International Journal of Technical Innovation In Modern Engineering & Science (IJTIMES),(UGC APPROVED)
Impact Factor: 5.22 (SJIF-2017),e-Issn:2455-2585
"Recent Trends in Structural Engineering" (RTSE-2018)
Volume 4, Special Issue 01, Sept.-2018

# SEISMIC EFFECT OF SOFT STORY AT DIFFERENT LEVEL IN VARIOUS CONFIGURATION OF TALL BUILDING: A REVIEW

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***Abstract—Vertical growth is necessity due to increasing population and scarcity of urban land. Due to this reason, RC tall buildings with soft story are usually constructed in many countries where the soft story is constructed without infill walls at different levels. Such buildings have performed poorly during moderate shaking in the past. The existence of infills in upper stories makes them extensively stiffer as compared to the soft story. As a result, the soft story columns are inadequate to resist high ductility demand. For that lateral load resisting systems for tall buildings were developed. These systems are developed to deal with gravity loads and seismic activities. This paper reviews about seismic effect of soft story and structural systems for tall buildings. Different types tubular systems such as framed tube, braced framed tube, bundled tube and tube-in-tube systems are explained. Here, preliminary design methods are explained for analysis of various systems for 20 to 80 story buildings. It is remarked that it is needed to observe seismic effect of soft story on tall building with different configuration of tubular system.***

***Keywords—Vertical irregularities, Soft Story, Tall building, Seismic Effect, Story Stiffness, Structural Systems, Tubular systems***

## I. INTRODUCTION

Now days, vertical development is common due to increasing population and shortage of land in terms of high rise and tall building. The building higher than 50m is called tall building. It is common because of increasing demand of residential and business, economical and technical growth of country. There are two types of structural system in tall building. The first is interior system includes rigid frame structure, outrigger system and shear wall structure. The other is exterior system includes different tube systems such as framed tube, braced tube, bundled tube and tube in tube, diagrid system, space truss etc. Braced frame system is inefficient above about 40 stories. So the outrigger system is used up to 60 stories. In case of resisting lateral loads tube system is most commonly in use. In tubular system the building is designed as to act like a hollow cylindrical cantilever at right angle to ground. The horizontal loads are resisted by the columns and the spandrel beams located on the perimeter of the tubes. The most common example of tubular system is 110 story sears tower in Chicago. For parking purpose and any other architectural or commercial purpose soft stories are being provided at different levels. So, the stiffness of that story decreases and it behaves poorly during earthquake. Open ground types of building act like an inverted pendulum which is dangerous. For example, 10 stories building located in Bucharest was collapsed due to soft story at ground level during earthquake. The building Yun Men Tsui Ti was collapsed during earthquake. Many buildings failed in Bhuj earthquake had one of the reason is soft story. By providing different systems of tall building the structure can be strengthening to resist seismic forces.

## II. LITERATURE REVIEW

### *A. Structural system of Tall building*

**N. Rana and S. Rana** [9] discussed about some of the major types of structural systems for tall buildings. They explained the different types of loads acting on tall structure. The systems such as braced frame system, framed tube system, outrigger braced system and shear wall structural systems were explained with its advantages and disadvantages.

### *B. Analysis and design of tall building with different systems*

**M.R. Paulino** [7] explained behaviour of various tall building and preliminary design method to analyse various system. It was difficult to observe microscopic behaviour of tall systems in ETABS, SAP2000 and STRUDL due to large numbers of parameters. So, the computer program walls_frame_2D was used and the results were compared with SAP2000 for 60 story steel building. For the analysis of structure with shear wall or braced frame, shear-flexure beam analogy was introduced. For the shear wall framed structure, the shear wall was considered to act as flexural cantilever with infinite shear stiffness and frame as shear cantilever with infinite flexural stiffness. The floor plan was assumed rigid in plan and no twisting was allowed. Computer program SWLFRM-2D was developed in Matlab® graphical user interface and compiled withversion2009a for solving the equations of shear-flexure interactive structure. In SAP2000, for analysis all columns were considered continuous through the joints and girder-column connections were fully moment resistant.

**X. Lu, L. Xie, C. Yu and X. Lu** [14] had compared two design systems fully braced and half braced system of actual engineering project in Beijing. They studied a multi-functional super-tall building with total 540m height approximately. Fully braced frame involved mega columns and mega braces throughout the height, parametric trusses, concrete core tube and secondary frames whereas the half braced system involved mega braces and mega frame in lower four zone, outer frame tubes in other four zones. There was 3D refined non-linear FE model was prepared using MSCMarc. Wind load was approximately 1/940 to 1/570 of total load. Static analysis and dynamic time history analysis were observed using FE models.

**R. Kamgar and M.M. Saadatpour** [10] presented a simple mathematical to determine the first natural frequency of tall building with systems such as framed tube, shear core, belt truss and outriggers with discontinuous in cross section of members. It was assumed that belt truss and outrigger system as rotational spring with constant rotational stiffness. They assumed that connections of outriggers were rigid and connections of belt truss were pinned. They partitioned the building into uniform segments between each discontinuity point. The structure was modelled as beam with box variable cross section. The differential equation of vibration of combined system was obtained using Hamilton's Variational principle. Separation of variable method on time and space was applied. The results were compared of approximate method and SAP2000. The building was modelled and FEM was performed.

**E. Brunesi, R. Nascimbene and L. Casagrande** [4] analysed the peculiar aspects in the seismic response of high-rise mega-frame prototype with belt truss and outriggers. They were considered thirty and sixty story planar frames composed of internal symmetric braced core which is designed with the use of European codes. The core comprised of concentrically braced frame. To limit inter story drift and second order effect outriggers were provided at every fifteen stories. For material and geometric nonlinearities numerical models were developed. To make the model structural members and mechanical idealization of behaviour of beam column joint and welded gusset plate connection, inelastic force based fibre elements were used. They compared non linear time history analysis and response spectrum analysis to quantify the potential of lateral force resisting system. The criteria such as inter-story drift and acceleration, shear and bending moment demand, static to seismic load ratio in critical braces at different level were taken in consideration. The term DAF and FRF were introduced. They had taken two prototypes HR-1 and HR-2 for analysis.

**S.J. Patel and V.B. Patel** [11] compared the different tabular system such as framed tube and bundled tube system. Tubular system was considered in two parts, exterior used to resist lateral loads and interior used to resist gravity loads. They modelled 64 story tall steel building of each framed tube system and bundled system in ETABS which was symmetric in plan. They assumed that the building situated in Bhuj (zone V) and basic wind speed was 50m/s. Modal damping was taken as 2%. They performed static and response spectrum analysis. They considered various criteria such as fundamental time period, maximum top story lateral displacement, base shear and story drift for the comparison.

**W. Hae Lee** [13] established approximate solution procedure for free vibration analysis tube-in-tube tall building. It was assumed that the transverse displacement was a harmonic vibration, based on that the governing partial differential equation of motion was reduced to ordinary differential equation with variable coefficient. Mode shape function of tube in tube tall building was derived as a power series solution. For numerical solution and obtaining the free vibration analysis, the building height was varied from 60 to 120m. The flexural stiffness of inner tube and outer tube was varied from $5x10^9$ $kNm^2$ to $10x10^9$ $kNm^2$ and $30x10^9$ $kNm^2$ to $55x10^9$ $kNm^2$ respectively. The analysis was also performed with variable cross-section. For that a typical shear wall structure was adopted, it could be taken as cantilever bar with different cross section and different axial loads.

*C. Analysis and design of building with soft story*

**N.K. Mohamed Riyas, Dr. K. Y. Raneesh and K.P. Marshiyath** [8] studied the behaviour of reinforced concrete framed multi-story building with soft story at different level. They also observed the variation in amount of reinforcement in soft story. They have taken G+ 24 stories symmetric office building situated at Calicut. The building was modelled in ETABS as RC building with soft story at ground floor level, $6^{th}$ floor level, $12^{th}$ floor level, $18^{th}$ floor level and $24^{th}$ floor level. Damping of the building was provided as 5% and basic wind speed was 39m/s. The deflection at different soft story level was compared. Displacement, story drift and story stiffness were the other criteria which were compared.

**T. Choudhury and H.B. Kaushik** [12] had quantified the fragility of low to medium rise building with open ground story and demonstrated their vulnerability in comparison with FI frames and bare frames. Three different prototypes were prepared such as bare frame, OGS frames and FI frame with different number of stories and varying size of central opening in infill wall. RC members were modelled as two node line elements with rigid beam column joint. The plan was taken 3 bays in both directions with 4 stories. The ground floor was 4.4m high and other floors were of 3.2 m height. An initial seismic assessment was carried out by using FEMA 440 and ATC 40. They had used non linear response history analysis. The analysis was carried out for sixteen sample of ground motion with different PGA. They did not consider soil structure interaction at base of columns.

**A.G. Costa, C.S. Oliveira and R.T. Duarte** [1] studied the seismic behaviour of RCC building with vertical irregularities. They studied 16 story building with 3 different horizontal layouts and 5 different vertical layouts. They idealized as a plane moment resisting frame linked with shear wall by rigid diaphragm. The building was modelled as an association of a shear wall and a shear beam joined by rigid links at each story. The moment resisting frames were represented by shear beams. There was the shear wall modelled by a beam with two degree of freedom, rotational and horizontal translation at each level. The criteria such as cracking, initial stiffness, stiffness after cracking and yielding were taken in consideration for the observation of seismic behaviour of RCC building with vertical irregularities.

## III. DISCUSSION OF RESULTS

1. The shear-flexural cantilever approach is rapid for analysis. The triangular and concentrated load cases caused greater deflection all over the structure.

2. The fully braced system induced uniform plastic energy dissipation whereas in half braced system plastic dissipation was concentrated in higher four zones and core tube was significantly damaged. So found that fully braced system was superior to half braced system.
3. It was observed that natural frequency was 2.68% overestimated than SAP2000. Natural frequency of model was estimated as 1.8034 rad/s. Mathematical modelling was preferred by them for the quick evaluation of preliminary design stage due to the time required for that is less.
4. DAF to FRF ratio increased with the system ductility reduction factor. Peak roof displacement for more severe was observed between 0.77 to 1.83m. Two prototypes which had average peaks of floor acceleration were 0.53 and 0.37g respectively.
5. Fundamental time period was more for framed tube than bundled tube system. Bundled tube is stiffer than framed tube system so attracted more base shear.
6. Power series provides accurate solution and error of approximate solution was reduced to 1.62%.
7. Deflection of soft story at ground level was more and decrease with floor level.
8. It was observed that the ductility of shear wall decreased with increase in coefficient of frame and ductility was constant for higher value of behavior was constant.
9. It was seen that columns in soft story has lack adequate stiffness, ductility and strength required to resist high story shear.

## IV. Conclusions

From the literature review, it has been observed that tubular system is most suitable whenever the lateral loads are there tubular system provides lateral stability to the structure. Also, tubular system allows the greater flexibility in planning of internal space than any other system. The main problem in tube system is shear lag effect due to which distribution of axial forces along the flanged frame columns at one floor is not uniform and the distribution of shear forces along the web is nonlinear. Shear leg effect results in corner or exterior columns experienced higher stress than central or interior columns. The effect of soft story on various configuration of tall building such as framed tube system, bundled tube system, diagonalized tube system, tube in tube system is needed to study. The safety measure to reduce the soft story effect is to be determined considering shear leg effect.

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