A Critical Evaluation of the Effect of Soft Storey and Column Orientation on RC Buildings

Mahapara Firdous
PG Student
Department of Civil Engineering
Amity University, Haryana

Sakshi Gupta
Assistant Professor
Department of Civil Engineering
Amity University, Haryana

Abstract

Earthquakes are the most challenging forces that affect the buildings and other structures. The behaviour of a building during an earthquake depends on various factors such as shape, size and geometry of the building. The growth of population and the scarcity in the availability of land has constrained the architects and engineers to provide areas of parking inside the building leading to the formation of a weak/soft storey inside the building. Also the desire to build aesthetically appealing structures has inspired the engineers to build structures different from the conventional ones. The engineers are nowadays building structures different in plan and configuration. Due to recent demand of building structures aesthetically different, the plan, configuration and other geometrical features such as shape and orientation of the columns are changed. These geometrical features such as shape of columns and their orientation influences the lateral stiffness of the building .The inclusion of a weak storey and change of orientation of columns creates vertical stiffness irregularity and lateral stiffness irregularity in the building which is a form of plan irregularity. Thus,making the building vulnerable to the earthquake forces. This review of past studies aims to find out how does orientation of columns and soft storey affect the seismic parameters such as deflection and time period. The study concludes that the soft storeys are to be provided in upper stories and combined effect of soft storey and column orientation is to be studied by means of software aid to prevent failure of building during earthquakes.
Keywords: Lateral stiffness irregularity, SAP2000, Seismic analysis, Soft Storey, Stiffness irregularity

I. Introduction

The buildings having ground storey open have collapsed during the past earthquakes. In this study the past studies done on the effect of soft storey on RC buildings and effect of shapes and orientation of columns on seismic parameters will be studied.

II. Past studies

B.M. Sontakke et al. (2015) studied that the buildings with soft storey exhibit poor performance during earthquakes. He studied the soft storey behaviour due to increase in storey height, absence of infills at ground floor storey and presence of both these cases by means of non linear static and dynamic response history analysis for mid rise reinforced concrete building displacement capacity when occupied immediately, provision for safety of life and collapse, performance level and storey drift demands. His study lead to the conclusion that the damages produced in the ground floor columns and ground storeys are very large for soft storey buildings because of the irregularity in mass and stiffness and collapse can be prevented by providing large strength to the columns of the soft storey. V.V.Halde, A.H.Deshmukh (2016) generated models in software SAP2000 with soft stories at different floors and carried out equivalent static analysis in the software. The models studied were reinforced concrete moment resisting frame buildings. The columns of the buildings were kept square in shape so that the effect of column orientation would not be introduced. In this study, the seismic vulnerability of buildings with soft first storey is shown through an example building. For buildings with open ground storeys/soft ground storeys, the drift was seen to be large and high strength columns were demanded in these type of buildings .Hence necessary measures should taken to improve capacities of the columns in the soft first storey. The following conclusion can be drawn by this study:-1) If shear walls are provided in these soft ground storey structures, the deflection, storey drift, shear forces and bending moments are reduced. Since soft storey creates vertical irregularity in the building, many studies were conducted to study the effect of irregularities on the building.

Ms V.M. Joshi et al (2016) by studying the ill effects of irregularity which includes Time period, axial load, bending moment, shear force, and torsion is reduced to remarkable extent by providing crumple section, which converts an irregular E-shape building into regular one. An irregular shaped structure does not promote easy load transfer for inertia forces generated due to earthquake. Due to which stresses and torsion effects are generated at re-entrant corners. It is possible to plan and design less vulnerable multistoried building having irregularity in plan as well in vertical plane even in earthquake prone areas. A building is analyzed having regular and irregular shape under the effect of earthquake loading by using latest software Aid. Analysis make possible to plan an irregular structure even in earthquake prone areas. M. Kumar et al (2015) studied that the vertical irregularities are one of the major reasons of failures of structures during earthquakes. To study the behaviour of the building having various vertical irregularities at different floor levels seven models have been considered in this project. All the models were analyzed by using SAP 2000. The methods used for the analysis are static method and response spectrum method. On the basis of the study, it is concluded that the stiffness irregularity should be provided in top floor levels.

M.P. Mishra, Dr S.K. Dubey (2015) reviewed some research works and concluded that buildings with soft first storeys can be prevented from damage and collapse by resorting to two design approaches as mentioned in clause 7.10 of IS: 1893-2002 (Part 1) (i) The dynamic analysis of the building is to be carried out and the strength and stiffness effects of infills as well as the inelastic deformations under the design earthquake force should be included without considering the Reduction Factor R. (ii) The building is analysed as a bare frame and the effect of infills is not considered , the dynamic forces so determined in columns and beams of the soft (stilt) storey are to be designed for 2.5 times the storey shears and moments or the columns are designed and detailed for the storey shear and moments calculated and in addition to this, shear walls should be constructed parallel and as far away from the centre as suitable and should be designed for storey shear 1.5 times as calculated before. Ashvin G.Soni et al (2015) studied a 10-storey building frame with two different irregularities as taken from IS 1893(part I): 2002. Thus, five frames including the base frame have been taken into consideration. The analysis of these frames is done by equivalent static method (as per IS 1893-202). The buildings are assumed to be in seismic zone IV, and importance factor is taken as 1.5. CSI-ETABS software has been used to carry out the analysis. The irregularities in the frames are studied by taking the values of lateral storey-displacements, storey drifts and base shears analysed through the software. The behaviour of various irregularities but with same dimension when subjected to lateral loads has been analyzed in this study. The frames were analyzed as per the method stated in IS 1893 (part-I):2002.Maximum drift was shown by the building with heavy loading on 4^{th} and 7^{th} storeys, thus making it vulnerable The least drift was seen in the base frame(regular). The buildings with irregularities also showed unsatisfactory results to some extent. This proves that irregularities are undesirable for the structures. Hence simple and regular shapes of the frames should be preferred and the distribution of the loads should be uniform around the building to prevent collapse.

D. Dohare, Dr S. Maru (2014) studied the behaviour of a building with different arrangement of storeys subjected to static and dynamic earthquake loading. It was observed that the infill improves the resistance of the structure against seismic forces. This study concluded that the RC buildings with soft storey do not perform well during earthquake shaking .The analysis is done using various softwares such as STAAD Pro ,ETABS,SAP 2000.The calculations show that when RC framed buildings have brick masonary infill on upper floor and soft ground floors subjected to earthquake loading, the base shear increases twice to that predicted by equivalent earthquake force method with or without infill or even by response spectrum method when no infill in the analysis model. Rakshith Gowda K.R.B. Shankar (2014) modeled and analysed a RC building using software ETABS where they provided different load combinations at different levels where soft storeys were provided. They observed that the storey drift was maximum in vertically irregular structure. P.B. Lamb and Dr R.S. Londhe (2012) defined soft storey as a storey having inadequate shear resistance or inadequate ductility to resist the earthquake induced stresses. The soft storey is highly undesirable in buildings built in seismically active areas. The discontinuity in the stiffness and strength gives rise to a soft storey. Soft storey construction has advantages over the conventional construction both technically and functionally. Because of the following reasons: 1) There is reduction in the spectral acceleration and base shear as the natural time period of the vibration of structure increases as in base isolated structure. 2) A large space becomes available for parking of vehicles or banking halls due to soft storey construction. The Indian seismic code IS 1893:2002 (Clause no.4.20 on Page no.10) defines the soft storey as the "one in which the lateral stiffness is less than 70% of that in the storey immediately above, or less than 80% of combined stiffness of three stories above." M.Inel and H.B.Ozmen (2008) investigated the soft story behavior due to increased story height, absence of infill amount at ground story and presence of both cases using nonlinear static and dynamic response history analyses for mid-rise reinforced concrete buildings. It is observed that, soft story due to infill walls may be as damaging as soft story due to increased story height. After evaluating displacement capacity and drift demands it is observed that soft story due to increased height (SSH) and due to lack of infill walls (SSW) have close values to each other. As a result, it should be kept in mind that soft story may arise not only because of increased story height, but because of abrupt changes in amount of infill walls which are not thought to be a part of structural system. Also, soft story due to both increased height and lack of infill wall at ground story is the most detrimental case in view of drift capacities and demands. R. Davis et al (2004) compared the seismic performance of two buildings located in moderate seismic zones of India and did pushover analysis (as per IS1893-2002).It was observed that the seismic demand of the building with soft storey having infill was large as compared to the other symmetric building with no soft storey. One of the buildings had both plan irregularity and vertical irregularity (soft storey) , while the other one was fairly symmetric.

S.Ladvikar and A.Mundhada (2016) studied the Seismic performance of buildings with specially shaped columns is better as compared to the building with rectangular columns as the displacement in R.C. frame building with specially shaped columns is less than the R.C. frame building with rectangular columns. Also the drift in R.C. frame building with specially shaped columns is less than the R.C. frame building with rectangular columns. This study concluded that the R.C. frame building with specially shaped columns is economical than the R.C. frame building with rectangular columns. S.Aggarwal & Dr P .S. Pajgade (2016) considered two buildings for the study viz G+14 commercial RC buildings with specially shaped columns and G+14 commercial RC buildings with specially shaped columns and shear wall. The buildings are assumed to be fixed at the base. The floors of all buildings act as rigid diaphragms, and are analyzed and designed by using ETABS v9.7.4 software for Amravati city (i.e. Zone III).This study concluded that displacement in R.C. frame building with Specially shaped columns and shear wall is less than the R.C. frame building with Specially shaped columns only. It further concluded that drift in R.C. frame building with specially shaped columns and shear wall is less than the R.C. frame building with specially shaped columns only. Also R.C. frame building with specially shaped columns and shear wall is economical than the R.C. frame building with specially shaped columns only.

M.V. MOHOD (2015)showed the larger response of complex shaped structures by preparing nine models using software STAAD Pro V8i.The complex shaped buildings showed large nodal displacement and storey drift under given loading conditions. B.S. Prasanth and J. Simon (2014) showed that the circular columns are not suitable to be used as they are having higher base shear and less fundamental time period .They recommended the use of simple shape and geometry in the construction of a building as complex structures generate larger responses during earthquakes. They studied the seismic behaviour of G+20 RC building using different slab systems. The Models were generated with three types of columns and two orientations for rectangular column as longer side of the rectangle along x and longer side of the rectangle along y and shapes as rectangle and square. They further observed that the base shear of the model increases with the increase in gravity loading.C.V.R. Murthy studied the effect of column orientation of rectangular columns. He observed that the orientation affects the lateral stiffness of the buildings along two horizontal directions. The change in the orientation of columns would mean change in the translational natural time period of the building .Two Buildings C and D (5-storey buildings) were observed with same column area, but with different orientation of rectangular columns. Longer side of 550mm×300mm columns is oriented along X-direction in building C, and along Y-direction in building D. Along the longer direction, the Lateral stiffness of the column is more. The time period is inversely related to the longer direction of the column cross section. Hence, natural period of buildings along the longer direction of column cross-section is smaller than that along the shorter direction. Building B Building C Building D Column 0.77 s T X1 = 0.93 s T Y1 = 0.89 s T Y1 = 1.1 s T Y1 = 0.74 s (Building B has square columns).

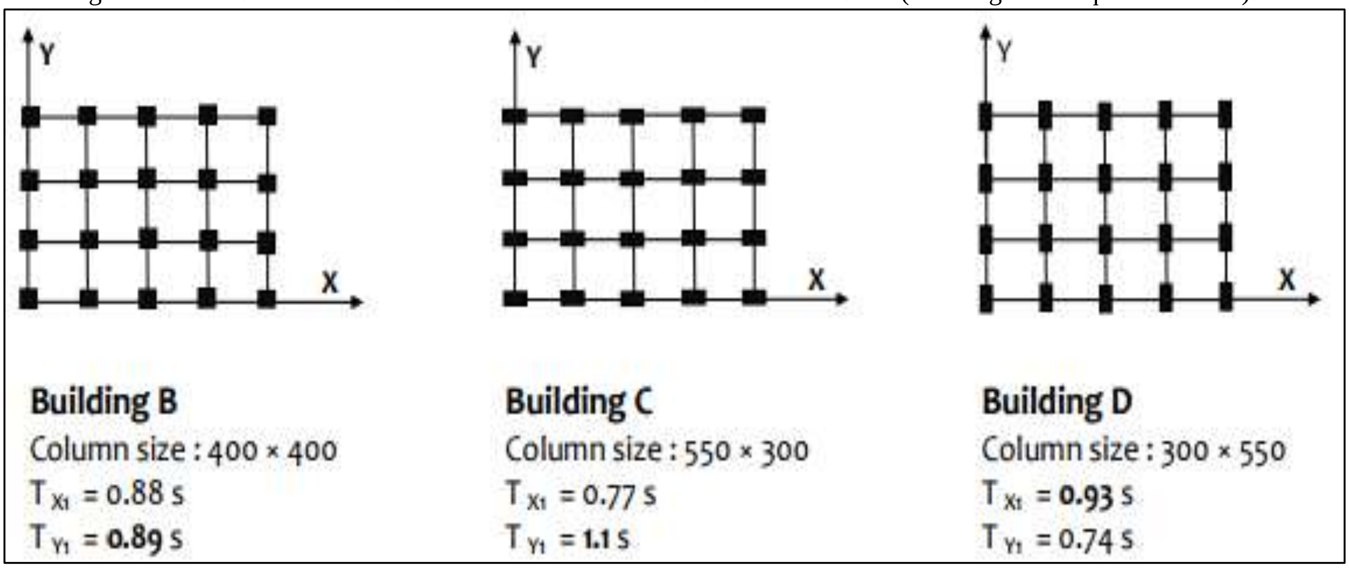

Fig. 1: Effect of column orientation: Buildings with larger dimension of the column cross section has less time period.

S. Verma and A. Batra (2014) studied about the effect of orientation of the columns along with vertical irregularities such as soft storey, mass irregularity and geometric irregularity on the seismic behaviour of buildings. It was observed that the buildings having mass irregularity and soft storey have large displacement values .The use of square columns in place of rectangular columns can minimise the displacement along both the axes. In buildings with geometric irregularity, exterior column orientation can be changed while keeping the orientation of the interior columns same as before to increase the stiffness in the shorter direction, hence reducing the displacement and drift in X and Y directions. It was seen that the response of the square columns was better as compared to the rectangular columns. Pu Xang et al (2008) studied the difference in the seismic behaviour of rectangular columns and specially designed columns (L, T, +). According to the current Chinese code and technical specification, some frame structures with rectangular columns and specially shaped columns are designed based on the criterion of the same section area, moment of inertia, initial stiffness of the specially shaped frame structure. Stiffness of the frame with rectangular columns with the same area is inferior to the frame with specially shaped columns. The frame structure with specially shaped columns designed by the code in this study could resist the earthquake effectively as the frame structures with conventional rectangular columns do.

J.N. Arlekar et al (1997) studied the behaviour of soft first stories of RC building.The provision of a soft storey as first storey is a common trend in India which makes the building prone to earthquakes. This feature is highly undesirable as it creates seismically active areas in the building as depicted by past earthquakes such as San Fernando 1971, Northridge 1994, Kobbe 1995, Bhuj India 2001.In buildings with soft storey as ground storey also known as open ground storey, the ground storey has no infill walls hence more stronger columns are provided in the ground storey than upper stories. Since upper stories have infill walls so they are subjected to less inter storey drift as compared to the open ground storey. When the lateral forces (earthquake forces) act on the building, the abrupt change in the vertical stiffness causes stress concentration in the open ground storey leading to the collapse of the building. Wen Hu Tsao (1992) proposed the finite difference method for standard as well as L shaped columns to study the effect of the behaviour of plastic hinge and ductility in columns .He carried out both theoretical and experimental study for complete load deformation of biaxially loaded slender reinforced concrete columns with square and L shaped cross section. The behaviour was studied by testing six square slender columns and eight L shaped slender columns and their load deformation determined experimentally was compared with the analytical results obtained from the theoretical studies.

III. SHORTCOMINGS OF PAST STUDIES

Since the growth of population has increased, the space for the construction of parking lots is not available hence the soft storeys are constructed. These soft storey although make the building vulnerable to earthquake forces so we have take the measures to make these soft stories less prone to earthquake. Also the above studies have not taken column orientation into consideration but both soft storey and column orientation affects displacement and other seismic parameters (lateral and vertical stiffness). Further the past studies suggest that the use of simple plan and configuration should be adopted to prevent failure during earthquakes but it is not always possible to follow simple plan and configuration as the modern trend is to construct buildings aesthetically appealing and that is achieved by diff shapes of columns and complex plans. The approach of an engineer should be to make these complex shaped buildings safe during earthquakes. These types of structures cannot be avoided in the recent times due to their increased need .This makes the study of combined effect of orientations of columns along with the presence of soft storey important.

IV. FUTURE SCOPE

The study of the combined effect of soft storey and effect of shape and orientation of columns on parameters like deflection and time period along with various other seismic parameters will enable engineers to design structures aesthetically different from the conventional ones and without avoiding soft storeys ,structures will be designed as such that they will not collapse during earthquakes. The scarcity in the availability of space will be sufficed by either making already existing structures safe or by building structures safe with regard to earthquake forces.

V. CONCLUSION

The studies conducted on the soft storey buildings suggest the use of shear walls to prevent collapse during earthquakes. The analysis is done on buildings with soft storeys such as nonlinear static, dynamic and response spectrum analysis. From the above studies, it can be concluded that the use of circular columns should be avoided as they increase the base shear. Also the ground storey columns should have high strength and stiffness to avoid failure. The orientation of columns affects the lateral stiffness of the building .Hence orientations and soft storey should be introduced in a way that the lateral and vertical stiffness irregularity is not created in the building.The need for the study has increased in the recent times because of the modern trend of building open ground storey and the growing demand of using different shapes and orientation of columns for aesthetic purpose.

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