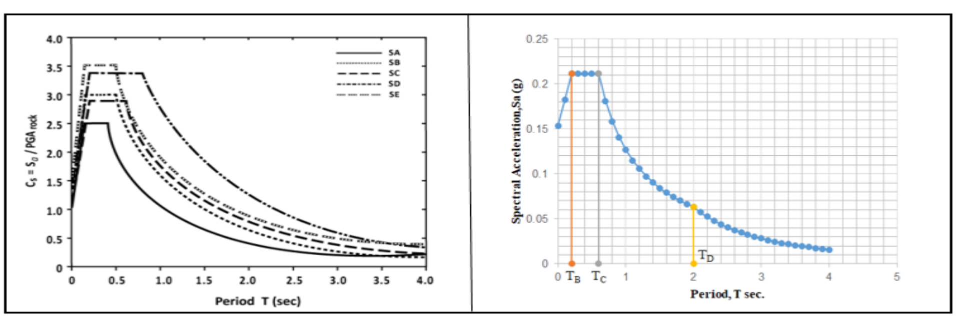

Figure 3: Normalized acceleration graph

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In addition to linear static and dynamic response spectrum analysis, nonlinear static pushover analysis was also performed to evaluate the structural responses. For pushover analysis in potential plastic hinge regions of the frame, plastic hinges were assigned according to FEMA 440.

Results and Discussions

Linear static, nonlinear response spectrum and nonlinear static analyses were carried out to assess the seismic behavior of irregular structures with discontinuous columns. Variation in value of storey drift of irregular models in comparison to that of regular model has been presented in Figures 5 to 10. From these figures, it can be assessed that storey drift of irregular structures has been found to be non-uniform whereas it shows uniform shape for the regular one. It is also seen that in all cases, the storey drift of irregular structures deviates from the uniform storey drift of the regular structure at the floor level where the discontinuity of columns were applied.

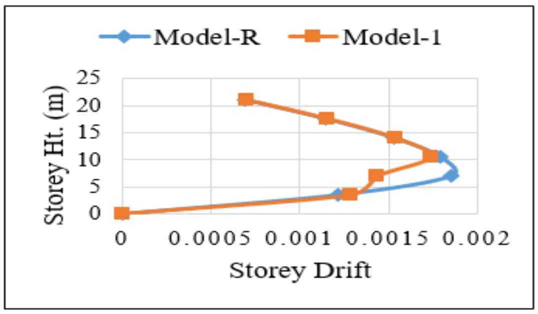

Figure 4. Storey drift of model-R and model-1

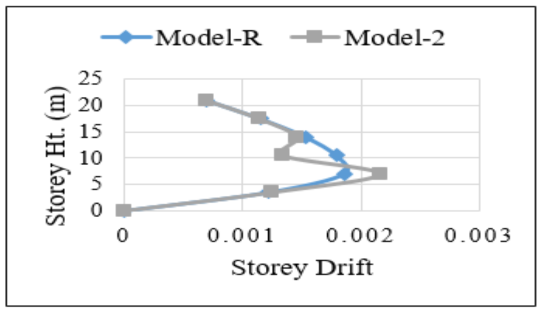

Figure 5. Storey drift of model-R and model-2

Figure 6. Storey drift of model-R and model-3

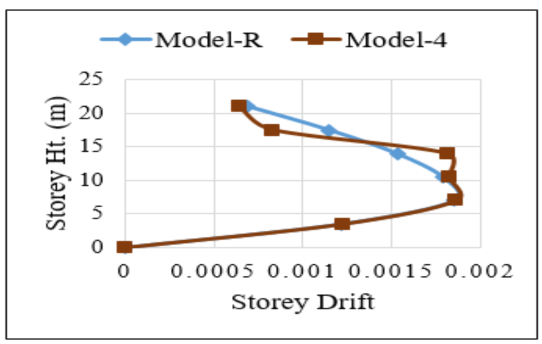

Figure 7. Storey drift of model-R and model-4

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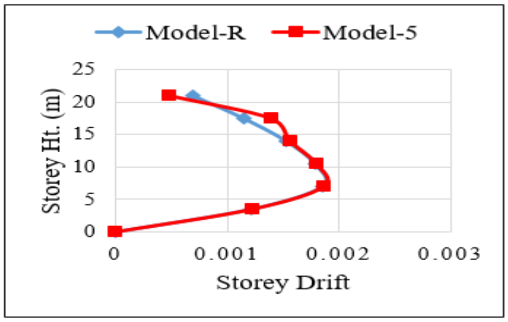

Figure 8. Storey drift of model-R and model-5

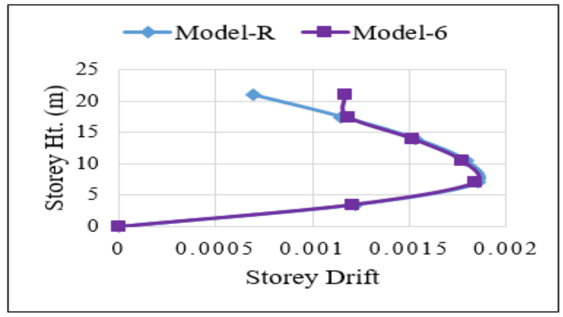

Figure 9. Storey drift of model-R and model-6

Storey drift obtained from static and dynamic analyses has been presented in Figures 11 to 16. From these figures, it is observed that dynamic response of the structure is quite different from that of the static response. Furthermore, dynamic storey drift demand is significantly large, when the column discontinuity is provided specially at lower storey level of the frame.

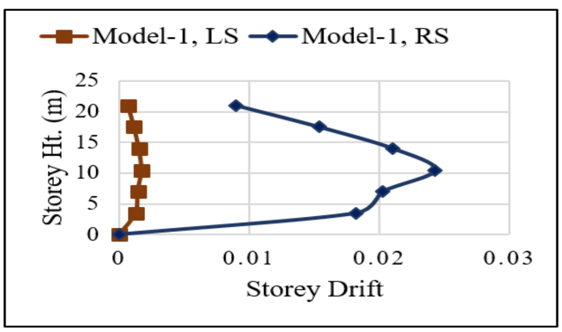

Figure 10. Model-1, Linear static (LS) vs. response spectrum (RS)

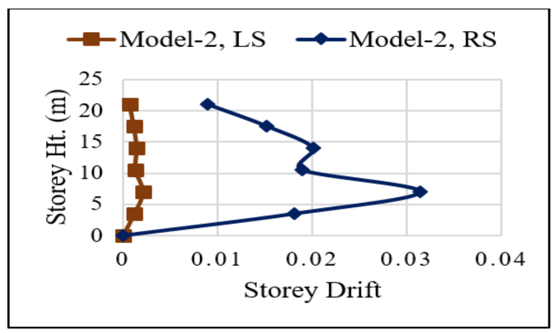

Figure 11. Model-2, Linear static (LS) vs. response spectrum (RS)

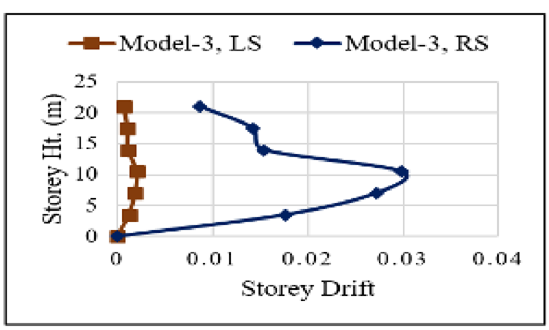

Figure 12. Model-3, Linear static (LS) vs. response spectrum (RS)

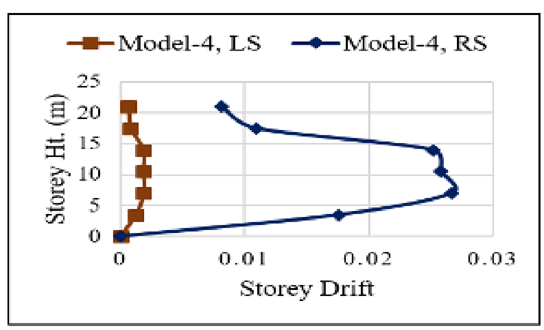

Figure 13. Model-4, Linear static (LS) vs. response spectrum (RS)

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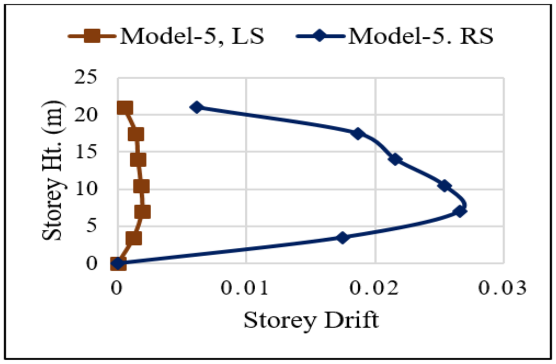

Figure 14. Model-3, Linear static (LS) vs. response spectrum (RS)

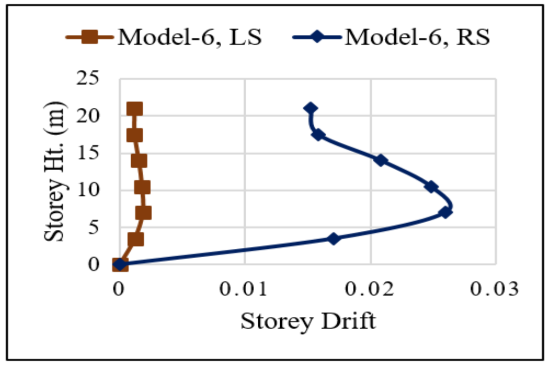

Figure 15. Model-3, Linear static (LS) vs. response spectrum (RS)

According to draft BNBC 2017, a soft storey is one in which the lateral stiffness is less than 70% of that in the storey above. To check the soft storey mechanism in column discontinuous floor, variation of storey stiffness (K) with the adjacent floor has been presented in Table 1. All irregular models except model-1 show the soft storey mechanism which is vulnerable under seismic excitation. On the other hand, regular frame shows no soft storey action any floor level.

To investigate the effect of discontinuous columns on lateral load bearing capacity, nonlinear static pushover analysis was performed. Top displacement of each frame vs. base shear has shown in Figure 17. From this figure, maximum base shear was found to be 111.15 kN for madel-R, while the minimum base shear 94 kN was found for model-1.

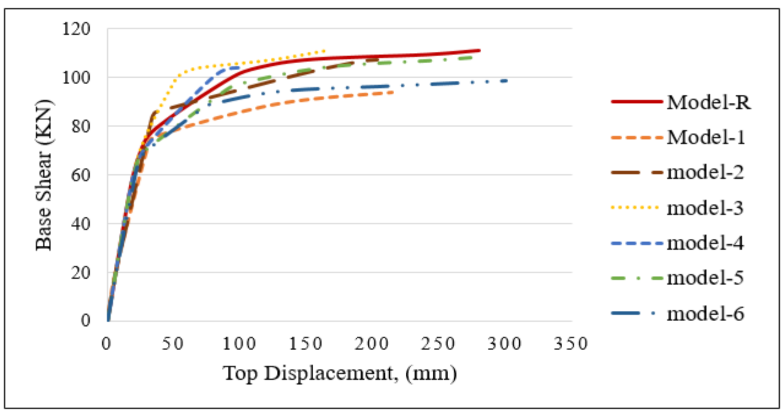

Figure 16: Pushover curves of considered models

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From pushover analyses, number of hinges formed in each structure at performance point has given in Table 2

Table 2. Number of hinges formed for different frames

	A-B	**B-C**	**C-D**	**D-E**	**>E**	**Total**
Model-R	33	27	0	0	0	60
Model-1	37	17	1	3	0	58
Model-2	36	16	1	5	0	58
Model-3	40	16	2	0	0	58
Model-4	38	20	0	0	0	58
Model-5	36	22	0	0	0	58
Model-6	32	26	0	0	0	58

Conclusions

The objective of this paper was to assess the seismic behavior of RC moment resisting frames with discontinuous columns. A 2D frame analysis has been conducted on structures with and without discontinuous columns following linear static, nonlinear static and dynamic response spectrum analyses. From the analyses results, following conclusions can be stated:

-Nonlinear dynamic response of irregular frames is quite different from that of the linear static behavior. Seismic demand on structure is quite larger than that of the static analysis.

-Storey drift obtained considering linear analysis of irregular structures with discontinuous column is not uniform shape as that of the regular one. There is a sudden change in storey drift of irregular structure which may weaken the seismic performance of the structure.

-A soft storey mechanism is developed in the specific storey level where the column discontinuity is provided.

-Lateral load bearing capacity of structure with discontinuous column is reduced in comparison to that of the regular one.

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