Dynamic Analysis of RC Frame in Relation to the Storey Drift and Lateral Displacements, Base Shear Using Software ETABS

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Abstract

The important objective of earthquake engineers is to design and build a structure in such a way that damage to the structure and its structural component during the earthquake is minimized. This report aims towards the non-linear dynamic analysis of a multi-storey RCC building with Varying Plan Geometry. The analysis is carried by using finite element-based software ETABS. Various response parameters such as lateral force, base shear, story drift, Displacement can be determined. For dynamic analysis time, the history method or response spectra method can be used. The time-history analysis is a step-by-step analysis of the dynamical response of a structure to a specified loading that may vary with time. The analysis may be linear or non-linear. Dynamic analysis can be performed for unsymmetrical building. The various response parameters like base shear, storey drift, storey displacements etc. are calculated. The maximum stress and moment to find out and compared within the considered configuration as per IS 1893:2002.

Keywords*: - Non-linear Dynamic analysis, ETABS, Varying Geometry.*

INTRODUCTION

Overview

Many multistorey buildings in India today have an open first storey as an unavoidable feature. This is primarily being adopted to accommodate parking or reception lobbies in the first storeys. The upper storeys have brick infilled wall panels. Reinforced concrete (RC) frame buildings with masonry infill walls have been widely constructed for commercial, industrial and multistorey residential uses in seismic zone regions. Masonry infill typically consists of bricks or concrete blocks constructed between beams and columns of a reinforced concrete frame. The masonry infill panels are generally not considered in the design process and treated as architectural (non-structural) components. The presence of masonry infill walls has a significant impact on the seismic zone response of a reinforced concrete frame building, increasing structural strength and stiffness (relative to a bare frame). Properly designed infills can increase the overall strength, lateral resistance and energy dissipation of the structure.

The seismic zone force distribution is dependent on the stiffness and mass of the building along the height. The structural contribution of the infill wall results in a stiffer structure, thereby reducing the storey drifts (lateral displacement at floor level). This improved performance makes the structural design more realistic to consider infill walls as a structural element in the earthquake resistant design of structures. The draft Indian seismic zone code classifies a soft storey as one whose lateral stiffness is Less than 50% of the storey above or below [Draft IS: 1893 - 2002]. Interestingly, this classification renders most Indian buildings, with no masonry infill walls in the first Storey, to be "buildings with soft first storey." Whereas the total seismic zone base shear as experienced by a building during an earthquake is dependent on its natural period, the seismic zone force distribution is dependent on the distribution of stiffness and mass along the height.

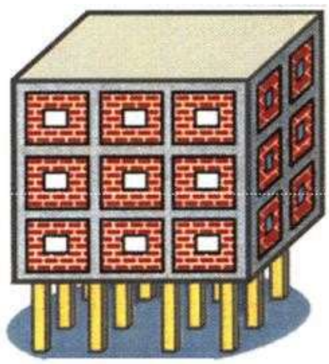

Fig. 1: Typical example of first soft storey

The above **fig. 1**.shows the first soft storey having infill with openings and infill were usually classified as non-structural elements, and their influence was neglected during the Modeling phase of the structure leading to substantial inaccuracy in predicting the actual seismic zone response of framed structures. Masonry infill has several advantages like good sound and heat insulation properties, high lateral strength and stiffness. These help to increase the strength and stiffness of the RC frame and hence decrease lateral drift, higher energy dissipation capacity due to cracking of infill and friction between infill and frame. This, in turn, increases the redundancy in building and reduces bending moment in beams and columns. Masonry infill has disadvantages like very high initial stiffness and compressive strength.

This also induces a tensional effect in the structure if not symmetrically placed. For a proper design of masonry infilled reinforced concrete frames, it is necessary to completely understand their behaviour under repeated horizontal loading. The only difference between the finished residential and office buildings are the type of materials used for partitions and building perimeter wall enclosures. Residential buildings commonly use masonry infills both internally and externally.

This necessitates the building system to consist of columns with lightweight, non-structural, easily removable internal partition walls, and the façade walls consist of full or part glazing. Despite having a masonry infills structural frame, size and shape, office buildings exhibit much less loss of life, damage or collapse when compared to residential buildings of the same size. The reason for residential buildings having significantly more damage is because the masonry infills placed in framed structures, due to their stiffness, causes a change in the structural behaviour of such structures. The observations and analysis results reveal that the use of masonry infill walls located in between the columns of reinforced concrete framed structures plays a major role in the damage and collapse of buildings during strong earthquakes.

Fig. 2 Behaviour of load transfer in buildings with infills Infill walls influence the behaviour of an RC frame:

a) a bare frame;
b) infill walls must be uniformly distributed in the building; and
c) if the infills are absent at the ground floor level, this modifies the load path, which detrimental to earthquake performance.

The below **Fig. 2** shows the behavior of RC building models with infills. In buildings with Soft first storey, the upper storeys being stiff undergo smaller inter-storey drifts. However, the inter-storey drift in the soft first storey is large. The strength demand on the columns in the first storey for third buildings is also large, as the shear in the first storey is maximum.

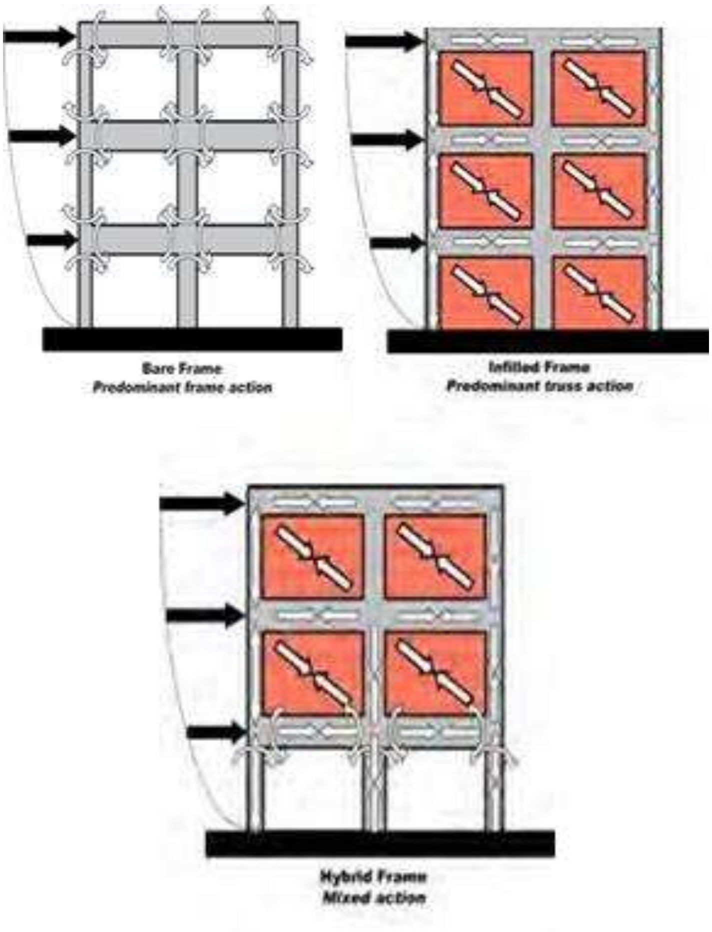

Figure 2

For the upper storeys, however, the forces in the columns are effectively reduced due to the presence of the Buildings with abrupt changes in storey stiffness have uneven lateral force distribution along the height, which is likely to induce stress concentration locally. This has an adverse effect on the performance of buildings during ground shaking. Such buildings are required to be analyzed by the Linear dynamic analysis and designed carefully with masonry infill walls in all the storey and building with no walls in the first storey, two storey soft storey, three storey soft storey, bare frame building Model and bare frame with slab element.

Linear dynamic analysis of building Models was performed using the software ETABS. The lateral displacements and drift and base shear in the soft storey of a building and bare frame are more in the infill wall of the building. Also, from the analysis, they concluded that RC frame buildings with soft storey perform poorly during strong earthquake shaking. The drift and the strength demands in the first storey column are very large for building with the soft first storey. The infill components increase the lateral stiffness and serve as a transfer medium of horizontal inertia forces. From this conception, the floors that have no infill component have less stiffness than other floors.

Soft Storey

A soft storey is one in which the lateral stiffness is less than 70 percent of that in the storey above or less than 80 percent of the average lateral stiffness of the three storeys above. Now a day’s constructions of multistoried Reinforced Concrete (RC) frame buildings with masonry infills are common in India. The most common type of vertical irregularity occurs in buildings that have an open ground story. Many buildings constructed in recent times have a special feature that the ground stories are left open for the purpose of parking, reception etc. Such buildings are often called open ground storey buildings or buildings on stilts. The first storey becomes soft and weak relative to the other upper stories, due to the absence of masonry walls in the first stories. Structurally those unbalances are unhealthy, and soft storey buildings are well known for being susceptible to collapse through past earthquakes.

The following two features are characteristic of soft storey buildings:

a) Relatively flexible ground story in comparison to the stories above, i.e., the relative horizontal movement at the ground story level is much larger than the stories above. This flexible ground story is called a soft story

b) Relatively weak ground story in comparison to the stories above, i.e., the total horizontal earthquake force (load) resisted at the ground story level is significantly less than the stories.

Behaviour of Soft Storey

In buildings with inter-storey drift in the soft first storey is large. The strength demand on the column in the first storey for these buildings is also large; however, in the upper stories the forces in the columns are effectively reduced due to the presence of brick infill walls, which share the forces. If the first floor is significantly less strong or more flexible, a large portion of the total building deflections tends to concentrate on that floor. The presence of walls in upper stories makes them much stiffer than the open ground storey.

Thus the upper stories move almost together as a single block, and most of the horizontal displacement of the building occurs in the soft ground storey. Thus, such a building behaves like an inverted pendulum, with the ground story columns acting as the pendulum rod and the rest of the building acting as a rigid pendulum mass during an earthquake. As a consequence, large movement occurs in the ground story alone, and the columns in the open ground storey are severely stressed. If the columns are weak (do not have the required strength to resist these high stresses), they may be severely damaged, which may even lead to the collapse of the building.

Fig. 3: Building damage due to effect of soft storey

Lateral displacement and storey drift

Lateral deformations at various levels in masonry infills-RC frame buildings depend upon the distribution of masonry infill walls in buildings. If more walls are present at the base, lateral deformations will be less and evenly distributed along the height of buildings. On the other hand, if more walls are present on the upper stories, then lateral deformations will be a requirement of masonry infills, minimum 20% of the total length of lateral load–resisting walls along both x and y directions to be placed in each of the external concentrated at the bottom, where stories are lesser infilled. Lateral deformations and inter-storey drift will also depend upon the ductility and damping of buildings. The lateral displacement and drift will be more in the bare frame as compared to the bare frame with slab element, frame with slab element and full wall element, first soft storey, second soft storey, and third soft storey.

Stiffness of masonry infill

Masonry infill walls are laterally much stiffer than RC frames, and therefore, the initial stiffness of the masonry infill-RC frames largely depends upon the stiffness of masonry infill walls. The stiffness of masonry in fill-RC frames significantly depends on the distribution of masonry infill in the frame. Generally, the masonry infill-RC frames with a regular distribution of masonry infill walls in the plan as well as along height are stiffer than the RC frames. IS 1905 code specifies the modulus of elasticity of masonry infill walls as modulus of elasticity as 550 times the masonry prism strength in the absence of tests. The Indian masonry infills code IS 1893-2002 requires members of the soft story, story stiffness less than 70% of that in the story above or less than 80% of the average lateral stiffness of the three stories above to be designed for 2.5 times the masonry infills story shears and moments, obtained without considering the effects of Masonry infills in any story. The factor of 2.5 is specified for all the buildings with soft stories irrespective of the extent of irregularities, and the method is quite empirical. The other option is to provide symmetric RC shear walls, designed for 1.5 times the design story shear force in both directions of the building as far away from the center of the building as feasible. In this case, the columns can be designed for the calculated story shears and moments without considering the effects of masonry infills.

LITERATURE REVIEW

The various literatures are collected from books, magazines and websites. To provide a detailed review of the literature related to assess the seismic analysis of the structures in their entirety would be difficult to address in this chapter. A brief review of previous studies seismic analysis of structures is presented in this section. This literature review focuses on the evaluation of seismic analysis structures and past efforts most closely related to the needs of the present work. From this literature, data is summarized for work. Abstracts of collected literatures are as follows.

Suchita and Ganga (2014) [22] discussed the performance of a building with the soft storey at different levels along with at ground level. The nonlinear static pushover analysis is carried out. Concluded, it is observed that plastic hinges are developed in columns of the ground-level soft storey, which is not an acceptable criterion for safe design. Displacement reduces when the soft storey is provided at a higher level.

Hiten and Anuj (2014) [8] investigated many buildings that collapsed during the past earthquake exhibited exactly the opposite strong beam weak column behaviour means columns failed before the beams yielded mainly due to soft storey effect. For proper assessment of the storey stiffness of buildings with soft storey buildings, different Models were analyzed using the software. Concluded, the displacement estimates of the lateral load patterns are observed to be smaller for the lower stories and larger for the upper stories and are independent of the total number of stories of the Models.

Dhadde Santosh (2014) [3] has carried out nonlinear pushover analysis on building Models using software ETABS, and evaluation is carried for non-retrofitted normal buildings, and retrofitting methods are suggested like infill wall, increase of ground story column stiffness, and shear wall at the central core. Storey drift values for soft storey Models maximum values compare to other stories, and the values of storey drift decreases gradually up to the top.

Rakshith and Shankar (2014) [19] modeled & analyzed RC buildings with the soft storey at different levels for different load combinations using ETAB. The inter-storey drift was observed to be maximum in vertically irregular structure when compared to that of regular structure.

Mr. D. Dhandapany (2014) [14] investigated the seismic behaviour of RCC buildings with and without a shear wall. Analyzed using ETABS software for different soil conditions (hard, medium, soft). The values of Base shear, axial force and Lateral displacement were compared between two frames. Results obtained using STAAD are found to be almost equal results to when compared to obtained using ETABS for all structural members.

Goutam and Sudhir (2008) [7] have carried out a parametric finite element analysis on the single-bay single-story, single-bay two-story and single bay three-story infilled frame to examine the effect of central openings of different sizes on the initial stiffness of infilled frames. Based on the study, he has concluded the effect of opening on the initial lateral stiffness of infilled frames should be neglected if the area of the opening is less than 5% of the area of the infill panel, and the strut width reduction factor should be set equal to one, i.e., the frame is to be analyzed as a solid infilled frame.

The effect of infill on the initial lateral stiffness of infilled frame may be ignored if the area of opening exceeds 40% of the area of the infill panel, and the strut-width reduction factor should be set to zero, i.e., the frame is to be analyzed as a bare frame. The proposed reduction factor is applicable for an infilled frame with normal openings. Extreme cases where openings are extended to full height or full width of the infilled frame cannot be covered by the reduction factor.

Haque et al. (2008) [21] was performed an investigation to study the behaviour of the columns at the ground level of multistoried buildings with soft ground floor subjected to dynamic earthquake loading. The structural action of masonry infill panels of upper floors has been taken into account by modeling them as diagonal struts. Finite element Models of six, nine and twelve storied buildings are subjected to earthquake load in accordance with the equivalent static force method as well as the response spectrum method. It has been found that when infill is incorporated in the FE Model, modal analysis shows different mode shapes indicating that the dynamic behaviour of buildings changes when infill is incorporated in the Model. The natural period of the buildings obtained from the modal analysis is close to values obtained from code equations when infill is present in the Model. This indicates that for better dynamic analysis of RC frame buildings with masonry walls, infill should be present in the Model as well. The equivalent static force method produces the same magnitude of Earthquake force regardless of the infill present in the Model. However, when the same buildings are subjected to the response spectrum method, a significant increase in the column.

METHODOLOGY

The two types of methods are available for the analysis of RC frame buildings with infill are the Finite Element Method and the Single Equivalent Diagonal Strut (SEDS) method. In the present study, the FE Model is first calibrated using ETABS in linear dynamic analysis to determine storey drifts, lateral displacement and base shear for all Models in all seismic zones. The width of equivalent diagonal strut for the SEDS method is estimated so as to obtain the same lateral stiffness as estimated from the FE method. That is, the equivalent width of the diagonal strut is determined that will give the correct value of lateral stiffness. Finally, a strut-width reduction factor is proposed to multiply the "strut- width for the fully infilled panel" proposed by some researchers earlier Over the past few decades, several methods for the analysis of infilled frames have been proposed in the literature by various investigators. These methods can be divided into two groups, depending on the degree of refinement used to represent the structure. The first group consists of the macro models belong to the simplified Models that are based on a physical understanding of the structure. The second group involves the masonry infill Models, including the finite element formulations, taking into account local effects in detail.

Macro Models

The basic characteristic of the macro Models is that they aim at predicting the overall stiffness and failure loads of infilled frames without considering all possible failure modes of local failure. This group of Models can be subdivided to their origin into the following three categories, based on:

- The concept of the equivalent diagonal strut
- The concept of the equivalent frame **Equivalent**

Diagonal Strut Analogy

The simplest (and most developed) method for the analysis of non-integral infilled frames is based on the concept of the equivalent diagonal strut. This concept was initially proposed by Polyakov (1956) and later developed by other investigators. In this method, the infilled frame structure is modeled as an equivalent braced frame system with a compression diagonal replacing the infill. The equivalent diagonal strut method is further subdivided into the following three categories

a) Single Diagonal Strut Model
b) Modified Diagonal Strut Model
c) Multi-Strut Model.

Equivalent Diagonal Strut Method

The equivalent diagonal strut model was initially based on the observation that the compressive path in the masonry panel, due to horizontal loads, develops mainly along its diagonal. The width of the strut depends on different features, such as the extension of the region of interaction between masonry and frame. The ultimate horizontal strength of the infills also depends on the failure mechanism (diagonal tension, slipping in a mortar bed, corner compression or diagonal compression failures). The prediction of the failure mode is rather difficult since it is influenced by the material properties, the dimensions of the system and the stress level in the panel. Keeping in mind that the masonry is a heterogeneous material, the strut Model can be regarded as a method to reproduce only the global behavior.

Micro Models

The development of finite element methods offered some relief to the masonry infills pointed out in the previous methods.

The first approach to analyze infilled frames by linear finite element analysis was suggested by Mallick and Severn (1967). They introduced an iterative technique taking into account separation and slip at the structural interface. Plane stress rectangular elements were used to Model the infill, while standard beam elements were used for the frame. However, as a consequence of the assumption that the interaction forces between the frame and the infill along their interface consisted of normal forces only, the axial deformation of the columns was neglected in their formulation. The effect of slip and interface friction was considered by introducing shear forces along the length of contact. The contact problem was solved by initially assuming that infill and frame nodes have the same displacement. Having determined the load along the periphery of the infill, tensile forces were located in the Model. Subsequently, the corresponding nodes of the frame and infill were released, which allowed them to displace independently in the next iteration. This procedure was repeated until a prescribed convergence criterion was achieved.

RESULTS AND DISCUSSIONS

Linear dynamic analysis is performed on all models. Loads are calculated and distributed as per code IS 1893 (Part I):2002 using ETABS. The results obtained from the analysis are compared with respect to the following parameters. The analysis of all the frame Models that include bare frame, bare frame with slab element, full infilled frame and soft storey at different levels of the frame has been done by using software ETABS in linear dynamic analysis and the results are shown below. The parameters which were studied are storey drifts, lateral displacement, and base shear for all Models in zones II, III, IV and zone V.

Permissible Storey Drift

It is the displacement of one level relative to the other level above or below. The storey drifts in any storey shall not exceeds 0.004 times the height of storey height, the permissible storey drift of each Storey = 3000mm 0.004(h) = 0.004(3000) = 12 mm. During an earthquake, large lateral forces can be imposed on structures. Lateral deflection and drift have three primary effects on a structure, the movement can affect the structural elements (such as beams and columns); the movements can affect non-structural elements (such as the windows and cladding), and the movements can affect adjacent structures.

Comparison of maximum storey drifts of all building models at different storey levels in all seismic zones

Drift is the displacement of one level relative to the other level above or below. The storey drift in any storey shall not exceed 0.004 times the height of storey height, Height of Storey = 3000mm 0.004(h) = 0.004(3000) = 12mm.The maximum storey drifts are to be evaluated from the overall storey drifts of six Models in four zones and compare the maximum drifts with building height.

SUMMARY

Linear Dynamic Analysis has been performed on six types of RC building Models such as RC bare frame, RC bare frame with slab element, RC building with first soft storey, RC building with the second soft storey and RC building with a third soft storey from the ground level of the building in zones II, III, IV & zone V as per IS 1893: 2002.

CONCLUSION

The IS code methods describing very insufficient guidelines about infill wall design procedures. Software like ETABS is used as a tool for analyzing the effect of infill on structural behaviour. It is observed that ETABS provides overestimated values of storey drift, lateral displacement and base shear. According to relative values of all parameters, it can be concluded that the provision of infill wall enhances the performance in terms of displacement, storey drift and lateral stiffness.

RC framed buildings with the soft story are known to perform poorly during strong earthquake shaking. Because the stiffness at the lower floor is 70% lesser than stiffness at storey above it, causing the soft storey to happen. For a building that is not provided any lateral load resistance component such as a shear wall or bracing, the strength is considered very weak and easily fails during an earthquake. In such a situation, an investigation has been made to study the seismic behaviour of such buildings subjected to earthquake load so that some guidelines could be developed to minimize the risk involved in such types of buildings. It has been found earthquake forces by treating them as ordinary frames results in an underestimation of base shear. Investigators analysis numerically and use various computer programs such as STAAD Pro., ETABS, SAP2000 etc.

Calculations show that when RC framed buildings having brick masonry infill on the upper floor with soft ground floors subjected to earthquake loading, base shear can be more than 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. This document highlights the poor seismic performance of RC bare frame buildings, bare frame with slab element, first soft storey, second soft storey, and third soft storey from ground level and the documents analyzing the variation of storey drifts, lateral displacements and base shear in all zones.

- The storey drifts observed of the structure are found within the limit as specified by code (IS: 1893-2002, part-1) in linear dynamic analysis.

- Story drift value is more in story 11 of the bare frame as compared to the soft storey at different levels of the building.

- The presence of masonry infill influences the overall behaviour of structures when subjected to lateral forces. Lateral displacements and storey drifts are considerably reduced while the contribution of the infill brick wall is taken into account.

- Infilled frames should be preferred in seismic zones more than the open first storey frame because the storey drift of the first storey of an open first storey frame is very large than the upper storeys, this may probably cause the collapse of the structure.

- Lateral displacement of bare frame Model is higher than other Models because of less lateral stiffness of storey, due to absence of infill walls. The lateral displacements were observed in model 2 are reduced to 13.14%, 20.68%, 30.74% and 45.82% as compared to model 1 in zone II, III, IV and zone V, respectively.

- First storey displacement of soft first storey Model is maximum than other Models due to the absence of infill in the first storey. In the soft first storey frame, there is a sudden change in drifts between the first and second storey in all seismic zones.

Concluded that the providing of infill wall in RC building controlled the displacement, storey drifts and lateral stiffness.

SCOPE OF WORK

The soft storey is a typical feature in the modern multistory constructions in urban India. Such features are highly undesirable in buildings built in seismically active areas. In normal practice, only the load due to masonry infills were considered, and do not consider the composite action. It will be interesting if the comparison made between the storey drifts, lateral displacement and base shear in zones II, III, IV, & zone V Earthquake vulnerability of buildings with open ground floor is well known around the world.

In such a situation, an investigation has been performed to study the behaviour of such buildings subjected to earthquake load so that some guidelines could be developed to masonry infills the risk involved in such type of buildings. It has been found that code provisions do not provide any guidelines in this regard. The present study reveals that such types of buildings should not be treated as ordinary RC framed buildings. It has been found that the calculation of earthquake forces by treating them as ordinary frames results in an underestimation of base shear.

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