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PERFORMANCE ASSESSMENT OF VERTICALLY IRREGULAR LOW-RISE AND MID-RISE REINFORCED CONCRETE STRUCTURES

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IN

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REBAZ KARIM D. FARAJ

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Assoc. Prof. Dr. Esra METE GÜNEYİSİ

By

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Rebaz Karim D. FARAJ

ABSTRACT

PERFORMANCE ASSESSMENT OF VERTICALLY IRREGULAR LOW-RISE AND MID-RISE REINFORCED CONCRETE STRUCTURES

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M.Sc. in Civil Engineering
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Nowadays, the application of vertically irregular type of buildings gains a lot of interest in seismic research field. Many structures are designed with vertical irregularity, which are widely used to achieve architectural and/ or functional purposes. This study investigated the structural response of various regular and vertically irregular low-rise and mid-rise buildings. All reinforced concrete (RC) frame models considered had three and seven stories having four bays with a uniform bay width of 4 m and uniform story height of 3 m. As a vertical irregularity, stiffness/strength irregularity with missing beams or columns, mass irregularity, and vertical geometric irregularity (set-back) were studied. Each irregularity type composed of various cases. A total of two regular and thirty irregular frame models were examined through nonlinear pushover analysis. The capacity curve and plastic hinge formation in the structural members were determined for all models. In addition, the variation in the axial force of the columns of the RC frame buildings having the discontinuous column was evaluated. The analysis of the results showed that different types of structural irregularities had different types of influences on the case study structures.

Keywords: Nonlinear pushover analysis; Regular structure; Reinforced concrete building; Seismic response; Vertical irregular structure.

ÖZET

DÜŞEYDE DÜZENSIZ AZ VE ORTA KATLI BETONARME YAPILARIN PERFORMANS DEĞERLENDIRMESI

D. FARAJ, Rebaz Karim
Yüksek Lisans Tezi, İnşaat Mühendisliği
Danışman: Doç. Dr. Esra METE GÜNEYİSİ
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Düşeyde düzensiz bina türü uygulamaları günümüzde sismik araştırma alanında büyük ilgi çekmektedir. Birçok yapı, mimari ve/veya işlevsel amaçlar doğrultusunda yaygın olarak düşeyde düzensiz olarak tasarlanmaktadır. Bu çalışma düzenli ve düşeyde düzensiz az katlı ve orta katlı binaların yapısal tepkilerini incelemektedir. Tüm betonarme çerçeve modelleri, 4 m genişliğine sahip dört açıklıklı ve her katta 3 m yükseliği olan üç ve yedi katlı yapılardır. Düşeyde düzensizlik olarak, eksik kiriş veya kolonların neden olduğu rijitlik / dayanım düzensizliği, kütle düzensizliği ve düşeyde geometrik düzensizlik (yapı planında anı küçülme) incelendi. Her düzensizlik türü farklı durumlardan oluşmaktadır. Doğrusal olmayan itme analizi ile toplam iki düzenli ve otuz düzensiz çerçeve modeli incelendi. Kapasite eğrisi ve yapısal elemenlarda plastik mafsal oluşumu tüm modeller için belirlenmiştir. Buna ek olarak, kesintili kolona sahip betonarme çerçeveli binaların kolonlarının eksenel kuvvetindeki değişim de değerlendirildi. Sonuçların analizi, farklı yapısal düzensizlik türlerinin vaka analizi yapıları üzerinde farklı etkilere sahip olduğunu gösterdi.

Anahtar Kelimeler: Doğrusal olmayan itme analizi; Düzenli yapı; Betonarme yapı; Sismik tepki; Düşeyde düzensiz yapı.

To My Family, I am grateful to God for having Family like you. Your unconditional love and support made my every achievement possible.

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LIST OF SYMBOLS/ABBREVIATION

ASCE	American Society of Civil Engineers
BH	Beam hinge
BIS	Bureau of Indian Standards
BL	Low-rise frame with beam discontinuity
BM	Mid-rise frame with beam discontinuity
BRB	Buckling restrained braces
BSSC	Building Seismic Safety Council
CH	Column hinge
CL	Low-rise frame with column discontinuity
CM	Mid-rise frame with column discontinuity
CP	Collapse prevention
CSI	Computers and structures, incorporation
D	Roof displacement
D_t	Inelastic displacement
ELF	Equivalent lateral force
ES	Equivalent static
FEMA	Federal Emergency Management Agency

H_i	The height *i*th story
IBC	International Building Code
ICC	International Code Council
IO	Immediate occupancy
IS	Indian Standard Criteria for Earthquake Resistant Design of Structures
LS	Life safety
MDOF	Multi degree of freedom
MF	Multiplication factor
ML	Low-rise frame with mass irregularity
MM	Mid-rise frame with mass irregularity
NDA	Nonlinear dynamic analysis
NEHRP	National Earthquake Hazards Reduction Program
NIST	National Institute of Standards and Technology
NSP	Nonlinear static procedure
NZS	New Zealand Standards
PGA	Peak ground acceleration
PGD	Peak ground displacement
RC	Reinforced concrete
RF	Regular frame
RSA	Response spectrum analyses
SDOF	Single degree of freedom
SL	Low-rise steeped (set-back) frame

SM	Mid-rise steeped (set-back) frame
SMRF	Special moment resisting frame
TSC	Turkish Seismic Code
UBC	Uniform Building Code
V	Base shear
VI	Vertical irregularity
WS	Weak story

CHAPTER 1

INTRODUCTION

1.1 General

Irregular structures occupy a great section of the new civilian substructure. The series of human participated in fabricating the building efficiency, contain of possessor, designer, constructional engineer, builder and domestic establishments, participate to the comprehensive planning, choose the construction scheme, and to its disposition. This may result in constructions with irregular allocation in the strength, stiffness and mass along the building height. these irregular form gives felicitous lighting and ventilation in the lower storys in a congested neighborhood with cramped spaces between tall buildings. The structural engineer's function becomes more difficult, while these structures are situated in a high earthquake zone. The constructional engineer also necessarily to have a comprehensive, thoughtful of the seismic response of irregular buildings, because the design and construction of this building types also provide commitment with law restrictions associated to floor area ratio in some areas of several countries. In the present era, numerous investigations have been conducted to calculate the response of irregular buildings. These researches would be an endeavor to outline the work that has been done and direct relate with the earthquake reaction of vertically irregular building frames (Soni and Mistry, 2006).

This kind of irregularities arises due to the abrupt diminishment of stiffness or strength in a specific story. In most of the cases, structures turn into vertically irregular in a similar arranging stage because of a few utilitarian and architectural causes. This sort of structure proved more weakness in the historical seismic activity. Those subjects deal with vertical irregularities have been in the point of investigation for quite a while. Numerous researches have been led around there in inevitability scope. Therefore, the concentrate of the study would assess the prorated performances of exemplary vertically irregular structures done a probabilistic area (Pryadarshini, 2013).

The building having an irregular formation and non-regularly distributed stiffness and mass along the elevation and plan undergoes greatly more destruction than the regular formations. But today’s architectural need and inventor prospect for the structure of new era infrastructural progress has made unavoidable towards the planning of irregular formations. Therefore, there is a prompt need to rubric the key case related towards comprehension of the function of building configuration. Damage to the structure through and the earthquake begins from the weakest structural member. This structural weakness engenders due to, the discontinuity in mass, the stiffness and the geometry of the structure. The structures are said to be irregular structures which own these types of the weakness. Vertical irregularities are the main reasons of failures of structures throughout earthquakes. Structures with soft story are the most reminiscent model of irregular elevation structures which were collapsed during earthquakes. Thus, the impact of vertical irregularities in the structure turns out to be truly essential for the seismic performance evaluation. Structural weaknesses seeming in the structures are due to discontinuity in strength, stiffness or mass among neighboring storys. Such discontinuity among the stories is frequently connected with the sudden variants along the frame geometry height of structures. In the past, numerous basic failures have happened because of the cause of the irregular configuration of the structure either in plain or in elevation. Figures 1.1 and 2.2 display the examples of typical irregular building present in the various parts of the world (Santoshkumar et al., 2015)

Figure 1.1 Residential tower in Paris 2015 (www.world-architects.com)

Figure 1.2 Shenye TaiRan Building in China 2012 (www.archdaily.com)

The structural performance assessment of vertically irregular reinforced concrete structures is needed to be investigated. Such buildings are one of the biggest part of the stock building in the world. This type of construction has substituted the conventional building techniques, particularly in thickly populated cities in recent years due to the quick growth. After recent earthquakes, this building which suffered broad damage (Erberik et al., 2006).

Numerous simplified analysis approaches, for example, the equivalent static (ES) method, are adjusted by means of the seismic response of the regular buildings. The ES technique may misinterpret the genuine requests of buildings with irregularities like a great variance in story strength, stiffness, or mass, with irregular plans or with elastic diaphragms, producing grave structures. Since of this, numerous current worldwide standards and codes (e.g. NZS 1170.5 and IBC, 2003), give confines for the extreme degree of irregularity for structures designed by the ES means. For example; NZS 1170.5 outlines irregularity as follows:

- Soft story (vertical stiffness irregularity) the stiffness of lateral floor is not more than 70% of adjacent floor stiffness or not more than 80% of the average stiffness of the floor below or higher-up.
- Weak story (vertical strength irregularity) the shear strength of the floor is not more than 90% that in the floor higher-up.

Therefore, when a structure does not conform the regularity limitations above, and much analogous limits for other forms of irregularities, there is a need to use a more complex approach to the general analysis (Sadashiva et al., 2010).

The performance of a building structure can be computed falling back on nonlinear static examination. This includes the assessment of the structural deformation and strength requests and the correlation through the accessible abilities at required performance levels, through days gone by twenty contracts furthermore more than that it need been identified that the collapse control ought to turn into express design investigation which are be able accomplished just by presenting several sort of nonlinear investigation into the seismic configuration technique. After this pushover examination need been sophisticated over the previous decades and further, has turned into the favored technique of investigation for performance based seismic design (Sai Himaja et al., 2015).

Nevertheless, because of the senior measure of information created in this investigation, it may be not favored workable and PBSE generally includes pushover analysis, otherwise called as nonlinear static analysis. The basic seismic assessment of buildings that represent non-elastic behavior approach, in general, to determine the inelastic performance of the building apply the outcome of the static damage investigation. Presently, hence the pushover analysis or nonlinear static procedure (NSP) defined in ATC40, FEMA273 papers are utilized. Nevertheless, the technique includes sure estimates and facilitations that some quantity of difference is constantly anticipated that would exist in seismic request foretell of pushover analysis (Sai Himaja et al., 2015).

The pushover examination has characterized concerning illustration a nonlinear static estimate of the reaction a building that will experience while exposed to static seismic activity loading. Since we have a convergence, intricate static loading distinguishing of ground movement through a considerably less complex monotonically expanding static load, there must be limits of the methodology. The purpose is on identify these restrictions. This is achieved through performing the pushover examination of RC of three storys low rises and seven storys medium rise with and without vertical irregularity (Sai Himaja et al., 2015).

1.2 Objective and scope

In this study, the structural response of low-rise and mid-rise reinforced concrete (RC) frame buildings with and without vertical irregularity subjected to lateral loading were investigated through nonlinear static (pushover) analysis. For a vertical irregularity, stiffness/strength irregularity with missing beam or column, mass irregularity and vertical geometric irregularity (set-back) were studied. As a result, the performance assessment of regular and irregular RC buildings was determined in terms of capacity curves and plastic hinge patterns. Moreover, the axial force variation in the side and middle columns of the frame buildings having the irregularity case of discontinuous column was examined completely.

1.3 Outline of the thesis

In this thesis, the whole work is demonstrated via five chapters;

Chapter 1 Introduction: This chapter is dedicated to the presentation of the research topic and the identification of the overall range and specific objectives. Knowledge and objectives of the thesis were introduced.

Chapter 2 Literature review: This chapter follows the foundation on the design codes and practical application as well as past studies on the frame structures with vertical irregularity.

Chapter 3 Case study: In this chapter, type of the frame system and properties and detail of building frame that used in this study is offered and the type of analysis procedures that has been done with the suppositions for modelling is debated.

Chapter 4 Results and discussion: This chapter discusses and presents the outcomes acquired from nonlinear static analysis (or pushover analysis) for evaluating the structural performance of each frame system and the effect of vertical irregularity on each type of frames.

Chapter 5 Conclusions: General conclusions are drawn with respect to the general results from all chapters.

CHAPTER 2

LITERATURE REVIEW

2.1 Design codes of vertical irregularities

A structure will be specified as vertically irregular if the apportion of irregularity achieved most extreme stipend as indicated by the standard specifications. There are a few sorts of irregularity in elevation that have diverse attributes, Also subject on seismic loads urgently.

The conformation of irregular buildings has been characterized plainly in the current version of IS 1893 (Part 1)-2002 (BIS, 2002). Five kinds of irregularity in elevation (vertical) have been perceived as indicated in Figure 2.1.

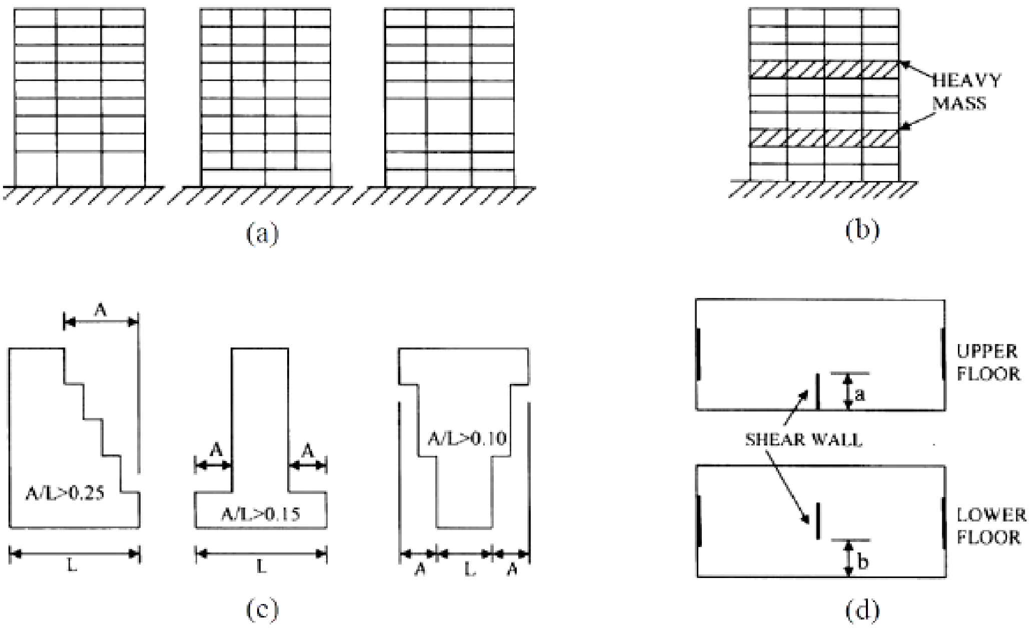


Figure 2.1 a) Strength/stiffness irregularity; b) mass irregularity; c) vertical geometric irregularity or set-back; and d) in-plane discontinuity in lateral-force-resisting vertical elements when $b > a$: plan view (BIS, 2002)

NEHRP code (BSSC, 2003) has arrangements of vertical irregularities like those portrayed in IS 1893 (Part 1)2002 (BIS, 2002). According to mentioned code, a structure is characterized to be irregular if the proportion amounts (Such as strength, stiffness or mass) among contiguous storys surpasses a least appointed value. Judgment has relegated These conditions (like as 70-80% for a soft story, 80% for weak story, 150% for stepped structures) and the rules so characterize the irregularities. Further, different construction codes recommend dynamic analysis (which can be elastic response spectrum analysis or elastic time history analysis) Will thought of design lateral force circulation for irregular structures instead of utilizing equivalent lateral force (ELF) methods (Sony and Mistry, 2006).

The international building code (IBC) (ICC, 2003) classifies different kinds of vertical irregularity as follows:

1. a) Stiffness Irregularity (Soft Story) has been noticed in story building which the lateral stiffness will not be more than 70% for that in the story over alternately not more than 80% of the average stiffness of the three stories over.

b) Stiffness Irregularity - Compelling soft story is thought be noticed when the lateral stiffness is not more than 60% of that in the story above or not more than 70% of the average stiffness of the three stories above

2. Mass (weight) Irregularity is acknowledged to be known where the dynamic mass for any story is additional prominent than 150% of the dynamic mass of a contiguous story. A rooftop that is volatile than the floor beneath shouldn’t be considered.

3. Vertical geometric irregularity might be found when the horizontal measurement of the lateral force resisting system in any floor is greater than 130% of that in a bordering floor.

4. Discontinuity in plane for vertical lateral force resisting elements will be viewed in the place in-plane offset of the lateral-force-resisting elements will be more than the period for the individual components or the place there is a diminishing clinched alongside stiffness of the opposing component in the beneath.

5. Weak story-discontinuity in capacity is particular case done when the lateral strengths of this story may be not more than 80% for that in the story overhead. The

story lateral strength is the downright lateral strength from claiming constantly on seismic resisting components offering the location of story shear beneath has been considered.

A seismic design class will be assigned with every frame building as following part 1616.3 in IBC. Seismic design classes had been utilized as a part of IBC to assess the acceptable structural systems, limits on the irregularity and height, those sections of the building that should be designed to resist the earthquake and the methods of analysis that should be accomplished.

In the IBC (ICC, 2003), those frame structures which need you quit offering on that one or a greater amount of the characteristics of the five focuses itemized over ought be designated likewise irregular in elevation excluding sorts 1a, 1b and 2 when no story drift ratio under design lateral load is not accessed 130% of the story drift ratio of the next story over, additionally irregularities of these sorts would not needed should be viewed for single story structures in any seismic design class or for multi-story structures in seismic design group A, B, C or D. For two special cases the structure is considered structurally regular

To the structures with be recognized vertically irregular in IBC (ICC, 2003), they should satisfy the shown prerequisites as stated by the seismic design population and the manifestation from claiming irregularity characterized over. Additionally, modal reaction spectral analysis alternately nonlinear time history analysis systems would have recommended by Salawdeh (2009).

In Eurocode 8 (CEN, 1998), the design proposals incorporate points of confinement to classify vertically regular and irregular frame buildings, where a frame building is thought to be irregular when one of the measures had been change such as masses and strength between contiguous floors turns out to be more than a base expressed values. A structure is thought to be regular in elevation when it satisfies the expressed underneath:

The auxiliary dividers, or casings, centers, and all parallel burden opposing frameworks must abandon intermittence from the footings to the highest point of the structure, or, if anomalies at fluctuated statures are existent, to the highest point of the related locale of the structure. Each of the lateral stiffness and the mass of the particular floors must stay unaltered or diminish gradually, without sudden varieties, from the base to the highest point of a particular building. The proportion of the genuine floor resistance necessary to be examination, in framed structures shouldn't differ to a great degree between adjacent floors. At the point when irregularities in elevation (setbacks) are existent, the beneath terms might be appropriate:

a) For progressive setbacks keeping up axial symmetry (regularity), the setback in any story might not be more than 20 % of the beneath arrangement length toward the setback as appeared in Figure 2.2 (a), and (b).

b) The buildings with one setback in the lesser 15 % of the entire height of the building, the setback might be 50 % or less of the past plan dimension as appeared in Figure 2.2 (c). The structure of the base part inside the vertically anticipated limit of the upper floors ought to be designed to bear not less than 75% of the horizontal shear forces that can exist in that region in a comparable building not contain the increase on base.

c) On account of unsymmetrical setbacks, in every face the summation about at setbacks in the least floors shouldn't surpass 30 % of the plan dimension at the ground floor over the foundation or over the highest priority of a rigid basement, and the single setback might not be more than 10 % of the past plan dimension as appeared in Figure 2.2 (d).

According to Eurocode 8 (CEN, 1998), the frame structures not perfect with the regularity standards clarified above, the modal response spectrum analysis method for design ought to be embraced. However, as a substitute for designing this sort of irregularity, non-linear time history analysis or nonlinear static analysis methods can be done.

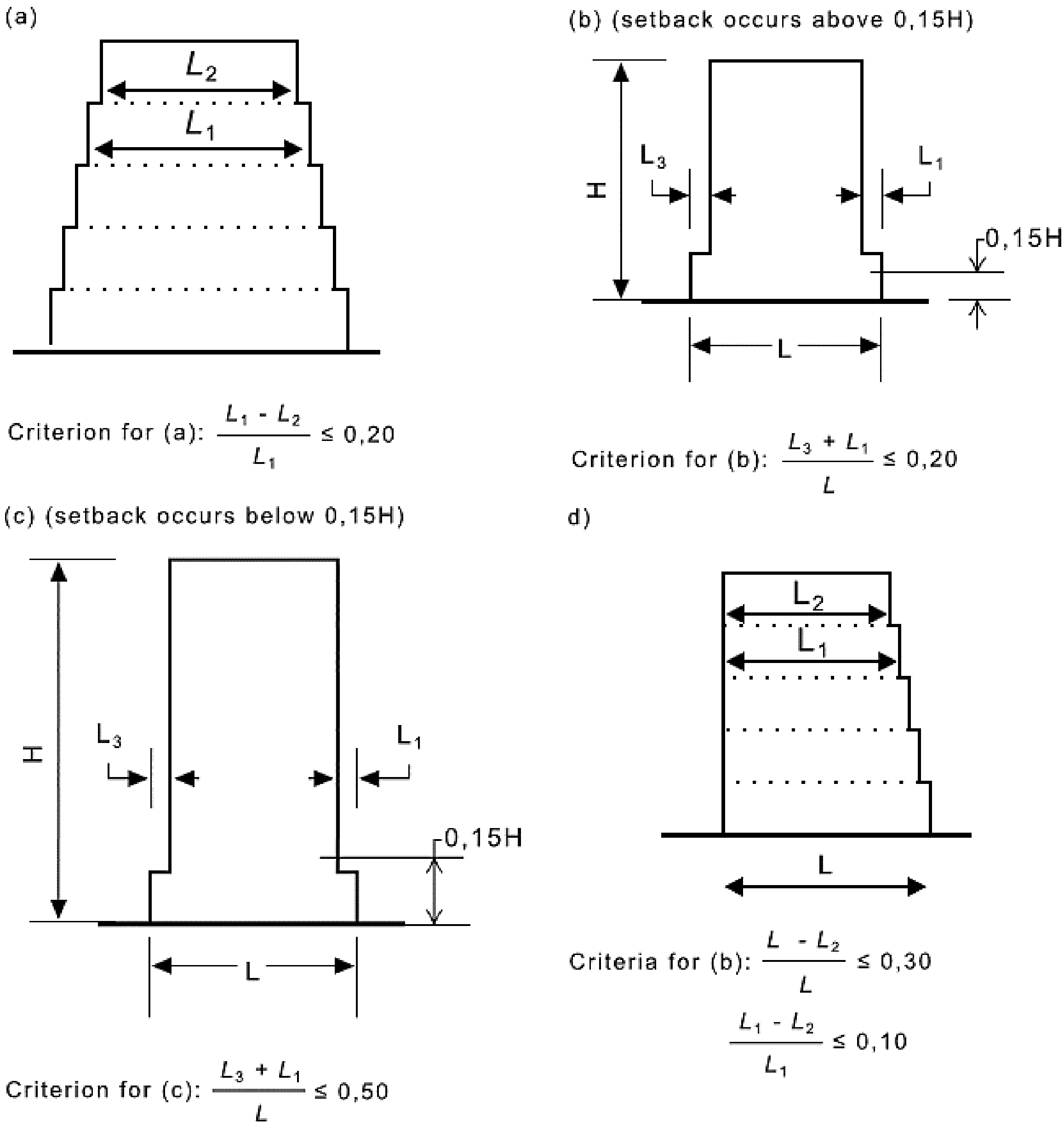


Figure 2.2 Criteria for regularity of buildings with setbacks (CEN, 1998; Salawdeh, 2009)

2.2 Review of existing studies related to irregularity in structure

Irregularities of strength, stiffness, mass and vertical geometry with building height may be called as the vertical irregularity. These irregularities might be available separately or together. Several sorts of vertical irregularities bring distinctive impacts for seismic reaction. The impact of these irregularities ought 11 to be taken into account and consolidated in popular seismic design codes. The research start dealt with vertical irregularities began in ahead of schedule 1970s with Chopra and Kan (1973) who investigated the seismic response of a group of eight-story shear buildings constrained to the earthquake action data. The fundamental purpose was to decide the impact of yielding of the first story on upper stories. From the outcomes of the systematic investigation, it was observed that a perfect plastic mechanism and a lower yield force are necessary for the first story for the safety of the higher floors of the structure. The irregularities of strength, stiffness and mass were denoted by parameters of the strength ratio (STr), stiffness ratio (Sr), mass ratio (Mr) which may be characterized as the ratio of mass, stiffness and strength of the story below thought to that of the nearby story.

Humar and Wright (1977) examined the seismic response of multistory steel building frames with and without setback irregularity utilizing one ground motion data. In view of expository study, it was inferred that, in the event that about fabricating frames for setbacks, the story drift had been observed to be more noteworthy at the top part of setback less than the bottom part. Additionally, the drift of building frames with setbacks has been observed to be less when contrasted to their regular counterparts. This approach was extended by Aranda (1984) who determined the seismic response of the structure with and without setback irregularity established on soft soil. Back to the diagnostic studies, it has been affirmed that the ductility requirement and its increment in the upper segment of the setback was higher when contrasted with the base divide and structures with setbacks endured higher ductility demand as correlated to their regular equivalents.

Fernandez (1983) decided the elastic and inelastic seismic response of multistory building frames with the irregular arrangement of stiffness and mass. Diminishment in story stiffness brought about expanding story drift and structures with a consistent variety of mass and stiffness in a vertical direction indicated reliable seismic performance when contrasted with the structures with sudden varieties. The behavior for shear walls prompts variety previously, stiffness furthermore investigators similar to Moelhe (1984) decided the seismic reaction about RC structures for irregularities. To explanatory research, nine-story building frames with three bays and structural walls had been displayed. The irregularity in building models is formed by cessation of structural walls at various story heights. In light of the investigative outcomes, it might have been determined that the seismic response did not depend on the degree of structural irregularities only as well as on the irregularities location. Test investigations are important to confirm the exactness of logical results and investigators like Moehle and Alarcon (1986) presented exploratory analyses on two little models RC building frames applied to the seismic movement data. The inspections were done utilizing shake table. The two building types utilized for the study had been called ‘FSW’ and ‘FFW’. The ‘FFW’ the design required two frames of nine-story consist from 3 bays for each model and the third frame was also of 9 stories but had a prismatic wall, this model characterized the building systems without any irregularity. The vertical irregularities were displayed in the building models by the discontinuation of the shear wall at the first story and these building models were assigned as ‘FSW’ Rest of the components in both ‘FFW’ and ‘FSW’ exactly identical. By utilizing elastic and inelastic dynamic analysis were computed the displacements of the top story for all these building models. From the systematic investigation, it is achieved that if there should arise an amount of "FSW" ductility request increased suddenly in the region of irregularity of shear wall and this increase was observed to be 4 to 5 times greater when compared with the "FFW" models. However, the elastic analysis is observed to be less effective as correlated to the inelastic dynamic analysis in defining the influence of structural discontinuities.

Moelhe (1984) discovered the seismic response of RC structures with irregularities. For systematic research, nine-story building frames with three bays with structural walls have been displayed. The irregularity in building models was made by discontinuance of structural walls at various story heights. In view of the logical outcomes, it might have been discovered that those seismic responses not best realized with respect to a degree about structural irregularities as well as on the area about irregularities. Test subjects are important to check the precision of diagnostic outcomes and researchers such as Moehle and Alarcon (1986) applied experimental examinations on two small models RC building frames applied to seismic data motion. The examinations have been performed, utilizing shake table. The two small scale RC had replicated frame of nine-story having three bays each and the third frame was additionally thirteen of nine stories yet prismatic wall, this model delineated the building systems without any irregularity. The vertical irregularities were presented in the building models by suspension of shear wall at the first story and this structure model has been designated as 'FSW' rest of the elements in both "FFW" and "FSW" were same. The top floor displacements had been registered for all these building models utilizing elastic and inelastic dynamic analysis. From the scientific research, it was inferred that if there should arise an occurrence of "FSW" ductility demand expanded suddenly into the region of discontinuity of shear wall and this increment has been observed to be four to five times greater when contrasted by the "FFW" models. Further, the inelastic dynamic analysis is observed to be extra productive when contrasted with the elastic analysis in deciding the impact of structural discontinuities.

Costa et al. (1988) considered the seismic performance of reinforced concrete structures exhibiting vertical irregularities. Sixteen story structures were examined for three diverse horizontal layouts and five vertical arrangements. The structures were glorified as an arrangement of plane moment resisting frames connected to shear walls by rigid diaphragms. Based on their study, Costa et al., put forward the following observations. A discontinuity in the frame obviously increased the ductility demand in the shear wall. Additionally, the distribution of ductility demand was irregular in shear walls, but was fairly regular in the frames, excluding for stories promptly over an irregularity, where there was a noteworthy increment in the frame ductility request. For irregular buildings, the ductility request was seen to be about twice as high as those of regular buildings clinched alongside general, it might have been noted that on the irregularity occurred them. In the frame, that shear divider exhibited a build previously, ductility demand furthermore the other way around.

Ruiz and Diederich (1989) investigated the seismic behavior of buildings with a first weak story in the condition of single seismic motion. They considered the impact of the ductility demand on lateral strength discontinuity at the first story under the movement of the acceleration up a record with biggest peak ground increasing acceleration, as determined on soft soil in Mexico City while the Mexico earthquake of September 19, 1985. A parametric investigation is done for 5and 12story buildings with a first weak story, and with brittle infill in upper stories at times and ductile in others. The crucial periods of these buildings were 0.67 and 1.4 s, separately. They noticed that the performance of first weak story buildings significantly relies on upon the proportion of the prevailing duration of excitation and response the resistances of upper and first stories, and on the seismic coefficient utilized for design. The proportion of prevailing periods of response also excitation might have been obtained with a chance to be nearly identified with the arrangement for plastic hinges, failure or yielding of infill walls, furthermore in the times of their appearances.

Bariola (1989) researched the influence of stiffness and strength variation on seismic response of structures. He considered the nonlinear response of an 8 story building, with five bays per floor, subjected to five different earthquakes. Three different sorts of building periods were investigated low, medium, and high. For each building, two instances were considered, one weak building and one strong. If the base shear strength equal 15 % of the total weight of the building it is considered as weak building, even though the strong building had a base shear strength of 30% of the total weight. The outcomes about this consider showing that the period of a structure increments throughout an earthquake, for bigger period elongation for weaker structures. He expressed that if this expansion period is considered alongside an expansion in damping, a standard linear elastic response by use spectrum to utilized estimate the response of the building.

Shahrooz and Moehle (1990) discovered the seismic response of vertical setback building systems. The researcher led both experimental and systematic examinations to enhance past configuration design for the outline of setback buildings. For performing the test study a six-story RC frame setback at mid height is readied from outcomes for test research it might have been discovered that there might have been no unexpected variations in the displacement the frame height. The inter-story drifts were observed to be bigger with increased damage and sudden reduction in lateral force at the position of setbacks. The variation of force and lateral displacement with building height proposed that the translational seismic response of the building parallel to the bearing of the setback was impacted by basic method of vibration. For performing investigative research six-story frame buildings with six various examples of setbacks has been designed and modeled as per UBC code of practice. For these frames the mass proportions and floor plan measurements might have been changed from 3 to 9 times as proposed by UBC 1988 code of practice that separated symmetric and setback buildings on the premise mass proportion and of plan dimensions. Those investigations about these frames has been conveyed absurd by the modal analysis technique being endorsed by UBC 1988 code of practice. From the outcomes of diagnostic investigation, might have been finished up that constantly on these frames encountered comparative extent and appropriation for ductility demand. The frames with comparable floor plan dimensions and mass proportions, however for various setback statures encountered a distinctive measure of damage which negated those approach of the UBC 1988 code.

Costa (1990) expanded the previous work on seismic performance of irregular buildings. The research depended on twelve, sixteen, and twenty stories RC building models. Promote conclusions that were drawn from this examination are identified as takes after. The part of a shear wall over a blended structural system might have been. Will circulate the frame ductility's uniformly along the height. The interference about a shear walls to some degree or to the total height of the structure prompted an unpredictable. Appropriation from claiming span ductility's. A noteworthy increment was seen in the main level over this intrusion of the shear wall. Underneath the intrusion, the conduct is like a regular frame.

Nassar and Krawinkler (1991) estimated the seismic necessities factors for stiffness and bilinear diminishing the single degree of freedom (SDOF) frameworks. Also, three sorts of Multi-degree of freedom (MDOF) buildings for 3, 5, 10, 20, 30, and 40 story height and 0. 217, 0. 431, 0. 725, 1. 220, 1. 653 and 2. 051 s fundamental periods, separately. They found that the three concentrated on MDOF models were: (a) CH (column hinge) model, in that plastic hinges form in columns only, (b) BH (beam hinge) model, in which plastic hinges form in beams only (as well as in supports), and (c) WS (weak story) model, columns of only the first story developed plastic hinges. Thirty-six strong ground movements were utilized, which were recorded amid a single earthquake, particularly, the Whittier Narrows quake of October 1, 1987, in and around Los Angeles, California, furthermore fifteen powerful ground motions from various Western U.S. earthquakes, recorded on firm soil. Those combined damage demands on SDOF models were assessed over inelastic strength also statistically for positive point ductility ratios. Strength demands were meant as inelastic strength necessities spectra or spectra of strength decline factors. Terms have been built up that related the pointed ductility proportion furthermore period with the factor of strength. They found examining MDOF models that those fundamental strengths for recognized meant ductility ratios depended principally upon the kind of collapse mechanisms that created throughout strong seismic. They inferred that first weak story prompted enormous amplifications in ductility and upsetting moment needs. This was additionally affirmed before by the study of Seneviratna and Krawinkler (1997).

Esteva (1992) considered the nonlinear seismic response of soft first story structures subjected to narrowband accelerograms. The variables secured were the number of stories, time period, the form of the difference of story stiffness with the height, proportion of post yield to initial stiffness, in addition to the variable of essential interest, i.e., factor r communicating the proportion of the normal estimation of the safety factor for lateral shear at the upper stories at the base story. He utilized shear beam methods illustrative of structures portrayed by various numbers of stories and characteristic time periods as presented in Table 2.1. The investigation involved instances of stories by hysteretic bilinear conduct, both involving and ignoring P-delta influences. The excitation has been now and again an accelerogram registered on soft soil in Mexico City amid the Mexico earthquake of September 19, 1985, and at times a group of fake accelerograms with comparative factual attributes he watched that the magnitude and quality of the impact of the ratio r on the greatest ductility requests of the first story rely upon the low strain period of the system. For brief periods ductility requirements might be diminished by around 30% while r develops of 1.0 to 3.0. For halfway periods, ductility demands are a few delicate with r, however, for more periods this have been achieve the augmentations of 50 to 100% when r shifts inside the said interim. He moreover, viewed the sway about r on the response of the story first will be unequivocally moved forward though P-delta affects need aid checked.

Table 2.1 Number of stories and fundamental periods of building frames considered by Esteva (1992)

Number of stories	Fundamental periods
7	0.4, 0.7, 1.0
14	1.1, 1.4, 1.5
20	1.8, 2.0

Wood (1992) examined the seismic performance of RC frames with setbacks. Two small scale reinforced concrete test buildings with setbacks has been constructed also submitted to recreated ground action. The displacement, acceleration, and shear responses of the setback frames have been compared for the individuals about seven a while ago tested frame with uniform profiles. Every structure viewed as by Wood in this contemplate were comprised about two indistinguishable twin planar frames. The tower structure might have been a regular system with a seven story tower furthermore a two story base. The setback building might have been an irregular cause of action of a three story tower, a three story middle segment, and a three story base.

The height of the first story is roughly 1.4 times of the upper stories height. These nine buildings have been listed utilizing the UBC 1988 descriptions for vertical structural irregularities. Given this study, the emulating conclusions were drawn. The displacement also shear reactions of the stepped buildings were legislated principally by the first mode. Acceleration reaction in the least levels showed the commitment of higher modes. The linear mode shapes for setback frames exhibited kinks that were not introduced for uniform buildings, nevertheless, there might have been no confirmed should be recommended that those complications negatively impacted the dynamic response of the setback frames. Circulations for 18 most extreme story shear were additionally great quell using the equivalent lateral force circulations for the sum structures. Further dependent upon her perceptions, Wood pointed attention to that the differences between the nonlinear behavior of setback and regular frames don't justify diverse design methods required in building codes (UBC 1988; BOCA1989).

Wong and Tso (1994) applied elastic response spectrum examination to discover the of structures seismic response with vertical setback irregularity also, it has been noted that structures for setback irregularity required higher modular masses creating a diverse seismic load circulation when contrasted with the static code methodology. The MRF structures viewed in the study, the explanatory model used to characterize a building with one level of setback. Treating those tower and the build of the structure similarly as summed up single degree of freedom (SDOF) patterns, the structure can be demonstrated as a 2DOF system. They concluded that the time of a frame with a setback is all things considered less that of a comparable working with no setback.

Hidalgo et al. (1994) presented an analytical examine to decide the influence of vertical structural irregularities on the results of static and response spectrum analyses. Two shear-wall building models, ordinary of Chilean reinforced concrete construction, were utilized. The number of stories in each of these models was 20 and 15, separately. Stiffness irregularities in these models were presented by lessening the stiffness of at least one floor. The stiffness ratios considered were in the range of 17% to 83% of the original stiffness’s. The coupling beam depth in the case of the coupled shear-wall system was additionally differed. In place to consider those varieties of lateral strength over the height, it was accepted that changes in strength were typically connected with changes in stiffness. Effects of mass irregularity were likewise concentrated on by either expanding or diminishing the mass of one floor with respect to the adjacent floor. The mass proportions considered to be in the scope of 25% to 175%. The locations of these stiffness, strength, and mass ratios were likewise differed along the height of the structure and were conceptualized as setbacks. The most related conclusions gotten from this study may now be compressed. Considering all instances of vertical structural irregularities, the most basic was that of a setback at mid-height of the building, including synchronous reductions in plan geometry, strength, and mass. The second most basic was that of a reduction in stiffness in the lower stories. Likewise, an irregular dispersion of strength could infer a bigger demand of ductility at weak segments close to the irregularity throughout extreme earthquakes. It was additionally called attention to by the authors that, for the sort of structures considered in their study, the UBC confinements for utilizing the static analysis procedure were excessively stringent.

Pinto and Costa (1995) estimated the nonlinear seismic behavior of setback buildings with RC structure. In the study, a set of 17 different buildings were considered: nine 4 stories, four 8 stories and four 20 story buildings. These structures had a similar plan configuration. Be that as it may, with respect to elevation, a few were regular however, others were irregular with various degrees of setback. The basic frequencies of these structures ranged from 0.49 Hz to 3.20 Hz. This covered. The quantity of the way frequencies of the design response spectrum in the Portuguese code. Those fundamental conclusions proposed toward the authors might be summarized concerning illustration takes after. For the most buildings, it was apparent that a more prominent convergence of the biggest values of ductility demands happened in the lower stories. However, a portion basic zone in moderate heights was likewise watched. To structures with similar frequencies and separate. Heights, the tallest showed those best values possibly for those ductility demands alternately. For the story forces during those floor levels. The results of the irregularities were obvious on the shear forces for all of the structures furthermore on the ductility demands of the 4 story buildings. However, the effect of those irregularities might have not been apparent on the displacements of the 8 and 20 story buildings. The influence of the attributes of ground movement on the response parameters of the buildings examined were too observed.

Duan and Chandler (1995) carried analytical considerations on structural systems utilizing the modal spectral and static analysis with setback irregularity furthermore in view of the outcomes of systematic investigations, it has been decided that for any modal and static analysis procedures were incompetent in limiting the convergence of damage in frame parts close level of setbacks. For setback outline buildings, the strength design technique ought to force expanded strength for members in the tower close to the notch and for those in the base nearby the perimeter at the inverse side of the tower.

Valmudsson and Nau (1997) concentrated on assessing structural code prerequisites for vertical irregular buildings. The seismic response of 5, 10, and 20 story framed structures with uniform strength, stiffness and mass circulations has been assessed. The buildings have been displayed as two dimensional shear structures. The reaction computed from the time history investigation is contrasted and that anticipated by the ELF methodology as typified in UBC (1994). In perspective of this examination, they assessed the necessities under which a frame can be viewed as regular and the ELF arrangements are important. They closed (as shown in Figure 2. 3 (a)) that when the mass of one story increments considerably, the expansion in ductility request is not more conspicuous than 20%. Decreasing the stiffness of the principal story by 30%, while keeping the strength unfaltering, forms the primary story drift by 20-40%, dependent upon the design ductility (μ) is appeared in Figure 2. 3 (b). Diminishing the quality of the first story by 20% builds the ductility demand by 100200%, contingent upon design ductility as appeared in Figure 2. 3 (c). Decreasing the first story stiffness and strength relatively by 30% build the ductility request by 80200%, contingent upon the design ductility as appeared in Figure 2. 3 (d). Along these lines strength basis outcomes in high increments response amounts and has not reliable with the stiffness and mass demands.

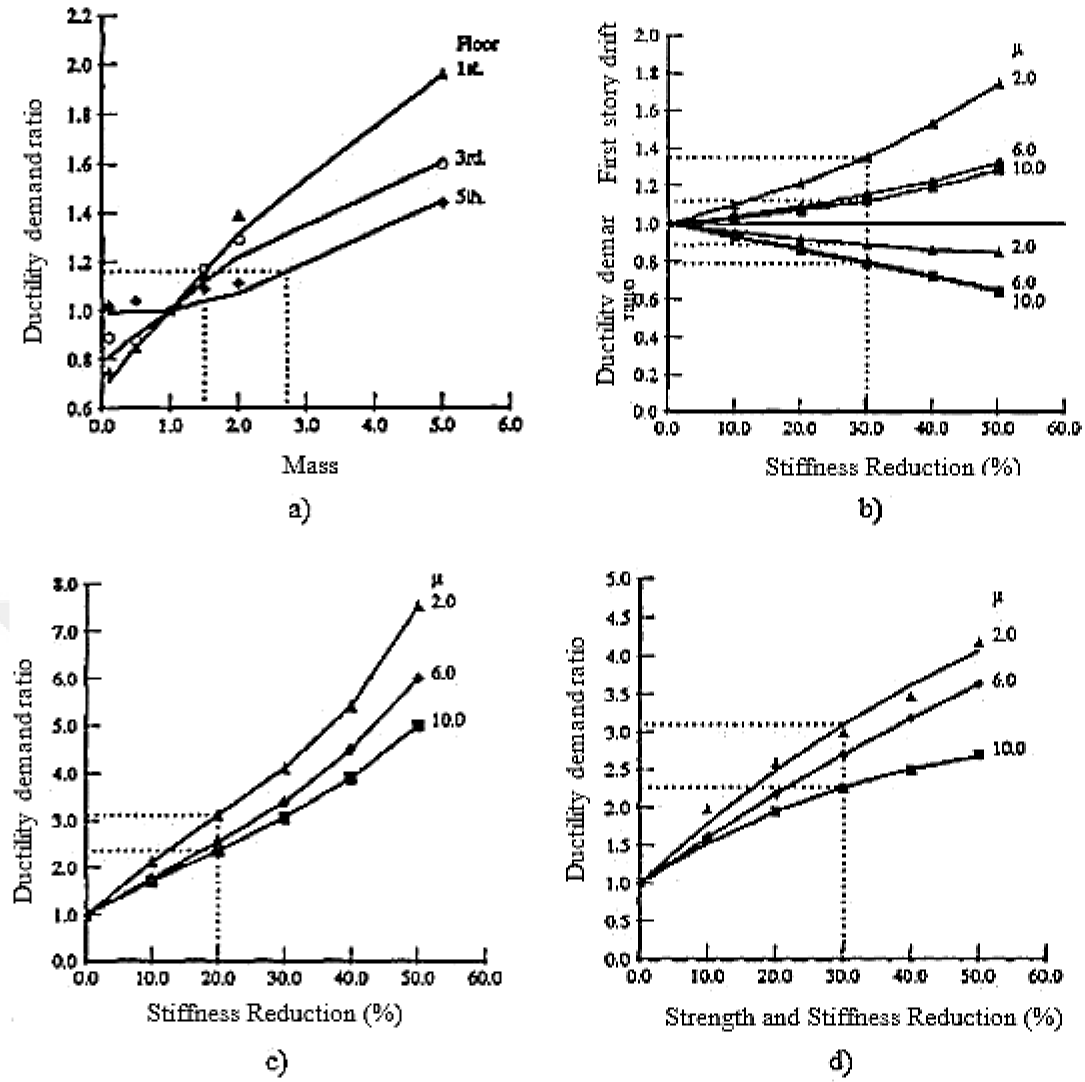


Figure 2.3 (a) Maximum ductility demand for 5-story frame with mass irregularity and design ductility = 2; (b) Maximum ductility demand and first drift story for 20-story frame with stiffness irregularity; (c) Maximum ductility demand for 20-story frame with strength irregularity; (d) Maximum ductility demand for 20-story frame with stiffness and strength irregularities (Valmudsson and Nau, 1997)

Al-Ali and Krawinkler (1998) examined the effects from demanding vertical irregularities around height insightful varieties from seismic demand leading elastic and inelastic dynamic investigation utilizing 15 records on a 2D single bay 10storey nonspecific structures. The beams were constructed stronger than the columns, permitting for a soft story appliance. Responses of buildings with strength or/and stiffness irregularity has been contrasted with the response of a situation building that needed a constant circulation of mass again the stature and a related stiffness circulation that brought about a straight line to begin with mode form. Story stiffness's were tuned to prepare a 1st mode fundamental period about 3s. Irregularity might have been acquainted clinched alongside a number of methods: (i) the stiffness's were altered in two ways. To one case set, stiffness's during the first story or during the mid-height of reference structures were increased by 0.1, 0.25 and 0.5. To the second set, story stiffness's of the lower half of every reference building were increased by factors of 2, 4 and 10. Those stiffness circulations for every one of the cases were then tuned until the irregular buildings had an essential time of 3s. Since stiffness irregularities vary the division of elastic story shear requests, story strengths to all that over cases for stiffness irregularities were tuned on their versatile story shear circulation got from SRSS investigations utilizing the 1997 National Earthquake Hazard Reduction Program range lessened by strength reduction factors of 3 and 6. Story drift requests rather than the DDR were the parameter utilized. They were observed to increase in the story with decreased stiffness furthermore reduce in the greater part of alternate stories. Roof drift demands were few delicate to the nearness of irregularity in stiffness. (ii) Influences of strength irregularities have been examined. The strength of a particular story may have been extended to 2 times the strength of a similar story in the reference construct structure. The mass and stiffness circulations were held the same as for the assemble case. This adequately brought about exactly weaker storys. The maximum drifts were larger than six times of the reference structure clinched alongside exactly cases the place there might have been a special case weak story. (iii) Strength and stiffness irregularity might have to been recognized. It might have been restricted to cases the place the stiffness and strength might have been changed by two times that starting with the build instance. It might have been connected independently toward the to start with the story, the mid-height, alternately in the bring lower half of the building. The strength/stiffness distribution at alternate story have been held the same with respect to their particular irregularity cases. Stating with strength/stiffness irregularity for the most part provided the similar response accordingly as the irregularity of strength cases, yet by a bigger quantity.

Kappos and Scott (1998) established the correlation amongst dynamic and static techniques of investigation for estimating the seismic response of RC structure with vertical setback irregularity. On correlation among consequences of tow systems it has been presumed the dynamic investigation yielded outcomes not quite the same as that of the static investigation. In any case, in the investigative research the alternate types of irregularities such as strength, stiffness and mass irregularity are not excluded.

Magliulo et al. (2002) attended parametric comparisons on multistory reinforced concrete structure. Five and nine-story regular frames are assumed as a reference with strength, stiffness and mass irregularity designed for low ductility class per EC 8 requirements. The writers assessed of the irregular frames seismic response. Also, resembled it to the seismic response of structures without irregularity. From the investigative contemplate it might have been discovered that all the variations with over strength relegated to the beams indicate an irregular conduct since actually vast additions of the ductility demand of the columns are detected, the inverse happens in the circumstance of frames described by additions of column strengths; the interstory drifts of all the strength changed frames are near the relative reference frame ones. The universal codes criteria on a strength irregularity in elevation are exceptionally questionable. Also, about the stiffness modified frames, the variations having altered beams demonstrate a more irregular performance with respect to the variations having the story height incremented. It appears exceptionally hard to decide a numerical edge amongst regular and irregular buildings, in light of either elastic interstory drift ratio or contiguous story stiffness ratio. At last, the authors presumed that the 56 parameters of story strength characterize as recommended by EC8 and IBC codes was incapable in anticipating strength irregularity.

Das and Nau (2003) estimated the influences of mass, stiffness, and strength irregularity on the inelastic seismic response of high numbers of multistory buildings. To explanatory investigation an extensive number about buildings for three bays previously, course from demanding seismic action and for number about storys going from 520 were displayed as indicated in Figure 2.4. The structural irregularities in these building models were presented by variety of stiffness proportion, mass proportion, strength story and had been designed as a special moment resisting frames (SMRF) based on strong column weak beam design philosophy in accordance with different codes of practice, namely ACI 1999 and UBC 97. The forces on these SMRF frames were processed utilizing ELF (Equivalent lateral force) technique as endorsed in ACI 99 and UBC 97 code from outcomes of investigative research it has been inferred that the parameters of seismic response corresponding first mode configuration time period being figured by ELF strategy did comparatively for regular and irregular frame. The story drift calculated for 5 story and 10 story frames with rearrangement of stiffness, strength and stiffness irregularities at lowest story presented a sudden increment over code directed limit of 2%. The ductility demands indicated a sudden increment close to the area of irregularity yet this increment never surpassed the capacity of designed ductility for the members. At last, the mass irregularity has minimum effect on the structural damage contents and for every frame models analyzed it has been observed to be under 0.40.

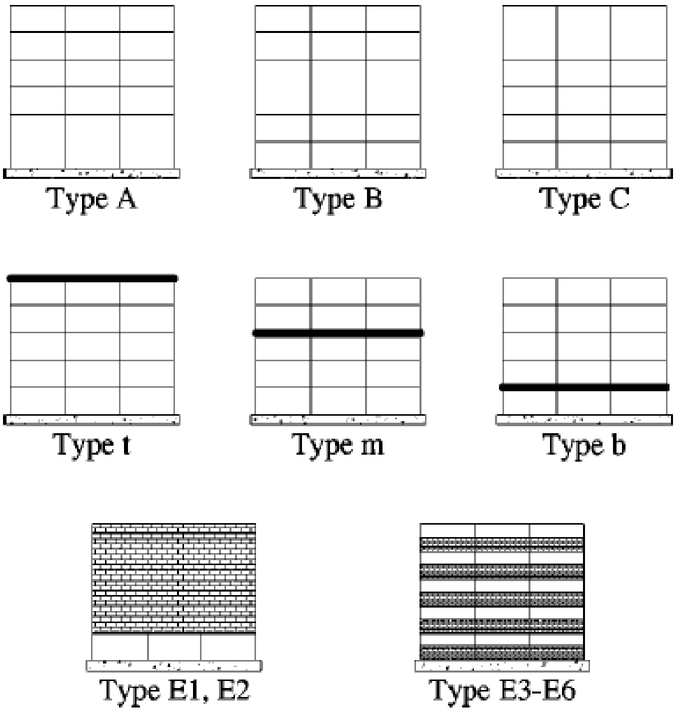


Figure 2.4 Different types of vertically irregular building models (a) Type A, B, C Taller first, middle and top story, (b) Type t, m, b - Irregular mass distributions, (c) E1-E2 Open ground floor, E3 E6 partial infill (Das and Nau, 2003)

Chintanpakdee and Chopra (2004) assessed the influences of stiffness, strength and combination of stiffness and strength irregularity on seismic response of multistory structure. For explanatory research, diverse twelve story casings have been demonstrated in light of weak beam –strong column principle. The stiffness and strength irregularities have been presented at diverse positions with the height of the frame models. The structure models had been investigated utilizing time history analysis by applying the building model to 20 distinctive 57 ground movement information. As per the investigative study, it has been inferred that strength and stiffness irregularity was being in the mix have the most extreme impact on the seismic response. Moreover, greatest variety in the displacement response with the height might have been watched at irregularities were available on the lower storys. Also, drift demands in the upper stories would considerably touchier to irregularities in the lower stories over that reaction of lower stories is influenced toward irregularities in the upper stories.

Michalis et al. (2006) investigated the effects of strength, stiffness and additionally their combined irregularity under various concentrations of shaking. The build structure might have been a realistic nine story steel model for a higher basement over the other storys. It needed an essential period about 2. 25s, and it might have been designed for a Los Angeles site. Strength and/or stiffness irregularities were acknowledged toward duplicating the base situations strength and stiffness by factors of 0.5 and 2. These components were connected at different positions in the height of the building. The writers received the incremental dynamic investigation technique. At every scaling level, the most extreme interstory drift proportion, θmax, was gotten. So as to differentiate the performance of the altered against the base case, a variety of limit states have been described, every at a specified amount of θmax, spanning every last one of building response ranged of elasticity to global dynamic instability. The circulation of peak interstory requests again the height of irregular frames, standardized toward that because of those base cases might have been discovered to every irregularity case. In the stiffness irregularity studies, they discovered that a story for lessened stiffness frequently diminished the drift demand relying upon the intensity of shaking. Additionally, the position of maximum demand was not generally at the location of irregularity. The strength irregularity concentrates by and large demonstrated comparative conduct. They expressed that for combined stiffness and strength irregularity, the adjustment in drift demand circulation was roughly equivalent to that got by including both the stiffness and strength irregularity results. Irregularities were likewise presented at numerous stories all the while. The influence of multistory adjustments was quantitatively appeared as included impacts of comparing single story influences. It might a chance to be seen that a number for fascinating investigations have been tackled with show how vertical strength/stiffness has influenced the response structures. This examination develops these past works, and hopes to augment them by considering the variety as a result of vertical strength stiffness irregularity on an extent of sensible structures to get a correlation betwixt the measure of irregularity and the variety response for these structures.

Ayidin (2007) used ELF method (as guided by Turkish code of system) also for measuring mass irregularity seismic response of buildings used time history analysis. The irregularity of mass is made by varying in of a story mass with a consistent mass at different stories. Dependent upon the systematic research, authors inferred that the mass irregularity impacts the shear in the story underneath and ELF method overvalues the seismic response of the structural systems when contrasted with the time history analysis. The examination of the investigation comes about demonstrating that the inexact strategy dependably overestimates the linear behavior paying little heed to structure height, building rigidity and level of mass irregularity. They concluded that the varying mass proportion of a story influences the linear shear response of the stories underneath the location of mass irregularity. This occurs in a path that as the mass proportion builds, the mentioned story shears also increment linearly. To the individual stories over the floors above, which the mass irregularity happens, in any case, the shear responses would not be impacted by the adjustment in floor mass proportion values.

Athanassiadou (2008) made the assessment of seismic capacity of the RC structures irregular in elevation. The author demonstrated three multistory frames. Out about these three frames, two ten story two dimensional plane frames with two and four vast setbacks in the upper floors individually also additionally a third one, regular in height, need been designed to the requirements of the 2004 Eurocode 8 (EC8) for those high (DCH) and medium (DCM) ductility classes, and the same top ground increasing acceleration (PGA) and material qualities. The sum structures bring is subjected with both inelastic dynamic time history analysis also inelastic static pushover analysis for chosen enter movements. The seismic performance evaluation may be in light of both worldwide furthermore nearby standards. It is inferred that the impact of the ductility class on the expense about structures may be negligible, same time the seismic performance from claiming all irregular frames gives the idea on be just as satisfactory, not second rate on (and for a portion instances unrivaled than) that of the regular ones, notwithstanding for developments twice as strong as the design seismic quake. Obviously, DCM frames are observed to be more grounded and less ductile than the looking at DCH ones. The over strength of the irregular frames is observed to resemble that of the regular ones, although DCH frames are obtained to arrange over strength than DCM ones. pushover investigation gives off an impression of being ought to defame those response amounts in the upper floors of the irregular frames. Drift ratios of irregular frames were discovered with remain very much low significantly on account of the 'collapse prevention' earthquake for a force level twofold that of the 'design' one. This event, joined by that restricted columns plastic hinge configuration, avoid the plausibility for the creation of a failure mechanism. Irregular buildings appear to be stronger because of the diminished estimations of the conduct mechanism and few ductile than the relating regular ones. At the different hand, every last bit DCM span frames appear should be, likewise expected, less and stronger ductile than the comparing DCH ones.

Güler et al. (2008) had worked on existing vertical irregular building which was retrofitted after the earthquake. It was taken in the investigation of performance evaluation. The building has four and three traverses x-x and y-y directions, individually. Story heights are same and equal to 3.0m. The 3D model of the structural system is utilized for numerical results by the utilization of SAP2000 and ZEUS-NL software's. Pushover analysis is completed for each of the x-x and y-y directions capacity spectrum method, which depends on static pushover analysis, is utilized to acquire of the current structural performance levels methods. Albeit current building act prefers on apply nonlinear static analysis to the seismic Performance evaluation of existing structures, one ought to recollect that these investigation techniques are constrained with the measure, one ought to recollect that these investigation techniques are constrained with the measure of the irregularities in elevation and plan, number of stories and first mode mass support component.

Sadasiva et al. (2008) assessed the influence of location of vertical mass irregularity on seismic response of the buildings. A 9 story regular and irregular (with vertical irregularity) frame had been evaluated and designed according to a New Zealand code of practice in two ways. Firstly, it might have been designed on need greatest inter story drift in the least levels (characterized likewise CDCSIR). Secondly, it might have been planned with having a steady stiffness (characterized eventually Tom's perusing CS) in the least levels. To create an obvious difference among regular and irregular building, a particular system design had been utilized by the writers of information

NSML(A), where no of storys, S Shear beam, M kind of model [i.e. S (Shear beam) or SFB (Shear Flexure beam), (A) – Mass proportion]. The distortion was characterized in the method of graphs. For the research Los Angeles quake records required to be utilized and inelastic time history analysis of the structure might have been performed using Ruamoko software. In light of this investigation, it might have been concluded that in the event about both CS and CISDR show the inter story drift delivered is greatest while irregularity of mass is available at the highest story and irregularity expands the inter story drift of the frame. Be that as it may, this extent varied for both CS and CISDR sort of models.

Ambrisi et al. (2009) calculated the seismic response of irregular structures by using the pushover analysis. In view of illustration, an evaluation of convenience of modified pushover analysis of irregular building frames was conveyed for evidence to a current reinforced concrete school building, introducing an intricate consolidation of the plan and vertical irregularities. The irregularity in elevation building frame was established for a 3D RC 4 story frame model. Vertical irregularity through a setback with X-direction of the third level with regarding to the second level, X plan value at the first and second level is 36.9 m long, while that gets 28. 9 m in length toward the two higher levels. It takes after this current building shows a vertical irregularity combination, mutually in elevation and in a plan, those made seismic behavior extremely perplexing. Hence, it was extremely intriguing to indicate if a changed pushover investigation had been reasonable for this specific contextual analysis, though in the standard such process has been expressed to study the effects of plan irregularity single. In light of the investigative comes about, it may have been discovered that changed pushover examination correlates great results about initial with inelastic dynamic analysis, very nearly dependent upon collapse, likewise it could be seen that, many portions of the cases, its requirements about Inter story drifts and plastic rotations need aid conservatively near qualities from inelastic dynamic investigation. Indeed, also collapse mechanism, comprising of a story system at the third level, is accurately anticipated beneath this involved irregularity forms. Even collapse mechanism, involving of a story mechanism at the third level, is accurately anticipated under such complex irregularity conditions. Consequently, it gets to be clear that modified pushover analysis is extremely encouraging as an improved technique for assessing seismic performance of structures frame with irregularity.

Kara and Celep (2012) studied the vertical irregularity structural system with discontinuities in column by using nonlinear seismic response. They considered nine frames one frame regular and eight frames are irregular due to discontinuous of columns all frames having eight stories and two spans. All column section is expected to be 0.45mX0.45m and the beams to be 0.3m/0.6m. Just the beams which support the discontinuous of columns have a cross section of 0.4m/0.8m so as to support the load of the column which is not transported to the column below because of the vertical irregularity of discontinuity of the column. The resulted of the difference of the axial force in the middle and the side columns along the height of the system for each frame under the factored gravity and live load (1.4G+1.6Q). They concluded, the axial force in the side columns increases quickly over the story where the discontinuity is available. At the point when the middle column shows up and transfers the normal force to the columns in the lower stories, then the increase of normal force turns out to be less in the side columns, in other word, the discontinuity of the middle column influences the side column by increasing its normal force fundamentally. Also, the axial force variation in the middle column along the elevation of the frame. The force vanishes, when the discontinuity happens, of course, when no discontinuity not present, a gradual increase of the normal force occurs downwards. Figure 2.5 shows that the pushover curves of the frames having column discontinuities.

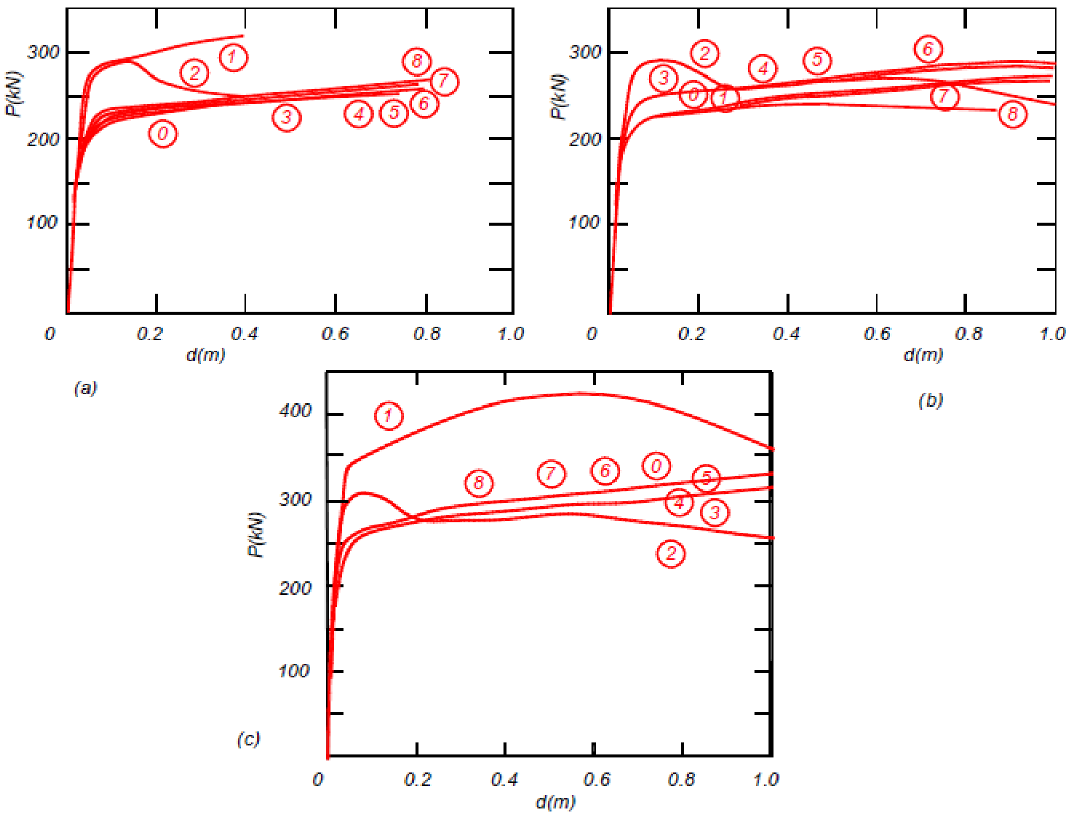


Figure 2.5 Pushover curves of the frames having column discontinuities, a) external load having the first modal variation, b) external load having the first modal variation with P-Δ effect and c) external load having a constant lateral force variation (Kara and Celep, 2012)

They detected the structural behavior of the frame under the seismic is numerically assessed by acknowledging those pushover analyses. In these investigations notwithstanding the geometry and the reinforcement details of the column and the beam sections are required. The frames are designed by acknowledging factored and earthquake loadings, i.e., 1.4G+1.6Q and G+Q+E. They discussed (Figure 2.5) that the maximum lateral load capacity of the frame (1) is greater than of the frame (0) which has no column discontinuity. In any case, the ductility capacity of the frame (0) much greater than that of the frame (1), as it is appeared in the pushover curve given in Figure 2.5 (a). Figure 2.5 (c) demonstrates the lateral load capability of the frame increments, at the point while the variety of lateral load is steady because of the constructive effect of the stacking. They inferred that the nonlinear behavior of the frame having column discontinuity entirely diverse that the linear behavior. It is regularly hard to anticipate the nonlinear behavior of the frame having a column discontinuity by assessing the linear analysis. Moreover, the nonlinear story drift demand is essentially large, when the column discontinuity is in the lower stories of the frame. Ductility demands in the area of the story of the irregularity are detected (Kara and Celep, 2012).

Sarkar et al. (2010) created another parameter called as regularity list (characterized concerning proportion of the first mode interest element of the stepped frame building to the regular frame) with express the degree about irregularity and the creators formed an experimental equation to estimate the time period building frames with setbacks vertical irregularity. By utilization of this equation the fundamental time period had been described as the capacity of regularity guide. To authorize the method, modal analysis of 78 diverse frame buildings with various sorts of vertical irregularity with setback were directed. Also, it might have been discovered that the experimental formula yielded exact effects significantly for 3D building models.

Kim and Hong (2011) discovered the failure resisting ability of the structure models with strength and stiffness irregularity. In those study, evaluated nonlinear static and dynamic investigations of the progressive collapse resisting capacities of tilted and twisted buildings. For study models, 30storey tilted structures with braced cores and 30storey twisted structures with RC centers were readied. The irregularity in the frame models had been formed by deletion of columns in the middle story. Be that as it may, examination results recommended minor variety in the collapse possibilities of irregular and regular structures. The performances of the irregular buildings had been contrasted from those of the regular structures designed without twisting or tilting. As per the investigation result, the dynamic failure potential of the tilted buildings changed altogether, contingent upon the position of the deleted column. Particularly, the corner column situated in the tilting course should be protected or strengthened from conceivable destruction to avert increasing failure of the entire building. It might have been also seen in the tilted structures that the plastic hinges framed not just in the bays from which a column have been deleted, additionally in the close by bays. Comparative marvel might have been additionally seen in the twisted buildings. Nonetheless, the general increasing failure possibilities of the twisted or tilted buildings studied in this investigation have been not especially greater than the relating regular structures. This had been mostly in light of the fact that the twisted or tilted structures were designed with bigger structural individuals respecting these irregularities. An additional cause appears to make that, compared with regular structures, a greater amount structural components were included for opposing progressive failure the point while a structural part might have been wiped out.

Van Thuat (2011) decided the story strength requests of irregular structures under strong seismic. The structure strength irregularity models had been presented as far as story strength factor that speaks to the comparative save strength of the story against collapse. The analytical models are considered three irregular building frames with same spans of 5m, in which the 7-story and 15-story had a discontinuity of inside columns in the first stories frame and the 8-story had an irregularity of inside columns in mutually the first and second stories. this discontinuities prompt manifestation of the exchange beams of a 15-m span for the irregular stories were led under 29 strong earthquake records with different aspects variety of seismic demands because of the presentation for irregularity. The results indicate that the earthquake response requests toward irregular stories of the buildings were great assessed as far as the story strength influence request with the evading progress of a story collapse system of the buildings, the point while a subject should strong seismic.

Akberuddin et al. (2013) studied pushover analysis of mid-rise multistory RC structure with and without vertical irregularity. The investigation on goes for assessing the response of five reinforced concrete buildings by utilizing nonlinear static pushover investigation of 4 story mid-rise RC residential building frame with 6 bays in each the directions and three storys on the ground story, the typical story and ground story height is 3. 0 m. The width of bays is 3.m may be should be designed by conventional design methodology. They discovered that irregularity in elevation of the building reduces the performance level of structure, there is also decreased in deformation or displacement of the building. Analysis the bare frame model with and without vertical irregularity is completed by utilizing Etabs software, as of the investigation outcomes acquired, for lateral displacement the rate of vertical irregularity changes the lateral displacement changes widely i.e., it reduces. The regular frame indicates the displacement of 0.265m, however, because of change in vertical irregularity it decreases to 0.085m for 200% irregularity and which goes down up to 0.026m for 300% reduction in vertical geometry. For inter-story drift the progress done rate of vertical irregularity make change in story drift, as the percentage increases with reduce in story drift. For story shear the change in rate of vertical irregularity additionally cause change in story, as the rate increments with decrease in story drift. The regular frame demonstrates the story shear of 1097.85kN at base, yet because of change in vertical irregularity it lessens to 1030kN for 200% irregularity. Also which dives down up to 960kN for 300% decrease in vertical geometry. From the pushover results for G+ 3 storys bare frame without vertical irregularity possessing extra Performance point value (lateral load capability contrast with bare frames with vertical irregularity. Additionally, infer that as the no of bays lessens vertically the lateral load conveying capacity reduction in lateral displacement. Likewise, they inferred that the bare frame without vertical irregularity possessing extra lateral load capability (Performance point value) compare to bare frames with vertical irregularity. i.e., (The vertical irregularity reduces the flexure and shear demand.) and the lateral displacement of the structure decreased when the rate of irregularity increase. There will be no more impact for geometric irregularity ahead story shear, however, there is 2 to 5% difference in lateral displacement. Also, inferred that as the no of bays lessens vertically the lateral load carrying capacity increments with diminishment in lateral displacement.

Habibi and Asadi (2013) studied on reinforced concrete buildings irregular in elevation indicate seismic performance designed according to Iranian seismic code. For this cause, many sorts of vertical irregular frames were primarily designed based on code 2800 and the ninth Iranian national building code and nonlinear dynamic time-history analysis that point might have been performed ahead them subjected with ten quake records. Also, designed regular frames in that research according to the ninth Iranian national building code and 2800 code and nonlinear dynamic analysis was led on them subjected to similar earthquakes. Inelastic dynamic time history investigation is achieved on all frames subjected to ten input movements. The evaluation of the seismic performance is finished in light of both the local and global standards. Figure 2.6 displays the model structures with various stories and irregularities (Seneviratna and Krawinkler, 1997).

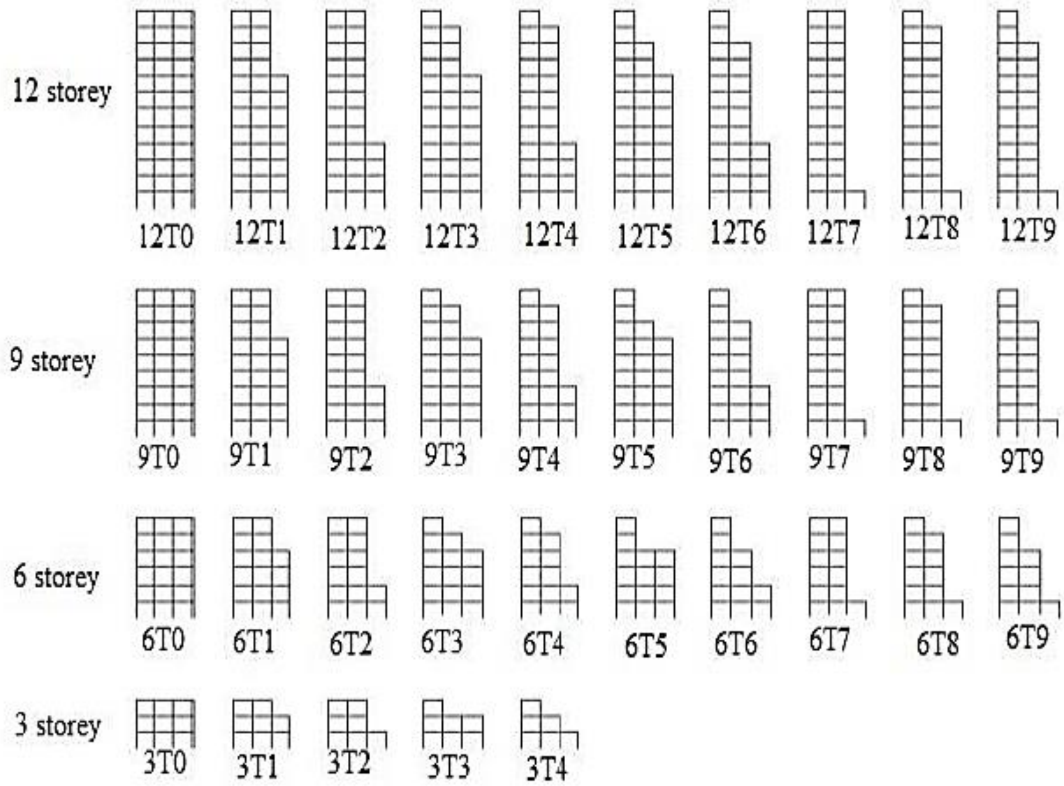


Figure 2.6 Structures studied by Habibi and Asadi (2013)

The results found from the study of Habibi and Asadi (2013) displayed that when setback happened in elevation, the necessities of the life safety level were not fulfilled. It was additionally demonstrated that the components close to the setback experience the greatest damage. Hence, it was important to strengthen these components by a suitable method to fulfill the life safety level of the frames. Habibi and Asadi (2013) also established that the life safety performance principles were nearly satisfied in the regular frames. They concluded that the earthquake performance of the considered multi story RC frame structures with irregularity in elevation might not be considered acceptable. It might make said that, despite the fact that the limit capacity design method by Iranian seismic code appeared to be effective for regular frames, yet it couldn't have the capacity to fulfill the life safety performance level principles in irregular frames with setbacks along their height, even a large portion of them collapse under design earthquake. Thus, those criteria appeared over require with to be produced so as on characterize furthermore recommend new indicators and techniques that might really predict seismic conduct for vertical irregular structures.

Priyadarshini (2013) used the fragility curves of vertically irregular buildings for calculating performance assessment. The ordinary moment resisting frames used for designed these frames, the design of the reinforced concrete components is conveyed out according to IS 456 (2000) criteria and estimated seismic load as per IS 1893 (2002). The structures are supposed to be symmetric in the plan. The common height of column is selected in this research is 3. 2m and bay with is 3m for all the structure frames. The fragility investigation had been completed with retreating investigation that affected by the seismic consistency capacity and the building demand. The seismic force ratio may be acknowledged for the consider as the movement of ground and the structural request is the building request parameter that will be those inter-story drift capabilities as far as top ground acceleration to era from demanding fragility curves for various performance levels. They concluded that from the vertically irregular fragility curves of structures it is detected that the setback frames were observed to the possibly safer than relating regular structure.

Kalibhat and Kumar (2014) studied the seismic performance of RC frames with vertical stiffness irregularity from pushover analysis of 2D frames with six models of four bays, four story have been considered. For this reason, ETABS a finite element programming has been utilized. The irregularity is progressively added starting with a frame of regular to extremely irregular frame. From the pushover results they have seen that as the irregularity in the structure increments the lateral load carrying capability of the building diminishes. Consequently, this structure is defenseless against seismic force as the vertical geometric irregularity in the structure is increased. Additionally, they concluded that the structure gets vulnerable with increment in vertical irregularity and with an increase in vertical irregularity the rate of plastic hinges crossing elastic limit increase, rendering the structure more assailable. The design of the frames is done by use the Indian Standard Code IS-456: 2000 and IS 1893 2002. Auto hinge properties like for PMM M3 hinges are allocated at the beam ends and PMM hinges are allocated at the column ends. The displacement controlled analysis is considering for carried out pushover analysis. The details of model cases shown in Figure 2.7.

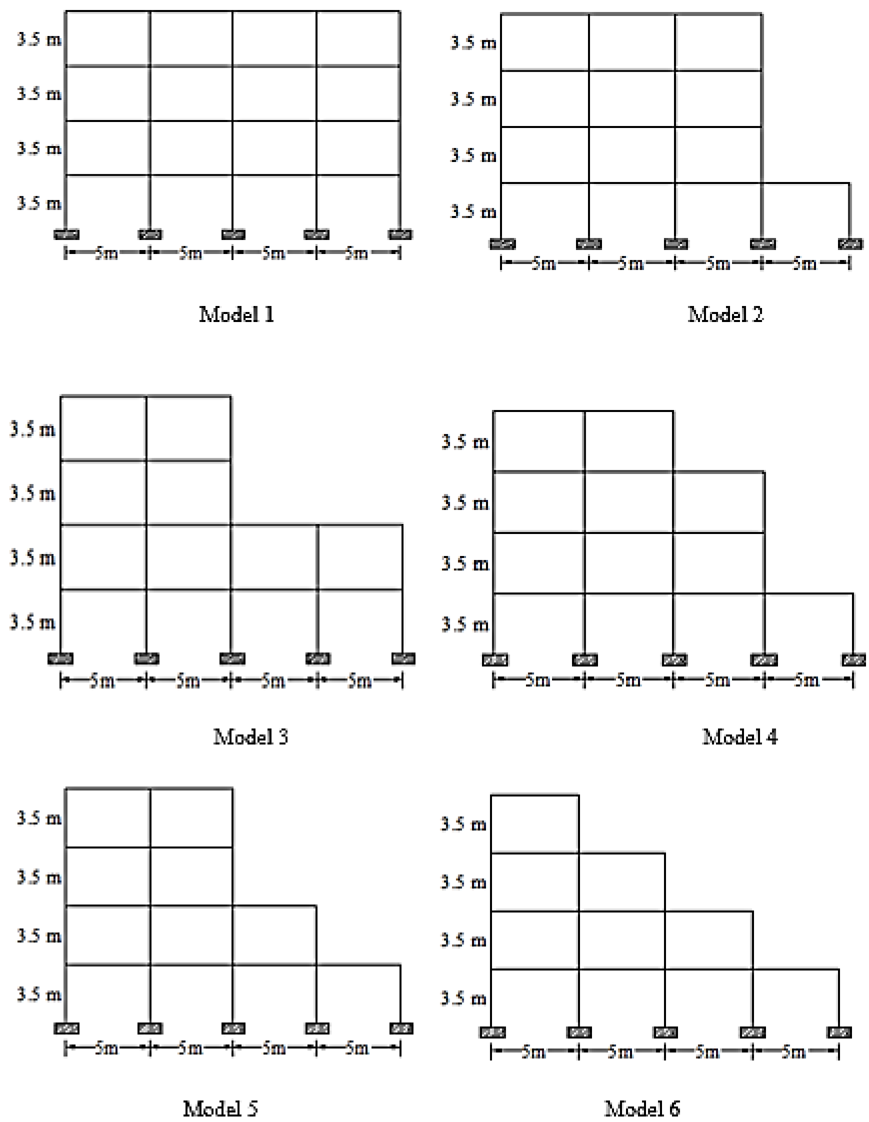


Figure 2.7 Typical elevation of the models considered for the study Kalibhat and Kumar (2014)

The capacity curves of various models considered in the study show in Figure 2.8. These pushover curves are planned between roof displacement carried and base shear undergone by the structure. It is seen that as the irregularity in the structure increases the lateral load carrying capability of the frame decreases. Thus, the structure is vulnerable to seismic force as the vertical geometric irregularity in the structure is increased (Kalibhat and Kumar, 2014).

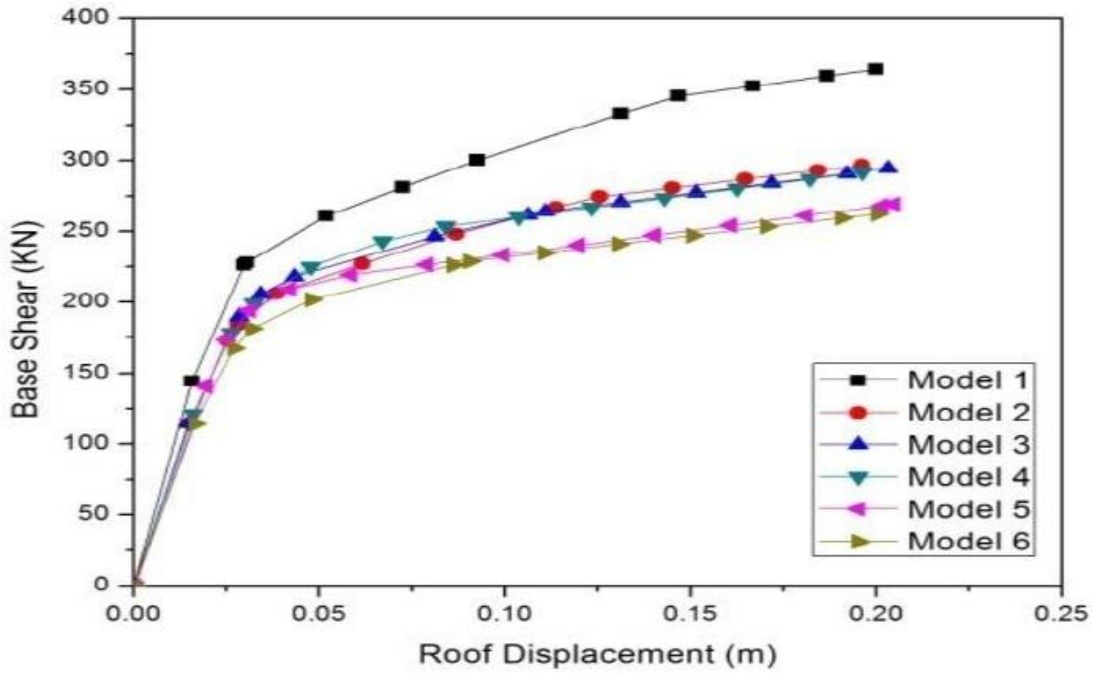


Figure 2.8 Pushover curves for the six frame models (Kalibhat and Kumar, 2014)

Sai Himaja et al. (2015) studied the assessing and contrasting the response of thirty vertically irregular RC structures by use nonlinear static analysis (pushover analysis) of mid-rises G+3 and high-rises G+9 RC residential infilled structural frame. This may be those essential and the with and without vertically irregular frame of the structure hosting 6 bays on both the directions furthermore four storys also ten story on the ground story. The typical story height furthermore ground story height are the equal i.e., 3.0m. The bay width is 3.5 m. From the outcomes depicted that the bare frame displacement increases the base shear diminishes. The estimations of the base shear and the displacement are the other way around. Also, if the height of the building extends the displacement additions and the base shear diminishes. Be that as it may, in the infilled outlines it resembles similarly as the displacement of the building expands those build shear 38 of the building also increments. Furthermore, concerning illustration those height of the building expands the displacement and the base shear diminishes. The behavior of the bare frames will be inverse of the infilled frames.

Naik et al. (2015) studied the structural seismic response with vertical irregularities having discontinuities of column by using nonlinear analysis they considered nine frames one frame regular also eight frames are irregular due to discontinuous of columns all frames having eight stories and two spans. All column section is expected to be 0.45mX0.45m and the beams to be 0.3m/0.6m. Just the beams which support the discontinuous of columns have a cross section of 0.4m/0.8m so as to support the load of the column which is not transported to the column below because of the vertical irregularity of discontinuity of the column. They instance study model represents medium rise building with regular and irregular elevations as appeared in Figure 2.9 four models were examined, the bay width is4m and height of every story 3m. Four models were analyzed, amongst which one model has regular elevation and another three models are with elevation irregularities.

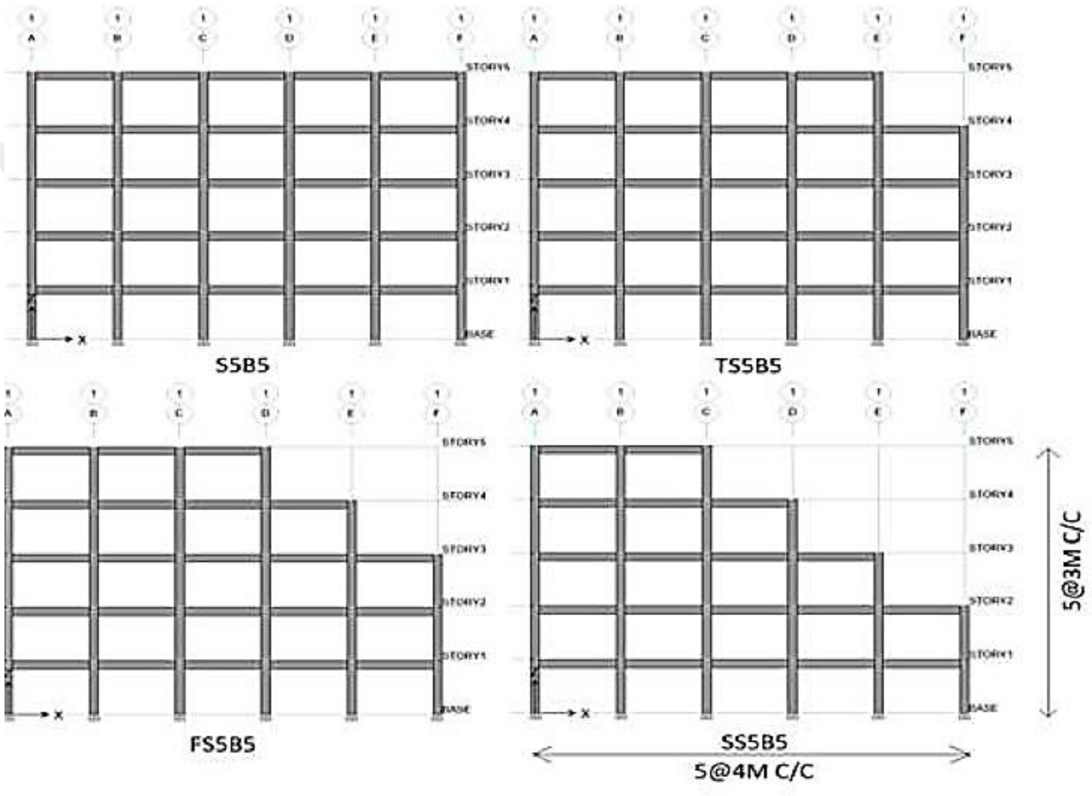


Figure 2.9 Typical elevation of example frame models (Naik et al., 2015)

Figure 2.10 displays the results of pushover curves for the example MRF models achieved for 4% target displacements at a specific node located in the roof. They concluded that as a percentage of irregularity increases base shear decreases by 17-30 %, thereby reducing the lateral load conveying capability of the frame, but for the moment of ductile behavior in inelastic zone increases up to 18% (Naik et al., 2015).

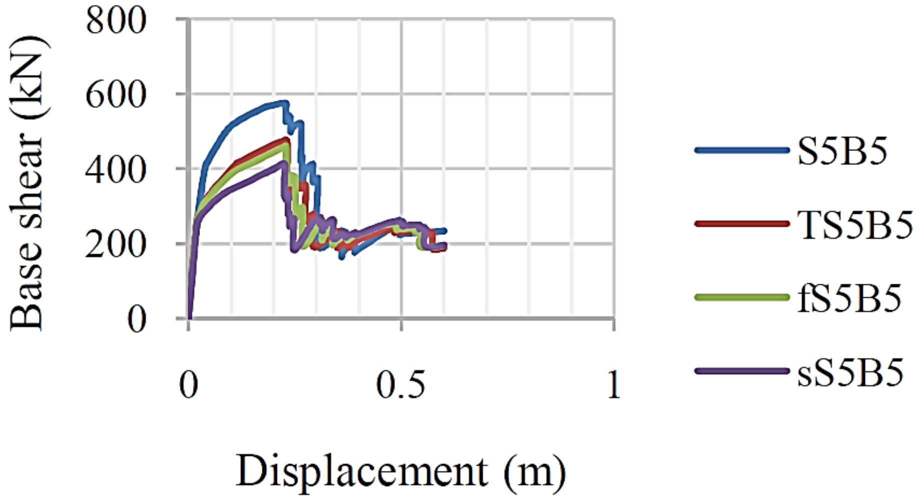


Figure 2.10 Comparison of pushover curve (Naik et al., 2015)

Also, they concluded that if the rate of irregularity in elevation increases the base shear decreases, thus reducing the lateral load carrying capacity of the structure. Thus, most extreme consideration ought to be taken by the structural engineers while designing the irregular structure. There will be noteworthy declines in performance of structure in respect of responses for example lateral displacement, storey drift, and storey, however the deformation is increasing because of formation of collapse mechanism, and the analysis demonstrates that, the seismic performance is particularly subject to the mass, stiffness, strength regularity and ductile or non-ductile behavior (Naik et al., 2015).

CHAPTER 3

CASE STUDY

3.1 Description of regular and irregular structures

In this case study, the pushover response of both regular and irregular reinforced concrete (RC) structures are investigated. Using SAP 2000 program, the nonlinear analysis is conducted to estimate the behavior of the models. According to the study, mid-rise and low-rise RC buildings are selected to represent both regular and irregular structures. Three story RC building is assigned as low-rise office building, while seven story RC represents mid-rise office building with different type of irregularity consists of stiffness/strength irregularity with missing beam and missing column, mass irregularity, and vertical geometric irregularity (set-back). The inter story height and ground story height of the structures are the same, three meters. Totally, eight models simulate regular and the other types of irregular buildings for both low-rise and mid-rise structures. In addition, each irregular model may have several cases to indicate which one the most severely affects the response of the structure to seismic loads.

In the present study, a building with four bays in each direction is selected, the span of each bay is four meters. The other characteristics are assigned based on assumption, and loads, dead load and live load, are taken from SEI/ASCE 7-02 code. Finally, the standards of irregularity are applied based on specifications. The results of both three story and seven story structures are recorded after applying the lateral loads. The detail basic specifications of the building are given in the below table:

Table 3.1 Building parameters considered in the study

NO	Contents	Description
1	Type of structure	Medium rise and low rise office building
2	Number of story	For medium rise G+6 For low rise G+2
3	Floor height	3.0m
4	Base floor height	3.0m
5	Size of column	0.3m×0.4m
6	Size of beam	0.35m×0.4m
	Beam which support the discontinuous of column	0.35m×0.55m
7	Depth of slab	0.15m
8	Dead load (for office building)	5.5kN/m^2
9	Live load	5kN/m^2
10	Beam reinforcement	(top) 600mm^2, (bottom) 2800mm^2
11	Column reinforcement ratio	1.20%
12	Stiffness modifier	0.35 for beam 0.7 for column
13	Load case 1	DL+0.3LL
14	Load case 2	1.4DL+1.6LL

With respect to the above structural and seismic information for demonstrating the plan, elevation and three-dimensional view of three and seven story regular models are presented in Figures 3.1 to 3.3. In Figures 3.4 and 3.5, the elevation views of the frames having strength/stiffness irregularity-missing beam are given for the G+ and seven story models, respectively. Figures 3.6 and 3.7 show the elevation views of the frames having strength/stiffness irregularity-missing column for the three and seven story models, respectively. Figures 3.8 and 3.9 demonstrate the elevation views of the frames having mass irregularity for the three and seven story models, respectively. Also, in Figures 3.10 and 3.11, the elevation views of the frames having vertical geometry irregularity-setback are presented for the three and seven story models, respectively. All dimensions are given in meter.

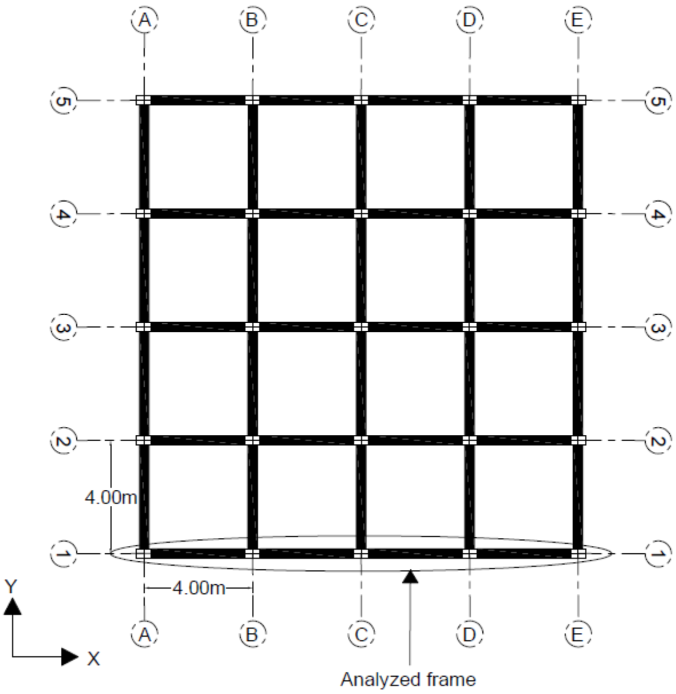


Figure 3.1 Plan view of regular RC buildings

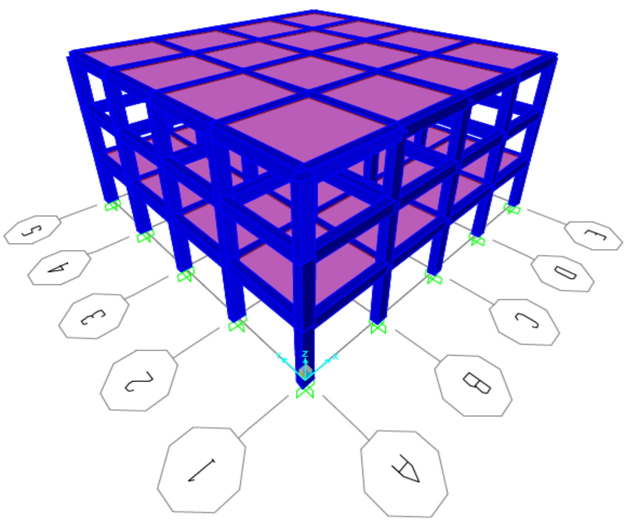


Figure 3.2 Three-dimensional view of low-rise (G+2) story regular RC building

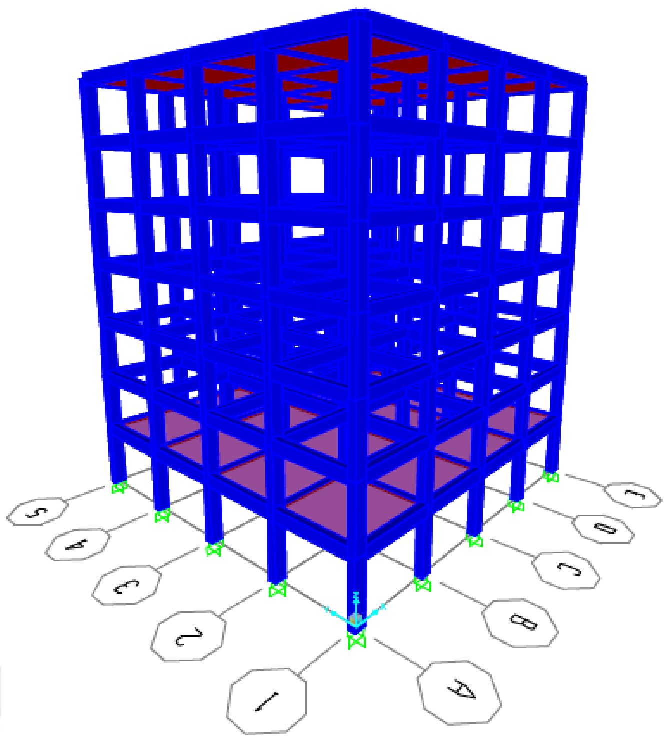


Figure 3.3 Three-dimensional view of mid-rise (G+6) story regular RC building

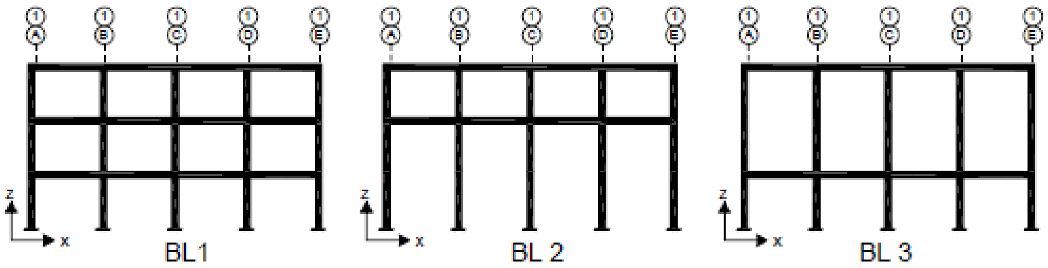


Figure 3.4 Elevation view of three story RC frame (strength/stiffness irregularity-missing beam)

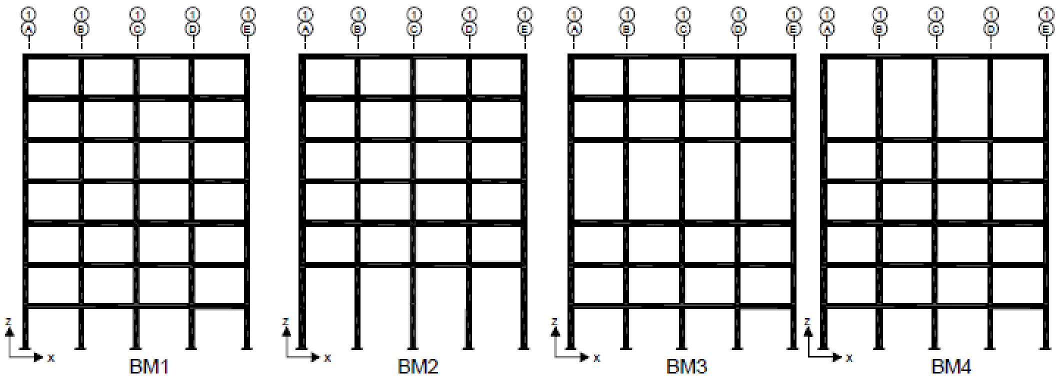


Figure 3.5 Elevation view of seven story RC frame (strength/stiffness irregularity-missing beam)

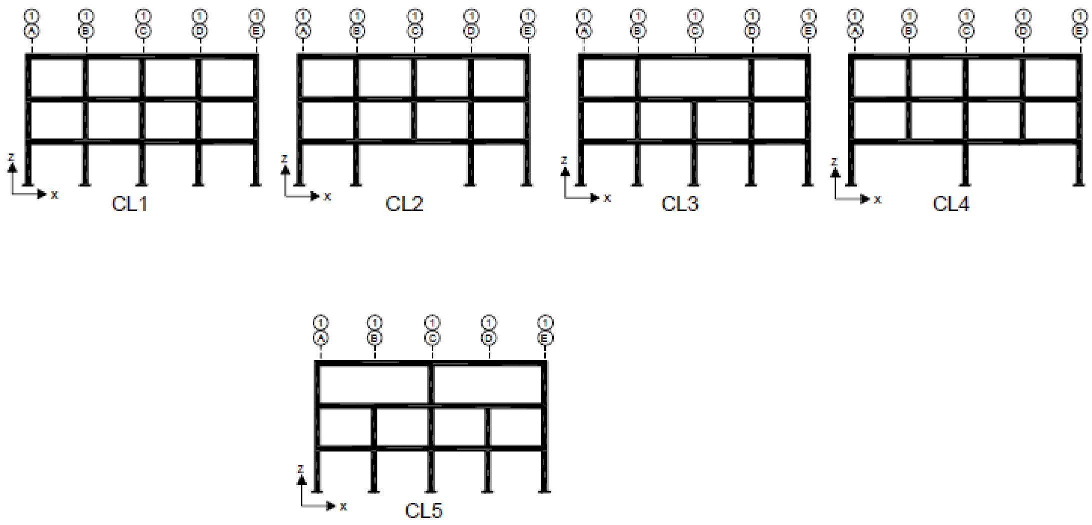


Figure 3.6 Elevation view of three story RC frame (strength/stiffness irregularity-missing column)

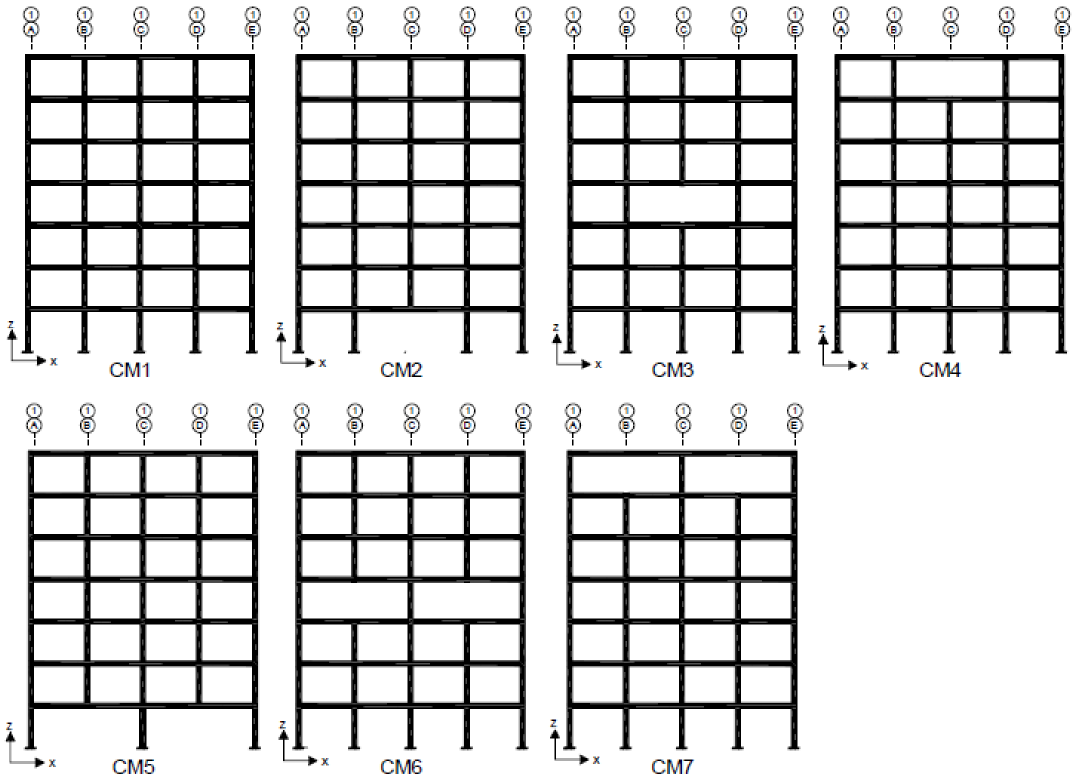


Figure 3.7 Elevation view of seven story RC frame (strength/stiffness irregularity-missing column)

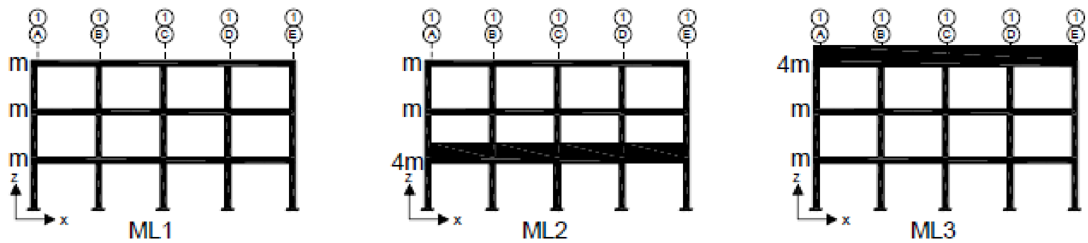


Figure 3.8 Elevation view of three story RC frame (mass irregularity)

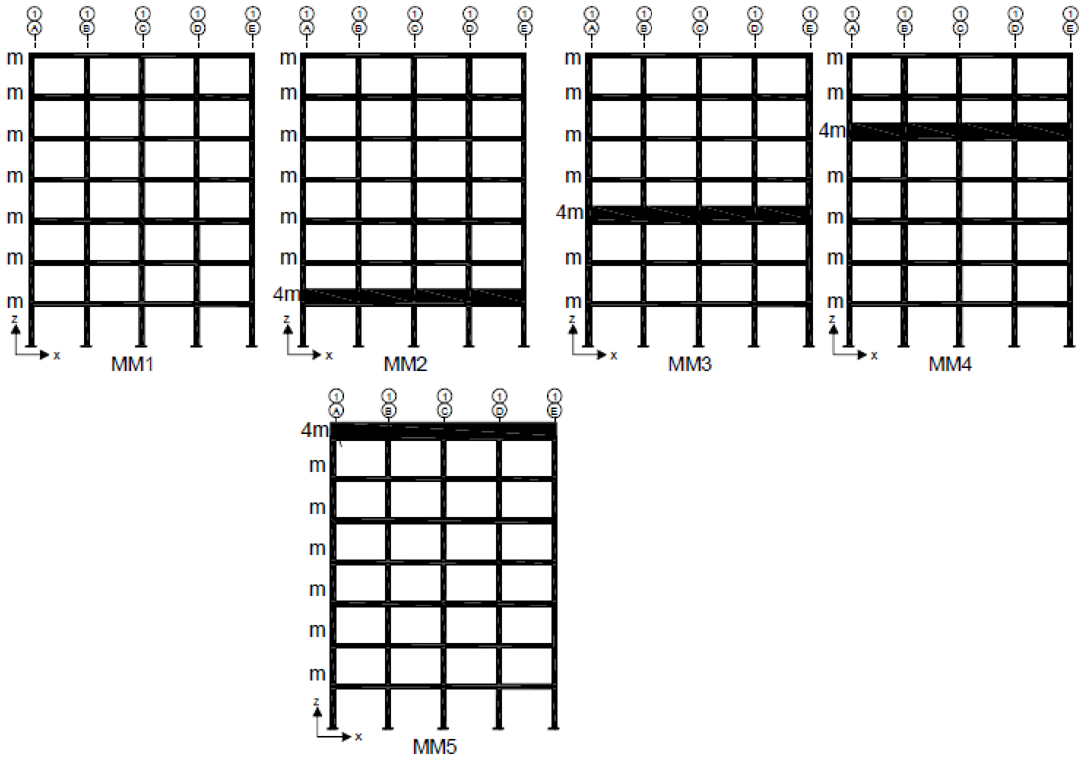


Figure 3.9 Elevation view of seven story RC frame (mass irregularity)

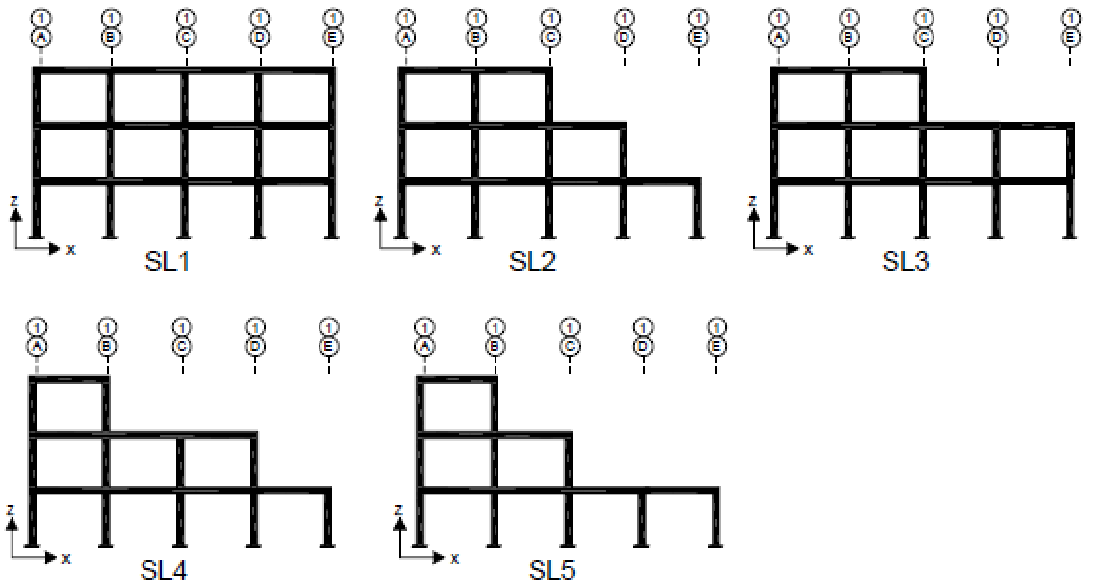


Figure 3.10 Elevation view of three story RC frame (vertical geometry irregularity-setback)

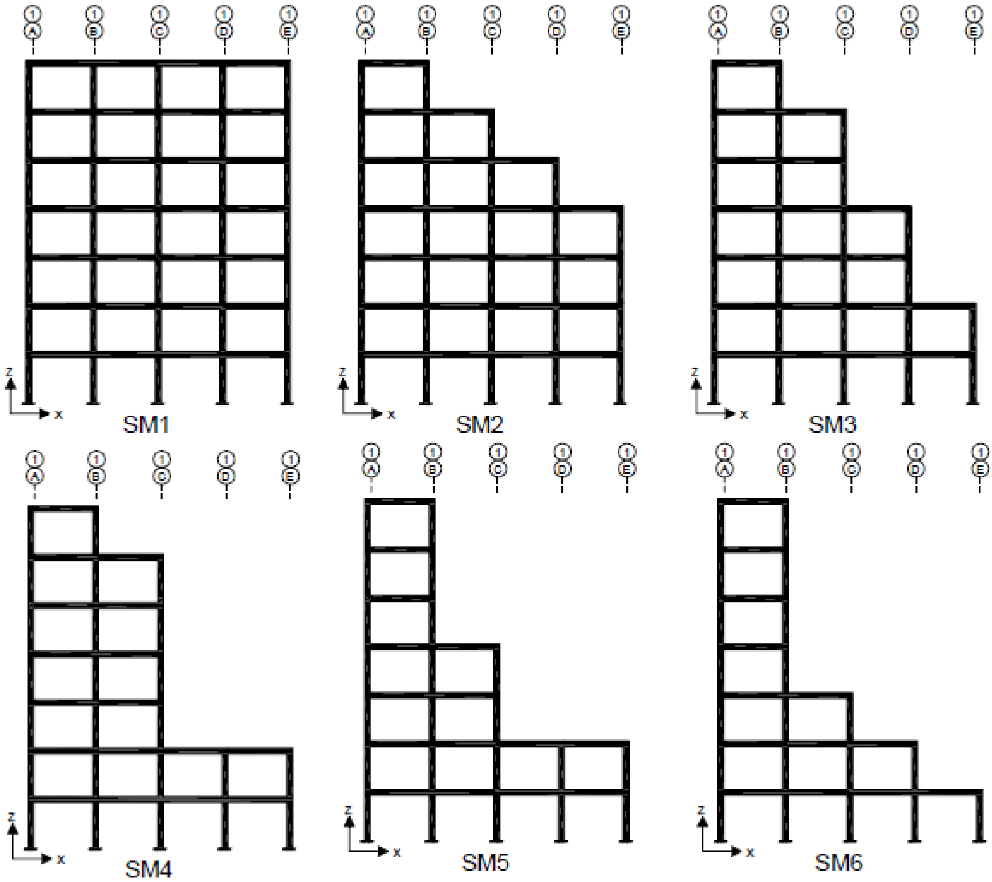


Figure 3.11 Elevation view of seven story RC frame (vertical geometry irregularity-setback)

3.2 Nonlinear analysis method

Nonlinear static analysis was done by the guide of the computer program of SAP 2000 non-linear version 14 (CSI, 2009) to decide the seismic response of the current reinforced concrete frames and those with and without vertical irregularity. Nonlinear static pushover investigation is the most broadly utilized technique to assess the nonlinear behavior of the structures. A nonlinear static (pushover) analysis is achieved by subjecting a structure to a monotonically increasing form of lateral forces, representative the inertial forces which might make experienced through the structure when subjected to earth quaking. Gravity loads are reserved constant. Under incrementally increasing lateral loads, different structural components yield successively. Thusly, at every occasion, the structure encounters a reduction of stiffness. In this study, a representation of the total base shear versus displacement in a structure was plotted by this analysis that would show any premature failure (Fardis et al., 2015).

The analysis was led up to failure, from here it empowered us to determine yielding point of the system. On the frames, on the edges, the plastic rotation was likewise watched, and lateral inelastic forces against displacement response for the total structure were analytically computed. According to FEMA 356 (2000), the hinge properties of the structural members were calculated as component type and failure mechanism. In the get for characterizing those plastic hinge properties in the model, the structures were subjected should monotonically growing lateral forces until a specified displacement might have been come to. The capacity curves identified with base shear versus roof displacement for regular and irregular frames structures with various sorts of vertical irregularity were accomplished at the end of the pushover analysis. Afterward, the targeted displacements which represented the maximum displacements possible to be qualified through the design earthquake were also computed.

In nonlinear static analysis, the post yield conducted by specifying concentrated plastic hinges to frame and ligament items was changed into simulated. Elastic response happened along the length of the member, after which deformation past the elastic range occurred totally within hinges, that have been modeled in separate places. Inelastic performance turned into realized by way of integration of the plastic curvature plastic strain and that passed off in a distinct length of the hinge, usually at the order of member depth FEMA 356 (2000). To obtain plasticity circulated with member length, a chain of hinges was created. Different hinges were likewise concurred at the similar location. Plasticity were related to force displacement conduct (shear and axial) or moment rotation (bending and torsion). The nonlinearity was occupied into account by adopting plastic hinges with hysteretic relations based on FEMA 356 (2000) at each end of the beam and column members. For the column members, axial force and biaxial moment hinges (PMM) and for the beams, flexural moment hinges (M3) were considered.

The definition of the material model is some other very critical issue in the pushover analysis which become used to simulate the ductility of the structural members. Figure

3.12 shows the simplified force-deformation relationship used to model the beam elements or columns whose actions are controlled by deformation (Bento et al., 2004).

For a structural number, the first line AB of the load deformation curve displays a linear response with a yield point at B. The inclination of the second line BC is generally low (0 to 10% of the value of the inclination of the elastic regime AB) and it represents some hardening. The third line CD represents the degradation of the resistive capacity while the line DE corresponds to the plastification of the structural element. The criteria of acceptable deformation are additionally included by suitable distortion proportions for essential elements (P) and secondary elements (S), which are also presented qualitatively in Figure 3.12 for three safety levels: Collapse Prevention (CP), Life Safety (LS) for the human life and Immediate Occupation (IO) for utility or serviceability of the structure. The values attributed to each point of the curve differ in function of the kind of structural element, and that they nevertheless rely upon different parameters as certain within the ATC-40 (1996) and in the FEMA-356 (2000). In easy framed structures, the non-linear behavior happens in sections or nodes that can be previously recognized and introduced inside the calculation model through hinges with non-linear conduct described as given in Figure 3.12 (Bento et al., 2004; Barros et al., 2013).

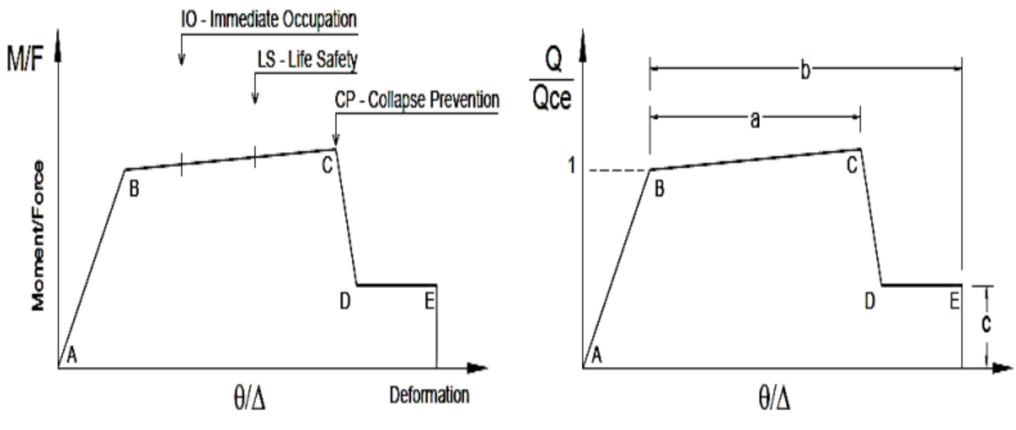


Figure 3.12 Constitutive relationships for the pushover analysis (FEMA 356, 2000)

CHAPTER 4

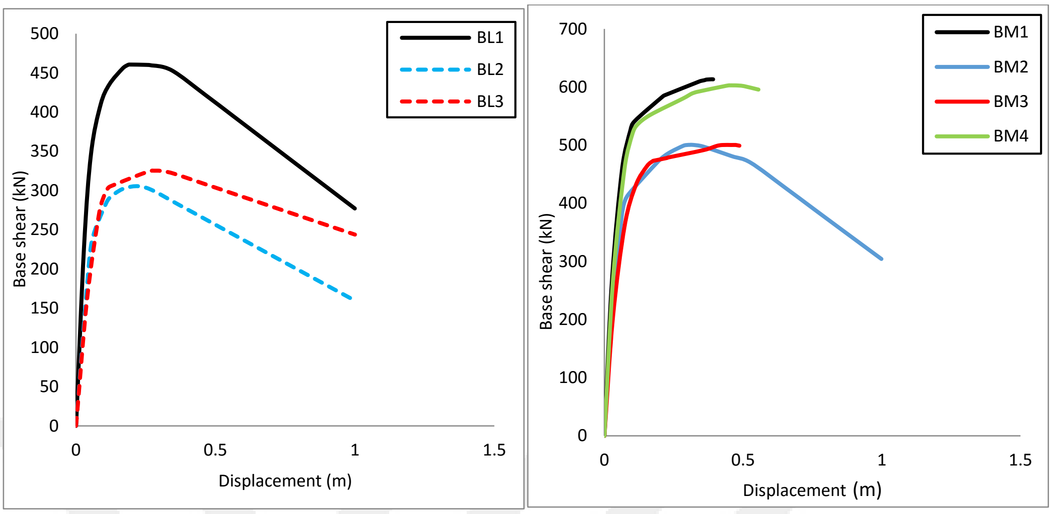
RESULTS AND DISCUSSION

In this case study, the analysis of low-rise (G+2) and mid-rise (G+ 6) frames, with and without vertical irregularities in strength/ stiffness, mass, geometry (set-back), is done using SAP 2000 program. The results are obtained from the nonlinear pushover analysis for both regular and irregular frames, and then they are examined. The comparison of the results to find out the effect of vertical irregularity are shown below.

4.1 Pushover Curves

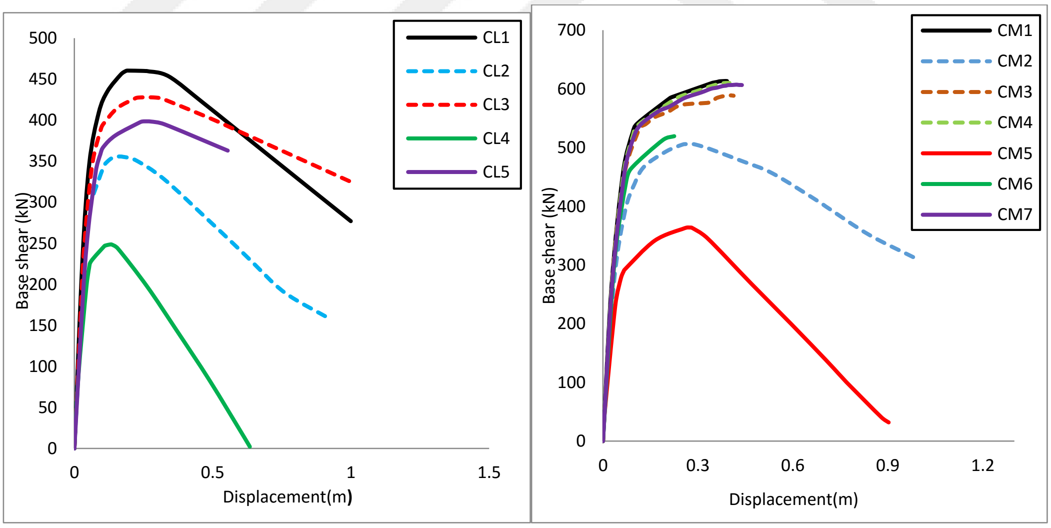
Based on the pushover curves, as given in Figure 4.1, the maximum base shear of the regular frame BL1 was about 250 kN while that of the irregular with strength/stiffness irregularities-missing beam in the cases of BL2 and BL3 was nearly about 300 kN and 325 kN, respectively. Also, the maximum base shear of the regular frame BM1 was about 620 kN at the same time the maximum base shear of the irregular frames in the cases BM2, BM3, and BM4 was about 520, 500, and 600 kN respectively. This indicated that the base shear in regular frames are greater than the irregular ones. The stiffness and strength of regular low-rise and mid-rise frames BL1 and BM1, respectively are higher than the irregular ones in term of strength/stiffness irregularities-missing beam. Even though the strength and stiffness of all cases are almost the same until the base shear reaches 200 kN and 350 kN for low-rise and mid-rise buildings, respectively, the gaps between them can be clearly observed after the base shear exceeds. Furthermore, as the missing beam is in lower storys as in the cases BL2 and BM2, not only strength but also stiffness of the frames is considerably smaller in comparison to those that the missing beam is in higher storys BL3 and BM3 cases. To conclude, the ductility of BL1 and BM1 cases reaches its peak, and decreases gradually, then its dip in the cases of BL3 and BM4.

Figure 4.2 illustrates the pushover curves of strength/stiffness irregularity-missing columns cases, it was showed that similar to the pervious strength/stiffness irregularity-missing beam cases, the base shear in regular frames is higher than the irregular ones. In addition, the strength and stiffness of the regular low-rise and mid-rise frames CL1 and CM1 are greater than irregular ones.



(a) 3-story frames (b) 7-story frames

Figure 4.1 Pushover curves of frames (strength/stiffness irregularity-missing beam)

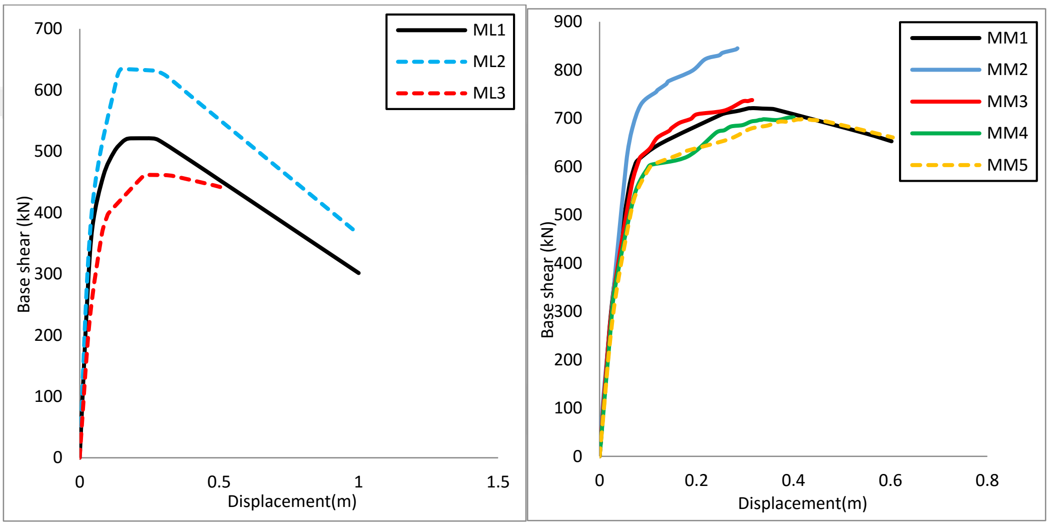


(a) 3-story frames (b) 7-story frames

Figure 4.2 Pushover curves of frames (strength/stiffness irregularity-missing column)

Figure 4.3 represents the pushover curves of the frames with mass irregularity. As seen from the figure, the stiffness and strength of three and seven story frames in the cases of ML2, and MM2 and MM3 are higher than regular and irregular ones in mass. Moreover, as the heavy mass is in higher storys as in the cases of ML3, MM4, and

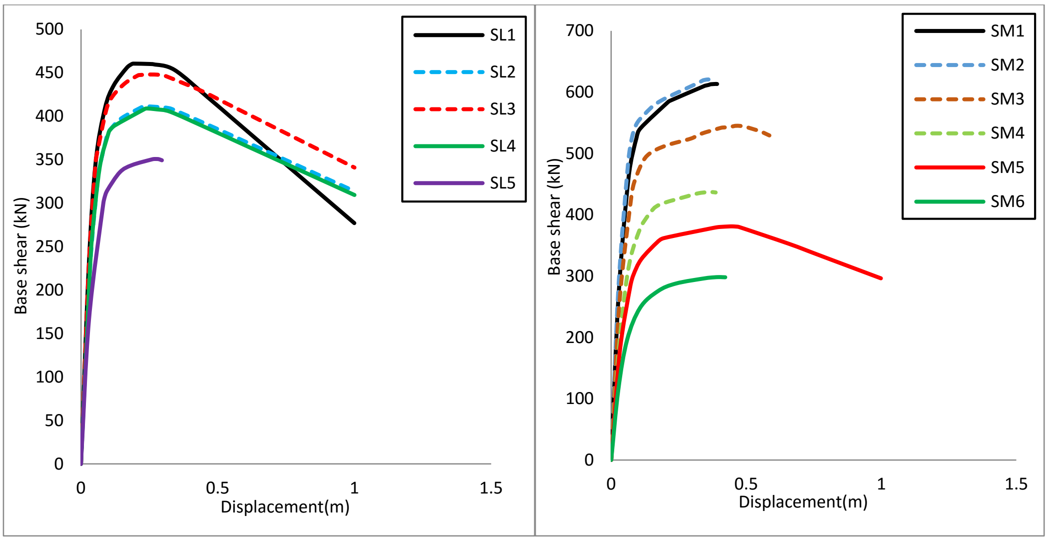
MM5, not only stiffness but also strength of the frames is greatly smaller in comparison to those that the weighty mass is in lower storys (ML2, MM2, and MM3 cases). It was found that the maximum base shear of the low-rise frames in the case ML2 was about 630 kN. Also, for mid-rise frames the maximum base shear in the case MM2 was about 850 kN. Consequently, the ductility of ML2 and MM2 cases reaches its peak, and decrease in regular ones in the cases of ML1 and MM1, then hits its dip in the cases of ML3 and MM5. In fact, the displacement of the irregular frame is between the irregular ones with heavy mass in lower storys and in higher storys. For heavy mass in lower storys, it is few and high when it is in higher storys.



(a) 3-story frames (b) 7-story frames

Figure 4.3 Pushover curve of frames (mass irregularity)

As shown in Figure 4.4, for the frames with vertical geometry irregularity-setback, the strength and stiffness are nearly the same of all cases until the base shear reaches 200 kN and 150 kN for both low-rise and mid-rise frames, respectively, the difference between them can be clearly seen after the base shear exceeds. Furthermore, if the ratio of setback increases, the strength and stiffness of the frames goes down considerably. Indeed, the displacement of the regular frame is fewer than the irregular ones. And it rises directly with the ratio of irregularity. To end, the ductility of SL1 and SM1 cases are in the peak, and decreases in other cases of SL5 and SM6.

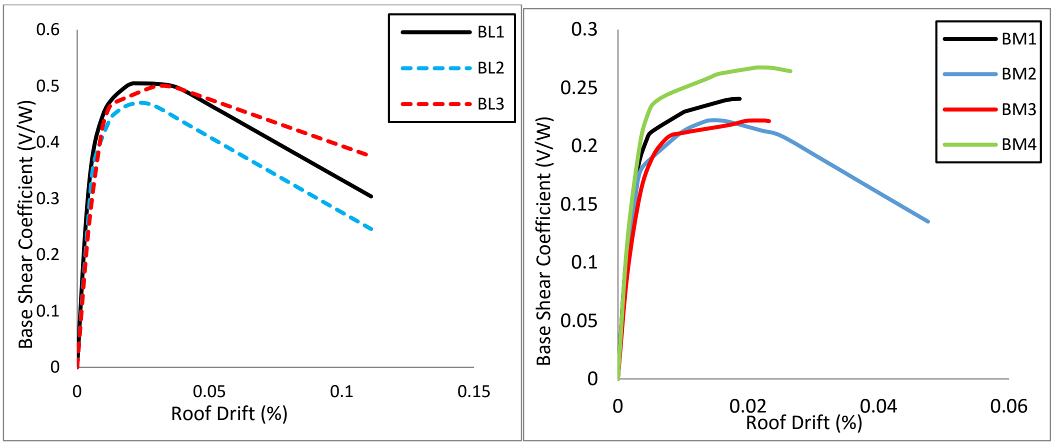


(a) 3-story frames (b) 7-story frames

Figure 4.4 Pushover curve of frames (vertical geometry irregularity-setback)

4.2 Base shear coefficient – drift relationships

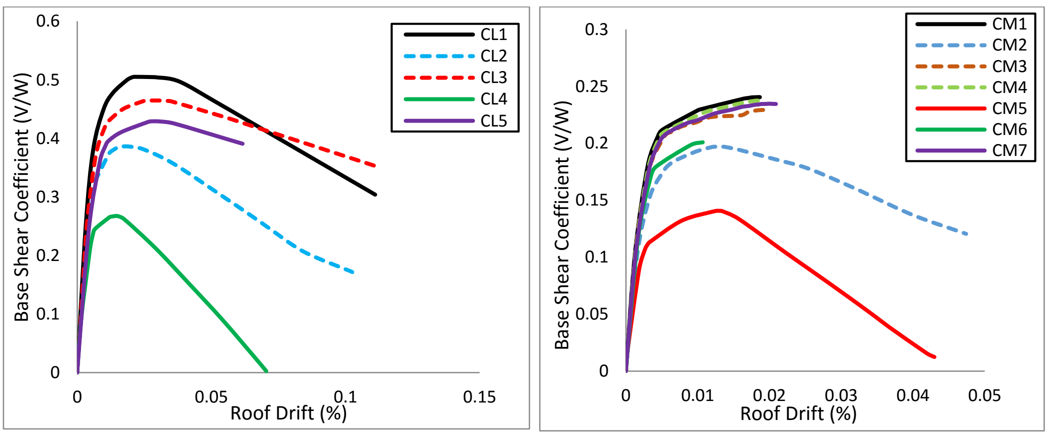
Based on the normalized pushover curves, as shown in Figure 4.5, the results of low-rise frames were observed that the maximum base shear coefficient of regular case BL1 was significantly greater than the irregular cases of BL2 and BL3. Also, the maximum base shear coefficient of the mid-rise frames is observed in the case of BM4. Even though the seismic response coefficients in terms of three and seven frames cases are almost the same until it reaches about 0.4 and 0.15 for low-rise and mid-rise buildings, respectively, the gaps between them can be clearly seen after it exceeds. It is worthy to mention that more differences are observed between the regular and irregular models in the inelastic behavior. In addition, the base shear coefficient increases when the missing beam is in higher floors as in the cases of BL3 and BM4.



(a) 3-story frames (b) 7-story frames

Figure 4.5 Normalized pushover curve of frames (strength/stiffness irregularity-missing beam)

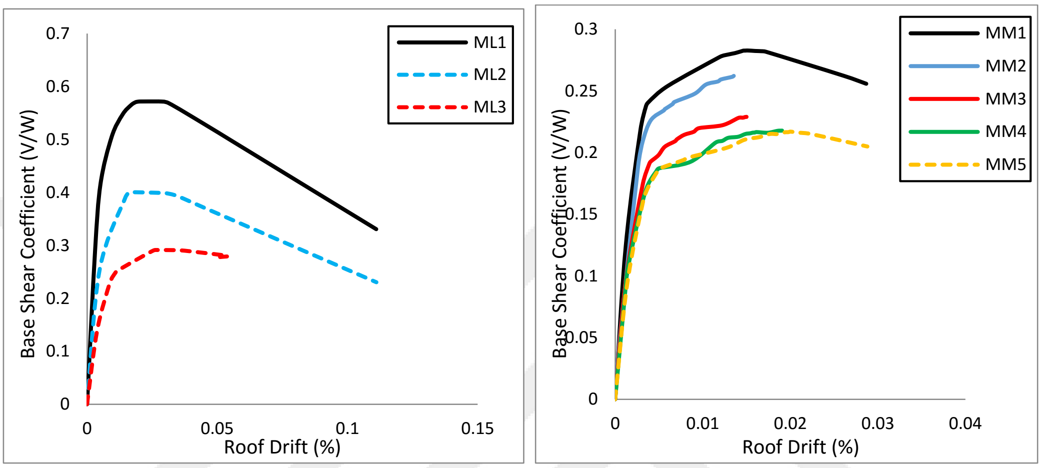
In Figure 4.6, it is pointed out that the base shear coefficient of regular low-rise and mid-rise frames (CL1 and CM1, respectively) are higher than irregular ones in term of strength/stiffness irregularity-missing column. Although the base shear coefficient of all cases rises simultaneously until it reaches about 0.2 and 0.1 for low-rise and mid-rise buildings, respectively, the differences between them can be obviously seen after it exceeds. Moreover, the seismic response coefficient is high when the missing column is in higher floors as in the cases of CL3 and CL5, however the coefficient is few compared to the regular frame.



(a) 3-story frames (b) 7-story frames

Figure 4.6 Normalized pushover curve of frames (strength/stiffness irregularity-missing column)

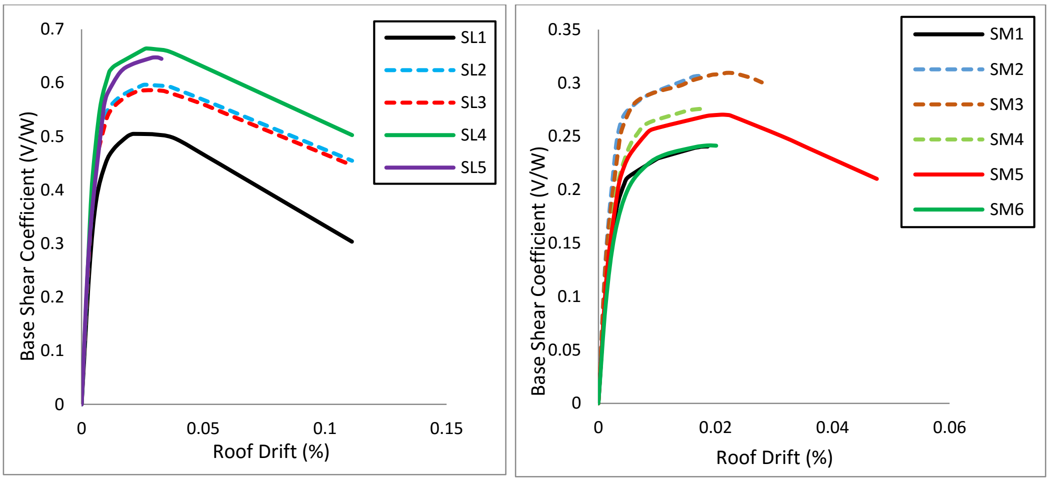
As per the normalized pushover curves given in Figure 4.7, the base shear coefficient of regular low-rise and mid-rise frames (ML1 and MM1, respectively) are larger than irregular ones in mass. Even though the coefficient of all cases increases simultaneously until it reaches about 0.1 and 0.15 for low-rise and mid-rise buildings, respectively, the disparity between them can be clearly seen after it exceeds. In addition, the base shear coefficient is low when the heavy mass is in higher floors as in the cases of ML3 and MM5, however the drift ratio is high.



(a) 3-story frames (b) 7-story frames

Figure 4.7 Normalized pushover curve of frames (mass irregularity)

From Figure 4.8, it was found that the cases SL4 and SM3 have the maximum base shear coefficient for both low-rise and mid-rise frames, respectively, in term of vertical geometry (set-back) irregularity. Despite the fact, the seismic response coefficient of all cases rises simultaneously until it comes to around 0.4 and 0.15 for low-rise and mid-rise buildings, respectively, the gaps between them can be obviously observed after it surpasses. Likewise, the seismic response coefficient changes unpredictably when the geometry of the frame changes.



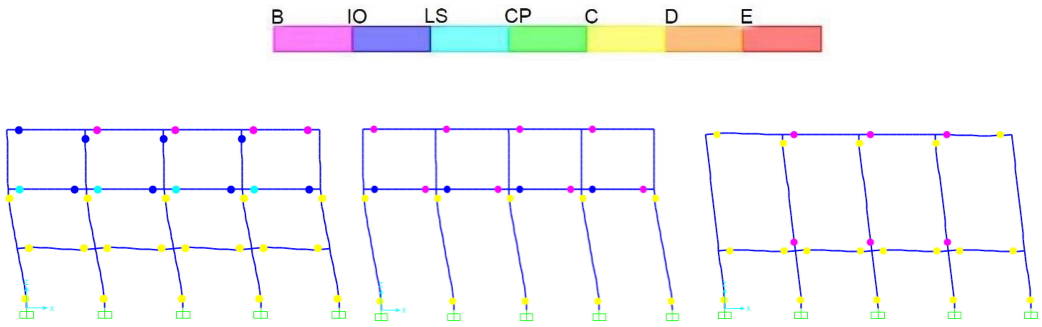
(a) 3-story frames (b) 7-story frames

Figure 4.8 Normalized pushover curve of frames (vertical geometry irregularity-setback)

4.3 Plastic hinge distribution at the final stage

At every deformation step of pushover analysis, it is possible to determine plastic rotation hinge situation in the components and which hinges reach the FEMA limit state, that are IO, LS, and CP utilizing colors for identification. Plastic hinges formation have been obtained at different displacement levels or performance points. The hinging patterns for each region are plotted in the figures. It should be noted that no plastic deformation happens till point B, where the hinge yields. Point C represents ultimate capacity of hinge and point D corresponds to residual strength of it. Point E describes the ultimate displacement capability of hinge after reaching to total collapse (Pambhar, 2012).

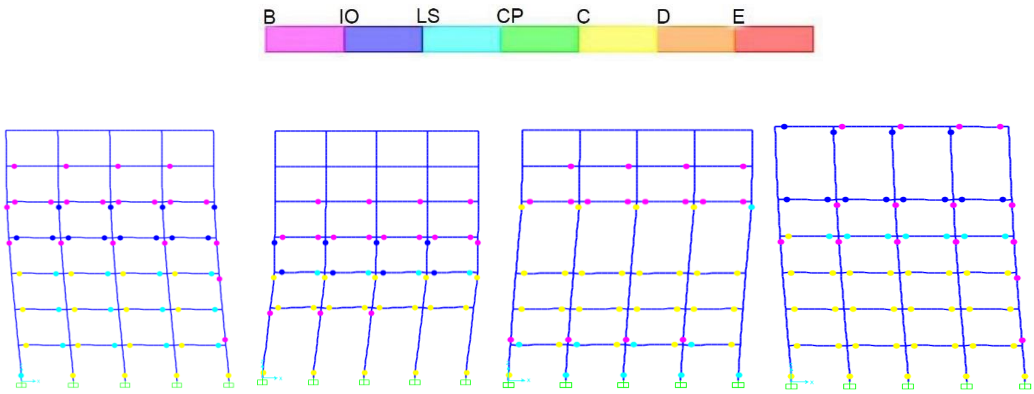
Figure 4.9 illustrates the plastic hinge distribution at the last step for the 3-story BL1, BL2 and BL3. As seen from the figure, the structure reaches collapse level in both columns and beams in the cases of BL1 and BL3, and only in columns in the case of BL2. In the case BL1, the columns of first and second floor hit collapse point while only beams of first floor reach it. However, in the case BL3, due to the elimination of second floor beams, the columns and beams at that floor reach collapse level. In other cases, the second-floor beams are in immediate occupancy level because they carry a relatively normal load.



BL1 BL2 BL3

Figure 4.9 Plastic hinge distribution at the final stage (strength/stiffness irregularity-missing beam)

According to the results shown in Figure 4.10, the first three floors reach collapse level in beams. Except in the case BM2, all other columns come to collapse level in the ground floor, carrying the total load. Eliminating the beams in fourth floor, the columns must carry their load, as a result, they reach collapse level too. On the other hand, the elimination of beams in the sixth floor does not have considerable effect on the structure. Moreover, the higher floor beams and columns are in safe state, immediate occupancy and effective yield.



BM1 BM2 BM3 BM4

Figure 4.10 Plastic hinge distribution at the final stage (strength/stiffness irregularity-missing beam)

Based on plastic hinge distributions as given in Figure 4.11, the worst case is CL4 when the ground floor beams reach the ultimate displacement capacity. This happens due to elimination of ground floor columns, beams must convey their loads to the adjacent columns. And result of collapse are observed for all columns in that floor.

The case CL2 is less dangerous than the case CL4, however the beams next to missing column go to the ultimate displacement capacity level. In other cases of CL1, CL3, and CL5, there are different levels at different places from effective yield to collapse presentation. In brief, it can be clearly seen that collapse occurs at most of the beams and columns.

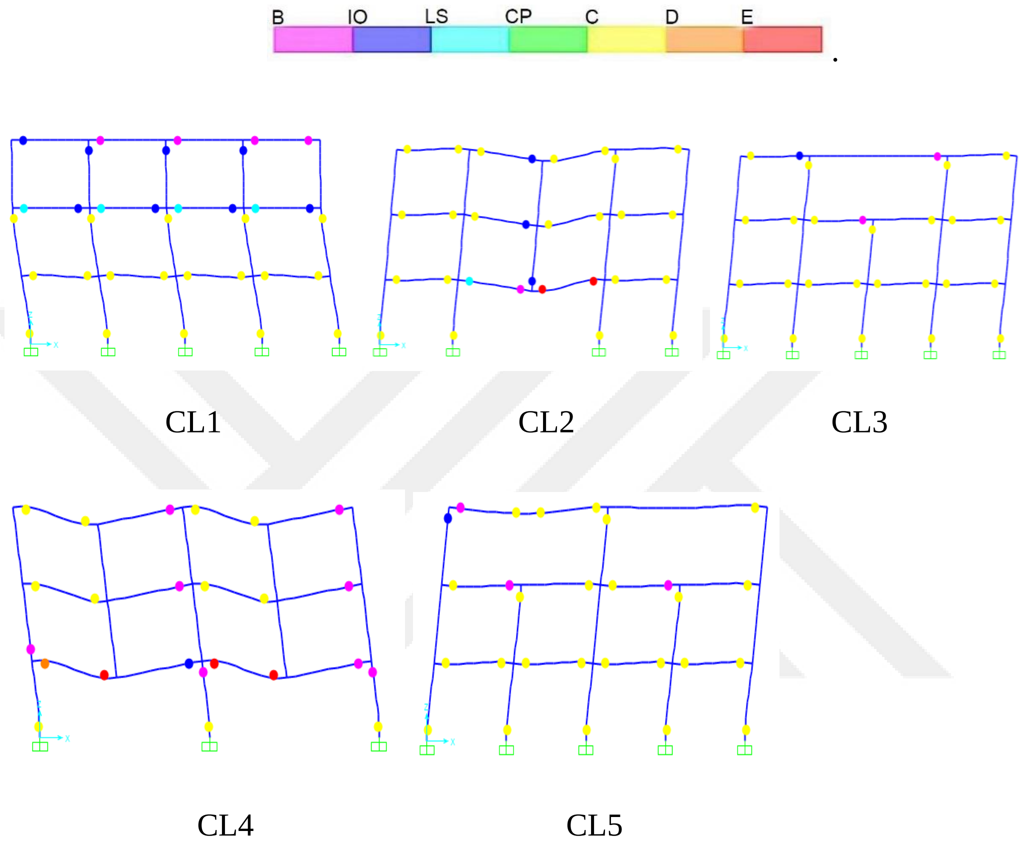


Figure 4.11 Plastic hinge distribution at the final stage (strength/stiffness irregularity-missing column)

As presented in Figure 4.12, it is clear that due to elimination of ground floor columns in case CM5, beams must carry their loads to the contiguous columns. This reason of the CM5 is a worst case, because of the ground floor beams achieve the ultimate displacement capacity. And columns at that floor hit the collapse level. The case CM2 is less dangerous than the case CM5, nevertheless the beams next to missing column reach the ultimate displacement capacity level. There are diverse levels at different places from effective yield to collapse presentation in other cases of CM1, CM3, CM6, and CM7.

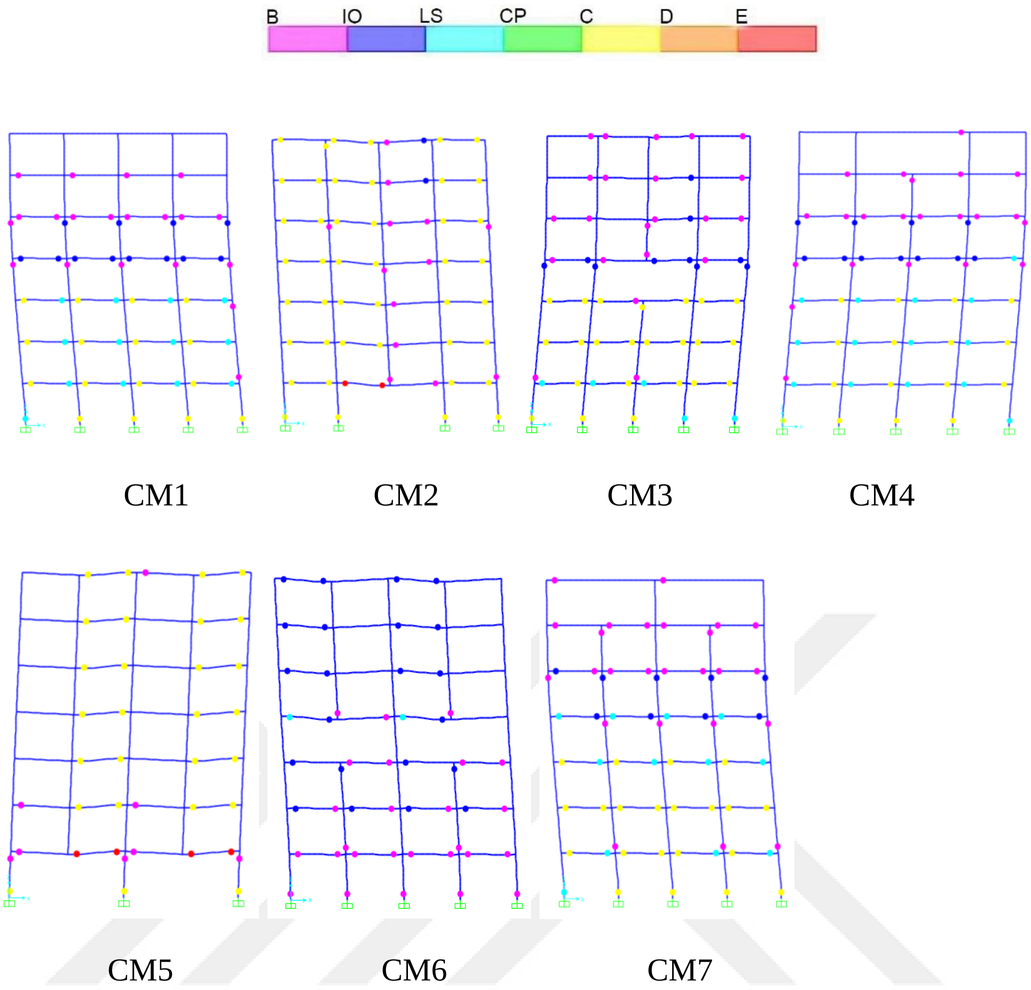
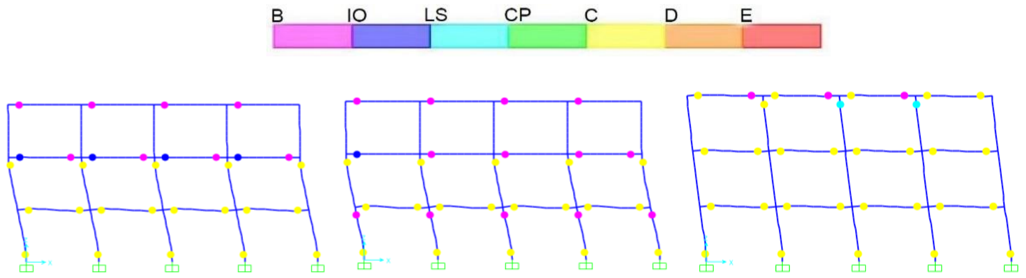


Figure 4.12 Plastic hinge distribution at the final stage (strength/stiffness irregularity-missing column)

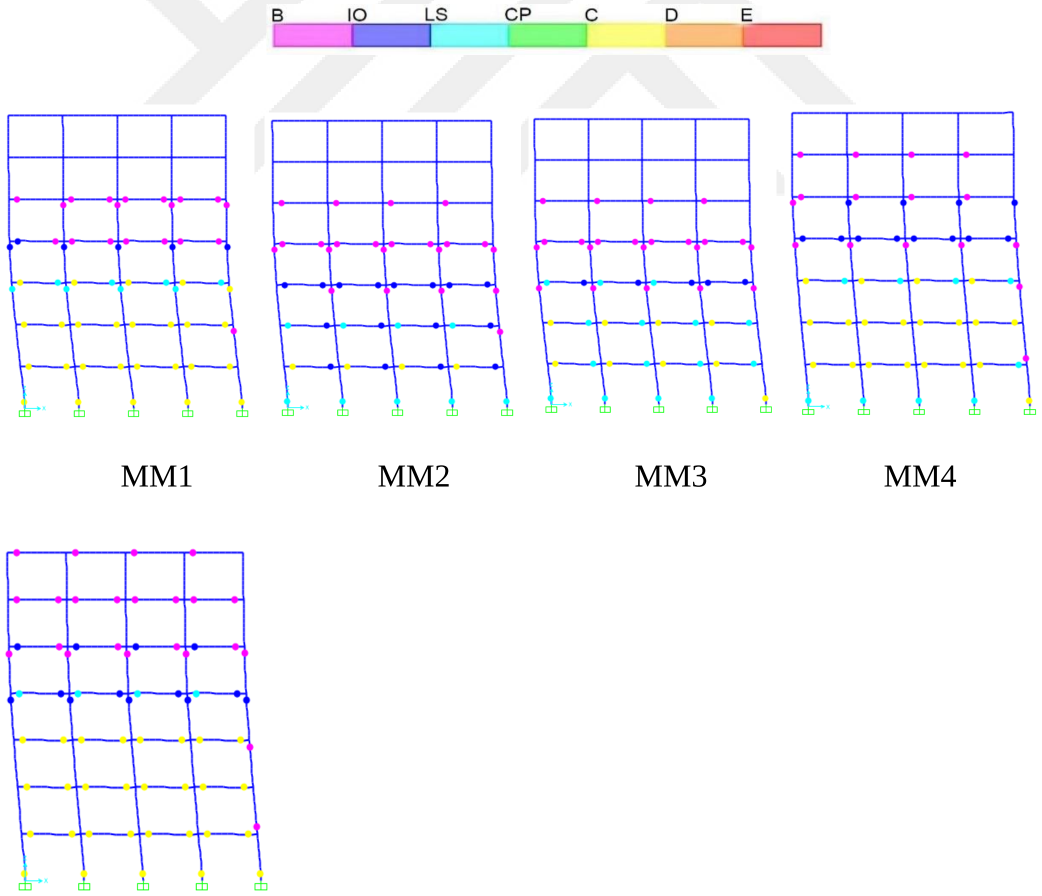
It can be clearly observed from Figure 4.13, there is no big difference between the cases of ML1 and ML2, when the heavy mass in the first floor in the case ML2, however, when the mass is at the second floor in case ML3, the whole structure collapses. It can be seen that beams and columns of all floors reach collapse level. In addition, middle columns of second floor reach life safety level under heavy mass.



ML1 ML2 ML3

Figure 4.13 Plastic hinge distribution at the final stage (mass irregularity)

Concerning the illustration given in Figure 4.14, as the heavy mass goes up, the beams and columns below the heavy mass achieve collapse and life safety. However, the beams and columns above the heavy mass hit effective yield and immediate occupancy. Concisely, the heavy load has indirect effect on the beneath structural members.



MM1 MM2 MM3 MM4

MM5

Figure 4.14 Plastic hinge distribution at the final stage (mass irregularity)

The variation of plastic hinge distribution for the regular and irregular (vertical geometry-setback) frames is shown in Figures 4.15 and 4.16 for low-rise and mid-rise buildings, respectively. From those figures, it was observed that the irregular geometry mostly effects on the beams than columns. All the beams reach collapse level in cases SL4 and SM3 for low-rise and mid-rise frames, respectively, and in the other cases SL2, SL3 and SL5 for low-rise frames and SM2, SM4, SM5, and SM6 for mid-rise frames, most of the horizontal members hit collapse level. However, only some vertical members reach collapse and most of them are at effective yield and immediate occupancy level. The regular low-rise frame (SL1) reaches collapse level at first floor beams and columns, and life safety at second floor beams. Also, the regular mid-rise frame (SM1) reaches collapse level at first floor beams and columns.

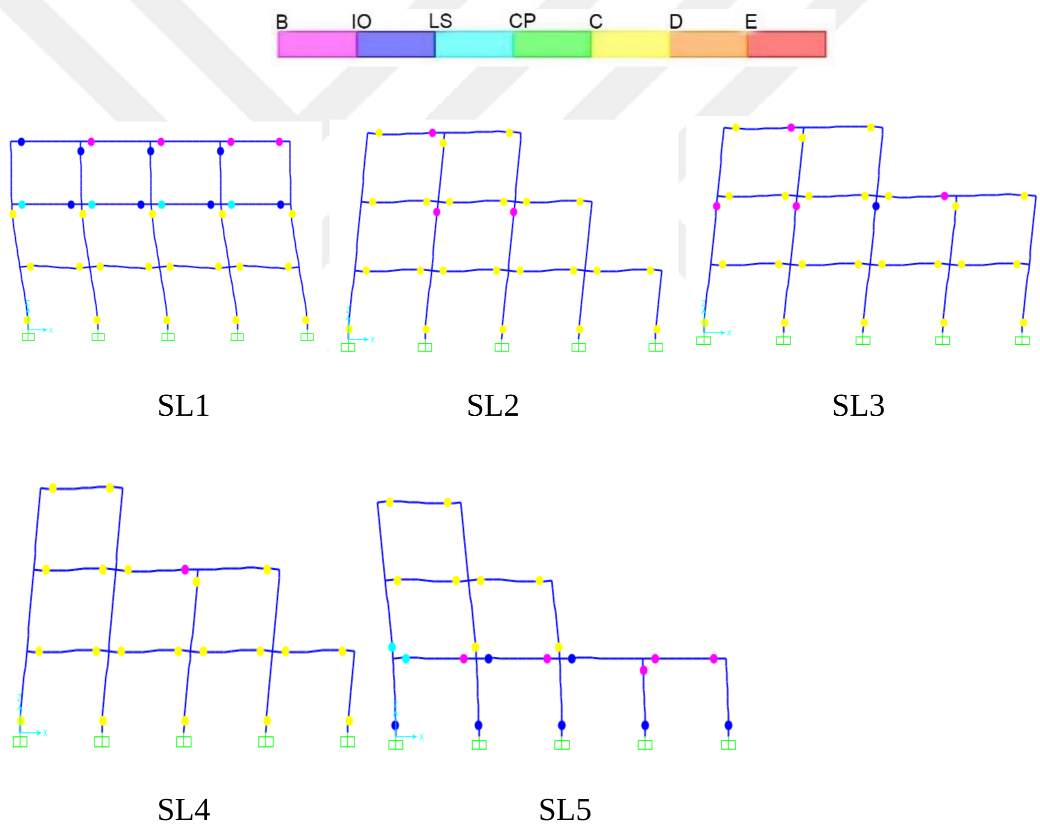


Figure 4.15 Plastic hinge distribution at the final stage (vertical geometry irregularity-setback)

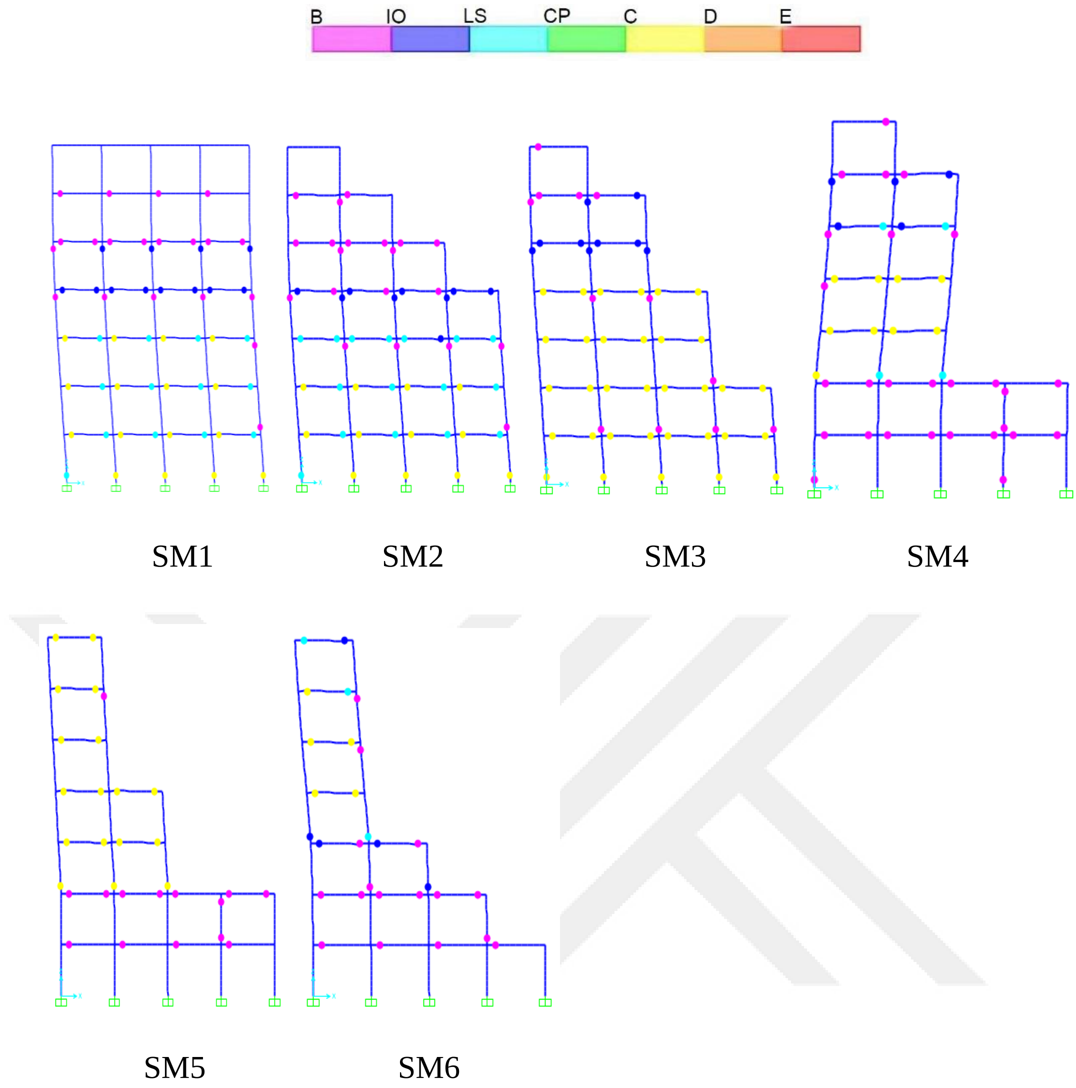
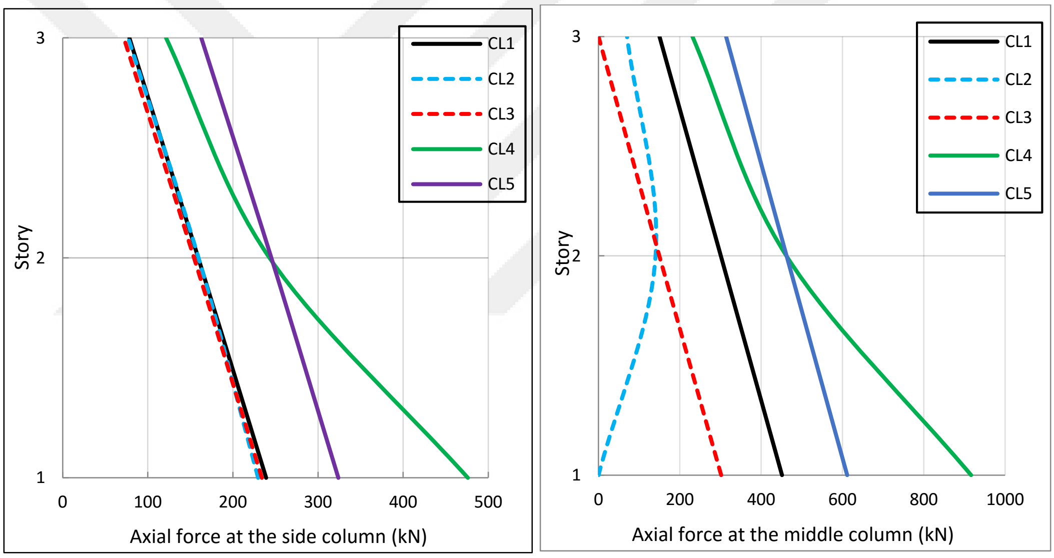


Figure 4.16 Plastic hinge distribution at the final stage (vertical geometry irregularity-setback)

4.4 Axial force of frame having discontinuous column

In this part, effect of missing column on the axial force variation of the side and middle columns of 3 and 7 story RC frames are discussed comparatively. As per the outcome curve given in Figure 4.17 (a), the axial force of the side column does not change due to middle missing column in cases CL2 and CL3 because the axial force exerts on the side columns, it does not on middles. Thus, the axial force for the cases of CL1, CL2, and CL3 decreases form 230 kN to 80 kN from the third to first floor linearly. In the case CL4, the axial force reached its peak in the side column at first floor because it must carry the axial force of the missing column. In addition, the axial force is higher when the missing column is in the third floor as in the case of CL5, however it increases linearly form the third toward the first floor.

It can be clearly observed from Figure 4.17 (b), in cases CL2 and CL3 the middle column axial forces are fewer than the regular frame axial force because of the missing column. On the other hand, the axial force is the highest in the other cases of CL4 and CL5 because the middle column must carry the axial force of the missing columns. The axial force is gradually increasing from third to first floor column in the case of CL4 when the missing column is in the first floor, nevertheless, the axial force increases rapidly in the case of CL5 because the missing column is in the third floor. We can clearly see that the axial force as in the case of CL2 is zero in the first floor because there is no column to carry the force.



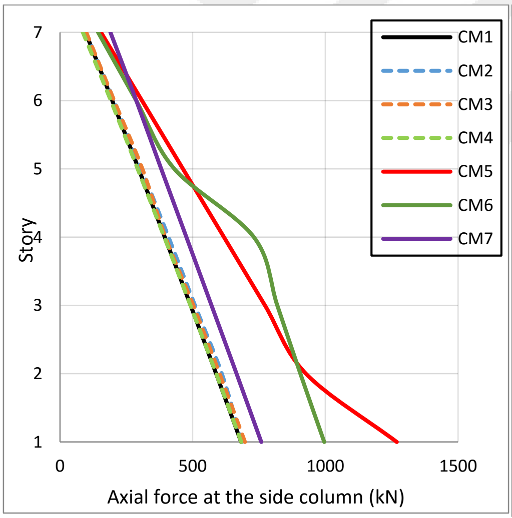
(a) 3-story side column

(b) 3-story middle column

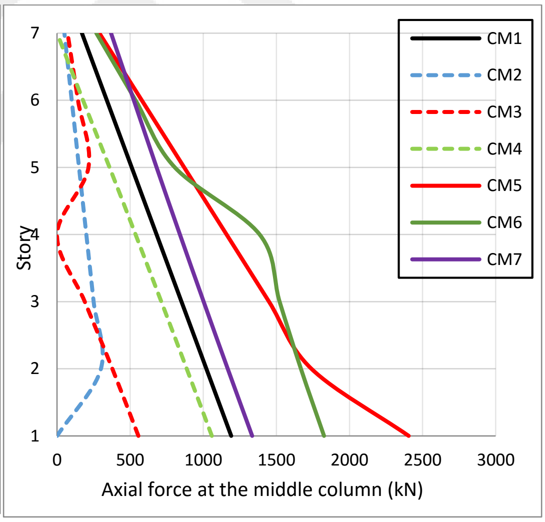
Figure 4.17 Variation of the axial force in the side and middle columns along the height of the 3story frame have discontinuous column (strength/stiffness irregularity-missing column)

From Figure 4.18 (a), due to the axial force exerts on the side columns, it does not on middles, therefore the side column axial force does not change due to middle missing column in cases CM2, CM3, and CM4. Thus, the axial force for the cases CM1, CM2, CM3, and CM4 decreases from 700 kN to 10 kN from the seventh to first floor linearly. When the missing column is not middle one at first floor, the axial force reached its peak in the side column at first floor in the case of CM5 since it must carry the axial force of the missing column. In addition, the axial force is higher when the missing column is in the fourth floor (middle column), but it increases linearly from the third toward the first floor. When the missing column is in the middle, both vertically and horizontally, the axial force fluctuates from the seventh to first floor positively.

According to the result curve shown in Figure 4.18 (b), we can obviously observe that the axial force of the case CM3 in the third floor and the case CM2 in the first floor is zero because there is no column to carry the force. The axial force is directly increasing from seventh to first floor column for the situation CM7 when the missing column is in middle in the seventh floor, though, the axial force increases quickly in the case CM5 because the missing column is in the first floor. Also, the axial force of the middle column, in case of missing column is in the middle in cases CM2, CM3, and CM4, is less than the regular frame due to the missing column. On the other hand, the axial force is the highest in the other cases CM5, CM6, and CM7 because the middle column must convey the axial force of the missing columns.



(a) 7-story side column



(b) 7-story middle column

Figure 4.18 Variation of the axial force in the side and middle columns along the height of the 7story frame have discontinuous column (strength/stiffness irregularity-missing column

CHAPTER 5

CONCLUSIONS

In this study, the effects of vertical irregularities on the seismic response of reinforced concrete (RC) building structures are investigated. The objectives are to advance the understanding of the behavior of buildings with vertical irregularities and to quantify the effects of irregularities in mass, stiffness/strength with missing beam and column and vertical geometric irregularity (set back) on seismic demands. The following conclusions are drawn from this study:

- Generally, all kinds of vertical irregularity have negative effect on RC structures in different ways.
- There is a reverse relationship between vertical irregularity and the base shear of RC structures. As the ratio of irregularity increases, the base shear of the RC structure falls. As a result, the lateral load carrying capacity of the structure declines directly. Indeed, this should be taken into account by structural engineers in designing vertically irregular structures.
- The response of RC structures to lateral displacement is directly proportional to vertical regularity. As the ratio of regularity climbs, the response to lateral load goes up too. The displacement of regular frame is fewer than the irregular ones for all cases in pushover result curves expect in mass irregularity the displacement of irregular frame is between the irregular ones with heavy mass in lower storys and in higher storys for heavy mass in lower storys it is few and high when it is in higher stores.
- The drift ratio demand of RC structures is directly proportional to vertical irregularity. As the ratio of irregularity climbs, the drift ratio of the RC structure rises as well. Also, it is concluded that the drift ratio demand of regular low-rise and mid-rise frames are fewer than the irregular ones for all cases of vertical irregularity, and there is a direct relationship between drift ratio and seismic response coefficient.

- The seismic response of RC structures highly depends on vertical regularity and ductile behavior. The ductility of regular frame reaches its peak in pushover curves for all cases of strength/stiffness irregularity with missing beam and missing column and vertical geometric irregularity (set-back).
- The strength/ stiffness irregularity (missing column) has more severe effects on the RC structure than other kinds of irregularity (strength/ stiffness (missing beam), mass, and geometry (setback)).
- The results from the plastic hinge distributions of the regular and especially irregular cases revealed that soft story at lower floors is more susceptible to seismic force because it carries higher seismic weight.
- In pushover results, it is observed that the stiffness and strength of regular low-rise and mid-rise frames are significantly higher than that of the irregular ones.
- The axial force of side column does not change in strength/stiffness irregularity-missing column due to middle missing column. Also, the axial force reached its peak in the side column at first floor for 3 story and 7 story cases since it must carry the axial force at missing column.

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