Dynamic Analysis of G+13 Storey RC Building Having Vertical(Mass & Stiffness) Irregularities

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Abstract- *Weight (mass) irregularity is defined where the effective mass of any story is more than 150% of the effective mass of an adjacent story and per Section 7.1 of 1S-1893-2002, "Mass irregularity shall be considered to exist, where the seismic weight of any storey is more than 200% of that of its adjacent storeys Generally, roof is lighter than the floor below is not to be considered.Stiffness-soft storey irregularity is defined, if a story lateral stiffness is less than 70% of the story above or less than 80% of the average stiffness of the three stories above.For analysis of models G+13 storey reinforced concrete buildings is selected, with considering mass and stiffness irregularities along the height of building. In first case the selected G+13 storey RC building is analyzed with considering mass irregularities. The heavy mass is added to the building at three different locations along the height of building. In second case the same selected G+13 storey RC building is analyzed with considering stiffness irregularities instead of mass irregularities, at three different locations along the height of building. The models are analyzed using IS-1893-2002 & IBC-2012 codes bylinear dynamic(Time History) method in STAAD Pro softwareand Bhuj Earthquake Time History (26 January 2001), Ahmedabad Station data is used in the analysis procedure.The aim of the research is to study the effect of mass and stiffness irregularities in different location along the height of building and compare the results of IS-1893-2002 & IBC-2012 codes.*

Keywords- Dynamic Analysis,Vertical Mass and Stiffness Irregular Building,Storey Drift & Displacement, Distribution of Lateral Loads and Torsional Moments Along the Height of Building, Using American (IBC-2012) and Indian (IS-1893-2002) codes.

I. INTRODUCTION

The purpose of dynamic analysis is to obtain the design seismic forces, with its distribution to different levels along the height of the building and to the various lateral load resisting elements similar to equivalent lateral force method. In IS-1893 (Part 1): 2002 has recommended of dynamic analysis of building in section 7.8 in the case of (i) regular building, those higher than 40 m in height in seismic Zones IV and V, and those higher than 90 m in height in Zones II and III, (ii) irregular buildings, all framed buildings higher than 12 m in Zones IV and V, and those higher than 40 m in Zones II and III. The procedure of dynamic analysis described in the Code is valid only for regular type buildings, which are almost symmetrical in plan and elevation about the axis having uniform distribution of lateral load resisting elements. It is further assumed that all the masses are lumped at storey level and only sway displacement is permitted at each storey. The procedure of dynamic analysis for irregular buildings should be based on 3D modeling of building that will adequately represent its stiffness and mass distribution along the height of the building so that its response to earthquake could be predicted with stiffness accuracy.

Once the structural model has been selected, it is possible to perform analysis to determine the seismically induced forces in structures. There are different methods of analysis which provide different degree of accuracy. The analysis process can be categorized on the basis of three factors; the type of external applied loads, the behavior of structure/or structural materials, and type of structural model selected. Based on the type of external action it can be classified static and dynamic analysis, due to the behavior of structure/or structural materials it can be classified elastic and elastic plastic analysis and based on the type structural model it is classified 3D, 2D and 1D. Based on the type of external action and behavior of structure, the analysis can be further classified as linear static analysis, linear dynamic analysis, nonlinear static analysis or non-linear dynamic analysis.

Main features of seismic method of analysis based on Indian standard IS-1893 (Part 1): 2002 are described as follows:

Equivalent Later Force: Seismic analysis of most of the structures are still carried out on the basis of lateral (horizontal) force assumed to be equivalent to the actual (dynamic) loading. The base shear which is the total horizontal force on the structure is calculated on the basis of structure mass and fundamental period of vibration and corresponding to mode shape. The base shear is distributed along the height of structures in terms of lateral forces according to Code formula. This method is usually conservative for low to medium height buildings with a regular configuration.

Response Spectrum Analysis: This method is applicable for those structures where modes other than fundamental one affect considerably the response of the structure. In this method the response of multi-degree-of-freedom (MDOF) system is expressed as superposition of modal response, each modal response being determined from the spectral analysis of single-degree-of-freedom (SDOF) system, which are then combined to compute the total response. Modal analysis leads to the response history of the structure to a specified ground motion; however, the method is usually used in conjunction with a response spectrum.

Elastic Time History Analysis: A linear time history analysis overcome all the disadvantages of modal response spectrum analysis, provided non-linear behavior is not involved. This method requires greater computational efforts for calculating the response at discrete times. One interesting advantage of such method is that relative signs of response quantities are preserved in the response history. This is important when interaction effects are considered in design among stress resultants.

II. PREPARING AND ANALYSIS OF MODELS

For analysis of models G+13 storey reinforced concrete buildings is selected and the selected building is analyzed by linear dynamic (Time History) method in STAAD Pro software, with considering mass and stiffness irregularities along the height of building. Generally the work has two major cases. In first case the selected G+13 storey RC building is analyzed with considering mass irregularities. The heavy mass is added to the building at three different locations along the height of building. Four models are prepared, Model-1 is without mass irregularities, Model-2 has mass heavy mass at second floor (Storey-3), Model-3 has heavy mass at 7th floor (Storey-8) and Model-4 has heavy mass at 12th floor (Storey-13) and these four models are analyzed using both (IS-1893-2002 & IBC-2012) codes. The results of that models having mass irregularities are compared with model without irregularities (Model-1) and also results of three irregular models are compared to each other. For mass irregularities in the three models at mentioned floors 30 kN/m^2 extra mass is added, so the total effective mass of that floor, which have heavy mass, is more than 200% of the effective mass of adjacent floor and as per Section 7.1 of 1S-1893-2002, “Mass irregularity shall be considered to exist, where the seismic weight of any storey is more than 200% of that of its adjacent storeys. The irregularity need not be considered in case of roofs” and as per section 12.3.2 of ASCE-7-10, “Weight (mass) irregularity is defined to exist, where the effective mass of any storey is more than 150% of the effective mass of an adjacent storey. A roof that is lighter than the floor below need not be considered”. The plan of building is shown in Fig. 1 and the assumed data that is used in analysis, is shown in Table 1.

Table 1 Assumed Data for the Analysis of Building

Live load	4.0 kN/m^2 at typical floor 1.5 kN/ m^2 on terrace
Floor finish	1.0 kN/ m^2
Water proofing	2.0 kN/ m^2
Terrace finish	1.0 kN/ m^2
Seismic zone	3rd
Important factor	1.0
Response reduction factor	5 in IS-1893-2002 & 8 in IBC-2012 (ASCE-7)
Type of soil	Medium
Storey height	Typical floor: 3.1 m, and height of column from base to Ground floor level: 2.5 m. In case of Stiffness irregularities soft-storey height is 4.1 m.
Floors	G.F. + 13 upper floors
Column size	Up to plinth level of ground floor 600mm*600mm, from ground floor to 4th floor 550mm*550mm and from 4th floor to 13th floor 500mm*500mm
Beam size	400mm*500mm
Slab thickness	120mm
Thickness of all masonry Walls	230mm
Parapet wall height	1.2m
Grade of concrete	M30 for all components
Grade of steel	Fe 415 HYSD

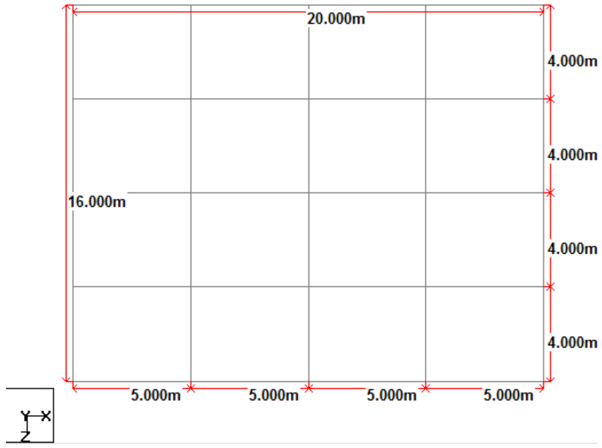


Fig. 1 Plan of Selected Building

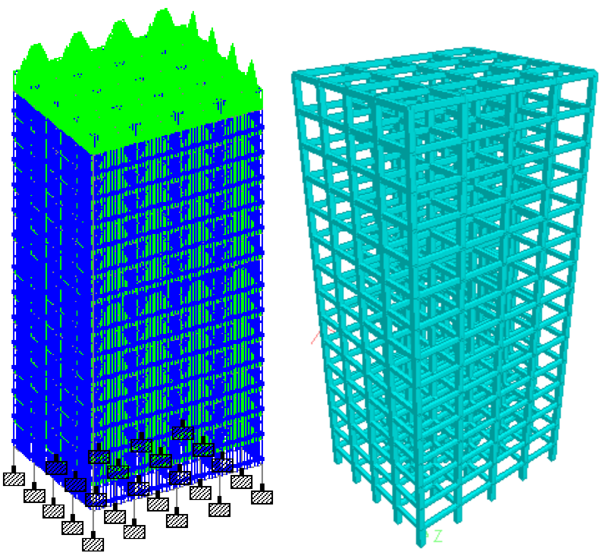


Fig. 2 3D of Model

In second case the same selected G+13 storey RC building is analyzed with considering stiffness irregularities instead of mass irregularities, at three different locations along the height of building. Four models are prepared, Model-1 is without stiffness irregularities, Model-2 has soft-storey at second floor (Storey-3), Model-3 has soft-storey at 7th floor (Storey-8) and Model-4 has soft-storey at 12th floor (Storey-13) and these four models are analyzed using both (IS-1893-2002 & IBC-2012) codes. The results of that models having stiffness irregularities are compared with model without irregularities (Model-1) and also results of three irregular models are compared to each other. At end, the results of models having mass irregularities are compared with the results of models having stiffness irregularities. For stiffness irregularities in the three models at mentioned floors the storey height is considered more, therefore the height of soft-storey is 4.10 m and height of other storeys is 3.10 m. Stiffness of storey columns is calculated as below:

$$K = \frac{12\,E\,I}{L^3}$$

The stiffness ratio of these storeys,

As per clause 7.1 of IS-1893-2002 and clause 12.3.2 of ASCE-7-10, "an extreme soft-storey is one in which the lateral stiffness is less than 60% of that in storey above or less than 70% of the average stiffness of the three storeys above". So the considered storeys at 2nd floor, 7th floor and 12th floor for Model-2, Model-3 and Model-4 are extreme soft-storeys respectively. The models are analyzed by Time History method, Bhuj Earthquake Time History (26 January 2001), Ahmedabad Station data has been used in the analysis procedure.

$$K = \frac{\frac{12\,E\,I}{4.1^3}}{\frac{12\,E\,I}{3.1^3}} = 0.4322 < 0.70$$

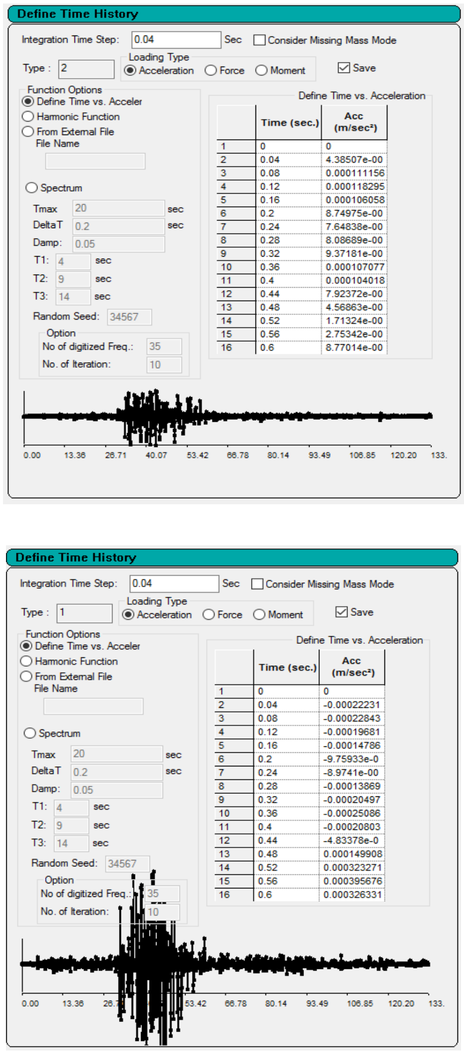
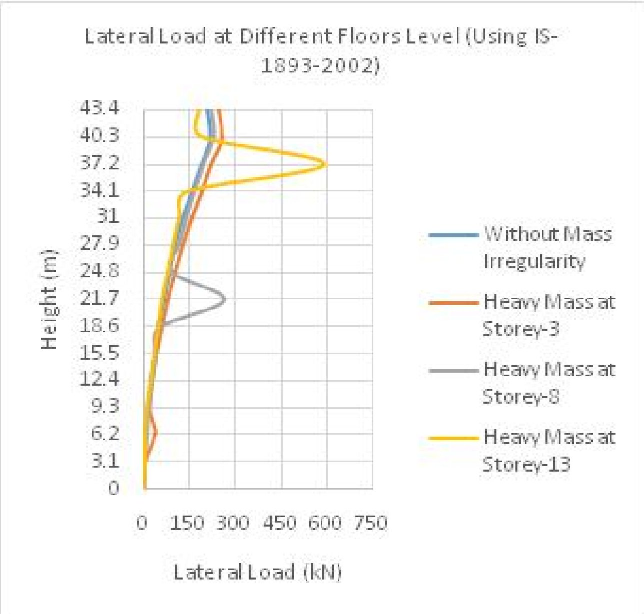


Fig. 3 Definition of Time History

III. RESULT AND DISCUSSION

As G+13 storey reinforced concrete building has been analyzed by Time History Analysis Method with two type of irregularities (mass & stiffness irregularities) along the height of building, the results are discussed as under:

1. Comparing of Lateral Load and Torsional Moment: As the same heavy mass added to the building at three loacations along the height of building and the lateral load distribution and tortional moment along the height of building are obtained from analysis result are show in the followin figures.



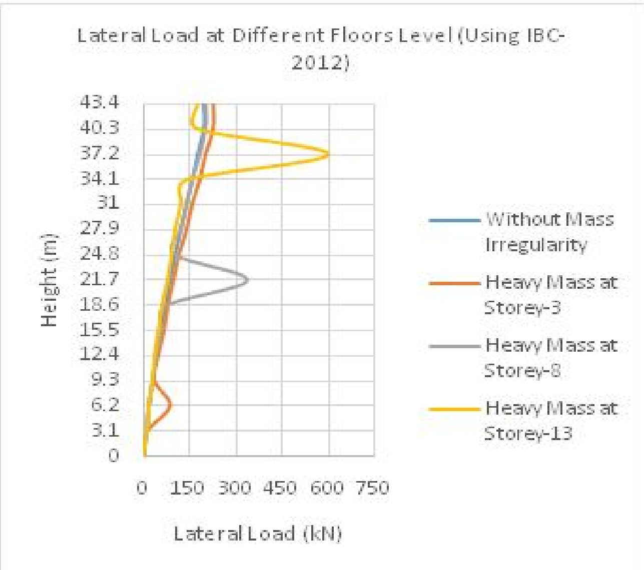
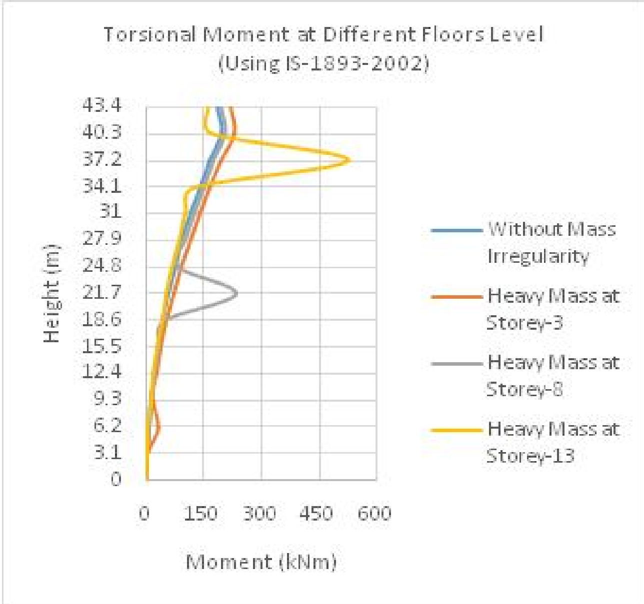


Fig. 4 Lateral Load at Different Floors Level



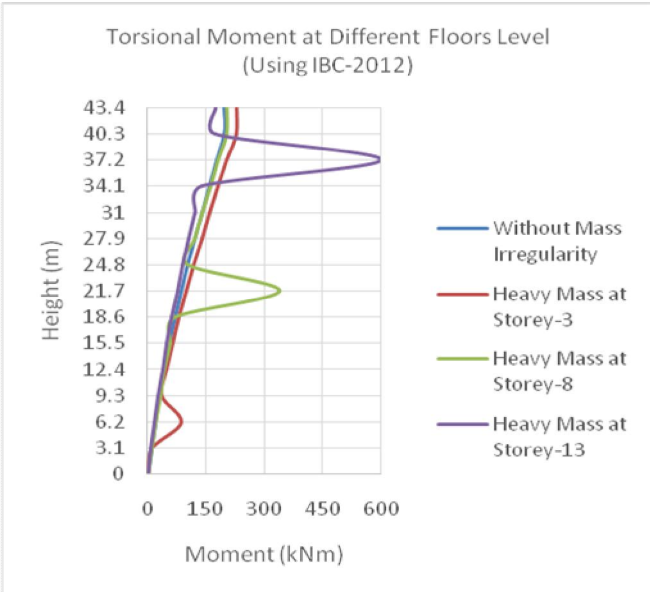
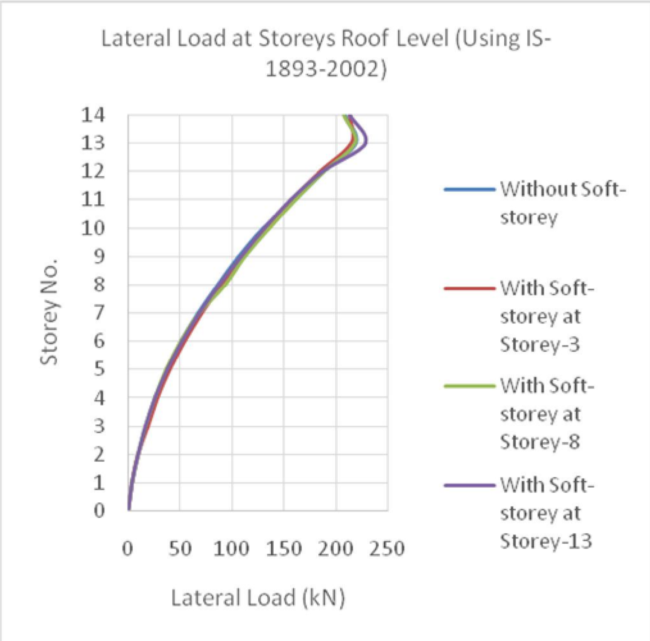


Fig. 5 Torsional Moment at Different Floors Level

From the Fig. 4 and Fig. 5 above, it is observed, that same heavy mass is added at three different loctions along the height of buildings (three models are prepared), the lateral load distribution and torsional moment due to heavy mass is added at lower storeys is better than heavy mass is added at upper storeys. If the heavy mass is added at upper floors, the lateral load and torsional moment will be too much higher in certain floors which have heavy mass, but the in lower storey (Model-2), which have the same haevy mass, the later load and tosional moment in that floor are not much higher as compared to Model-3 and Model-4. The Model-1 which is without mass irregularitie, its lateral load distribution and torsional moment are not chaneged in certain floor and its is the best model. Generally, performance of the buildings with mass irregularities, in which the heavy mass is located at lower storeys is better than the buildings with mass ir regularties having heavy mass at upper storeys.



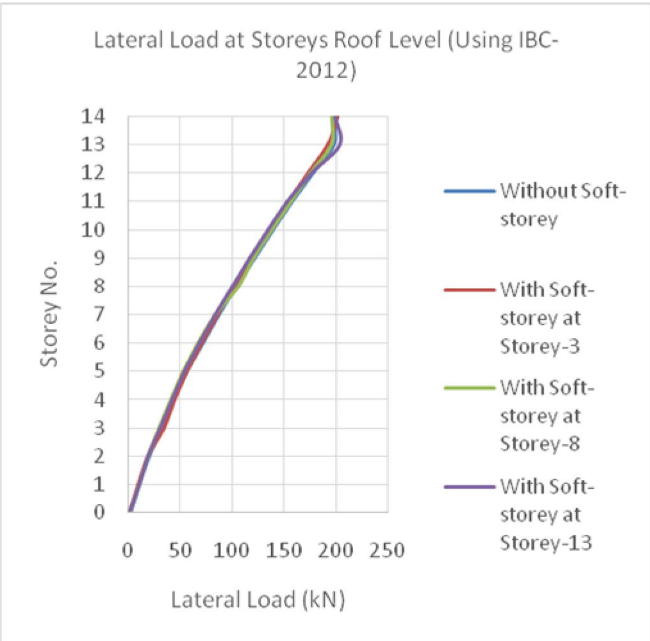
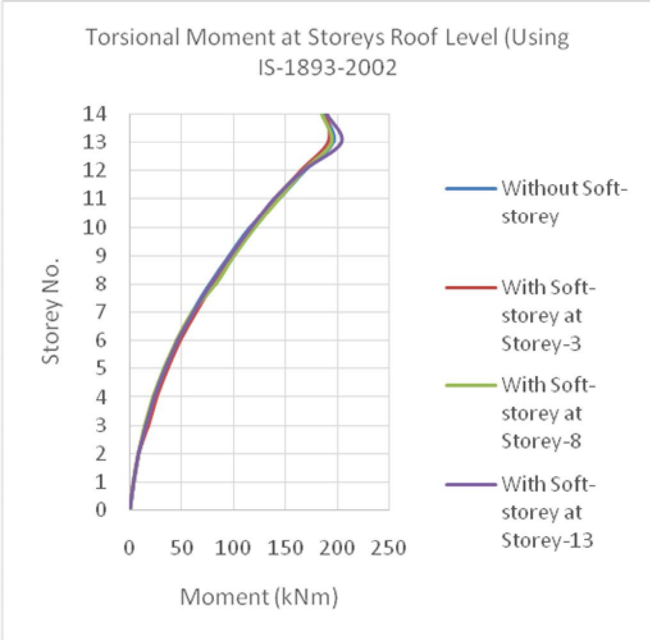


Fig. 6 Lateral Load at Different Storeys Roof Level



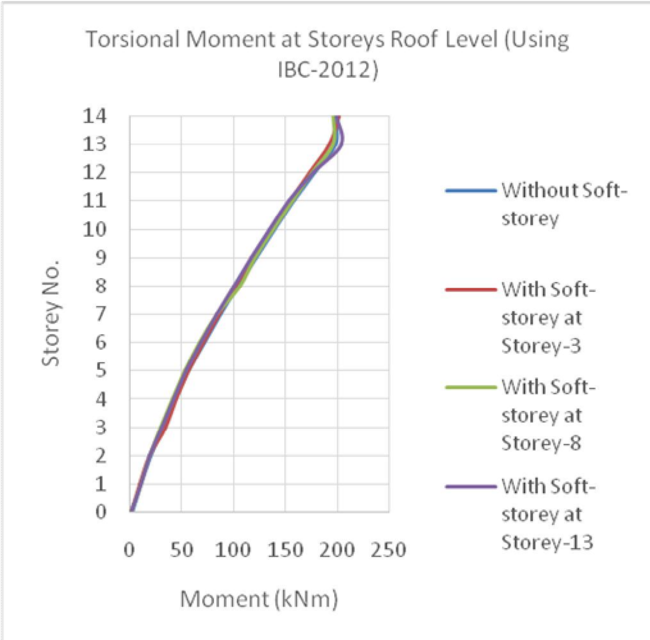
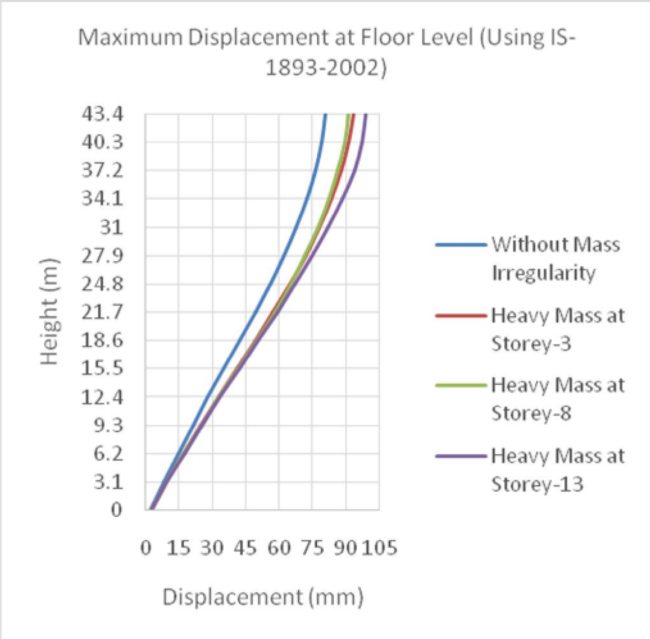


Fig. 7 Torsional Moment at Different Storeys Roof Level

In case of stiffness irregularities, the same soft-storey is considered at the three locations along the height of the building. From the Fig. 6 and Fig. 7 above, it is observed, generally the soft-storey is not affected more in lateral load distribution and torsional moment. In Model-4, which has soft-storey at upper storey, its lateral load and torsional moment in the upper storeys will be a little more than other models.

2. Comparing of Displacement and Storey Drift:



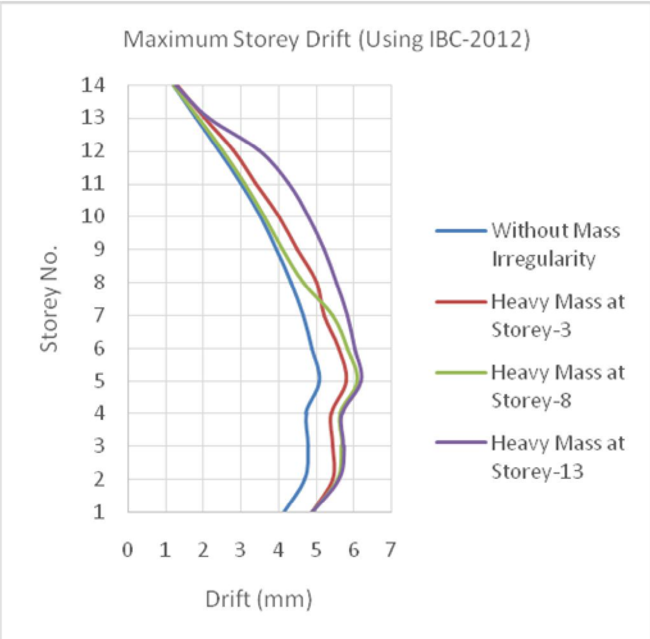
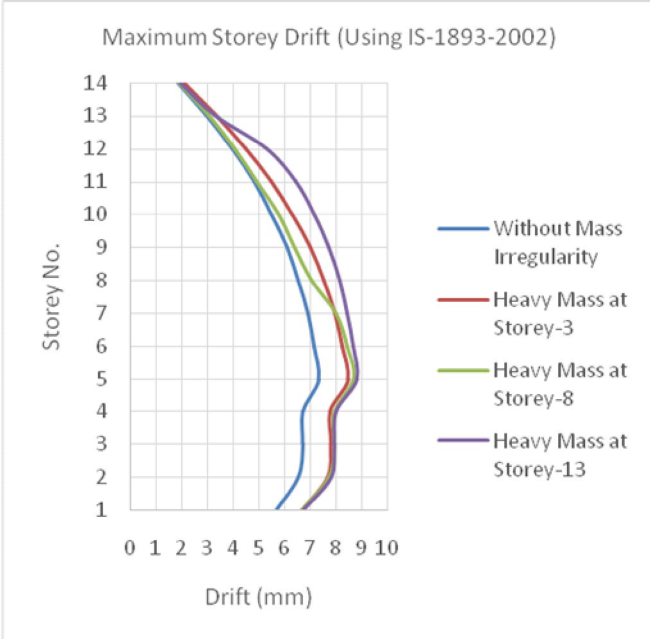


Fig. 8 Maximum Displacement at Floor Level



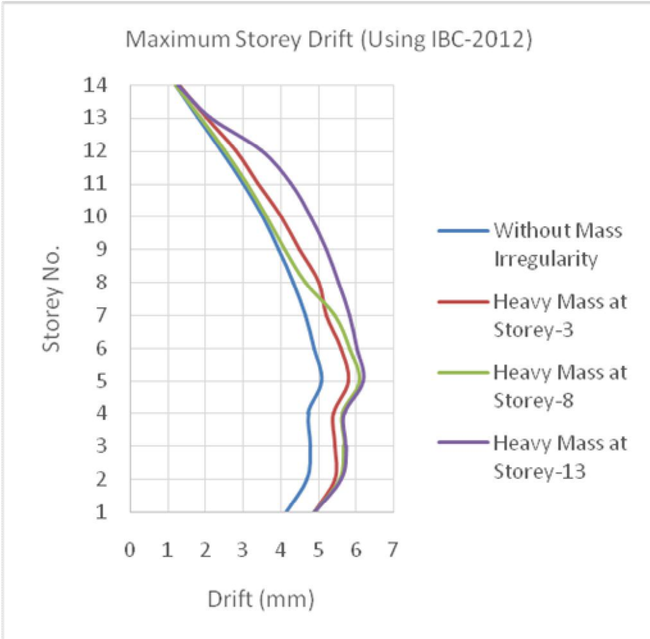


Fig. 9 Maximum Storey Drift

From the Fig. 8 its cleared, that maximum displacement of Model-4 having heavy mass at upper storey is so much more than models having heavy mass at medium or lower storeys. Generally, all three models having mass irregularities displacement is increased as compared to the model without mass irregularities. The displacement as per IS-1893-2002 is higher as compared to IBC-2012.

The storey drift of the models having mass irregularities is much higher as compared to the model without mass irregularities. The Model-4, having heavy mass at upper storey (Storey-13), its storey drift is higher than models having heavy mass at lower storeys (Storey-8 or Storey-3) and the increasing of storey drift due to mass irregularities in lower storeys is more than upper storeys for all three models. The storey drift in case of using IS-1893-2002 is more than using IBC-2012 code (see Fig. 9).

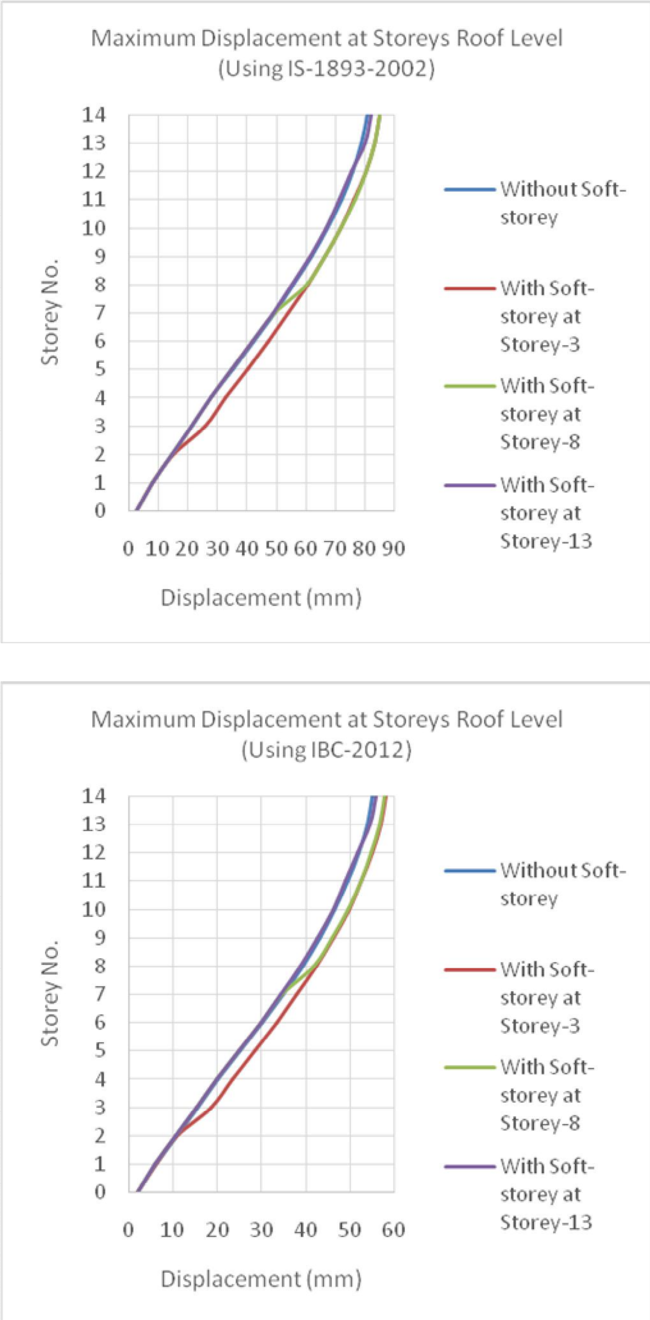


Fig. 10 Maximum Displacement at Storey Roof Level

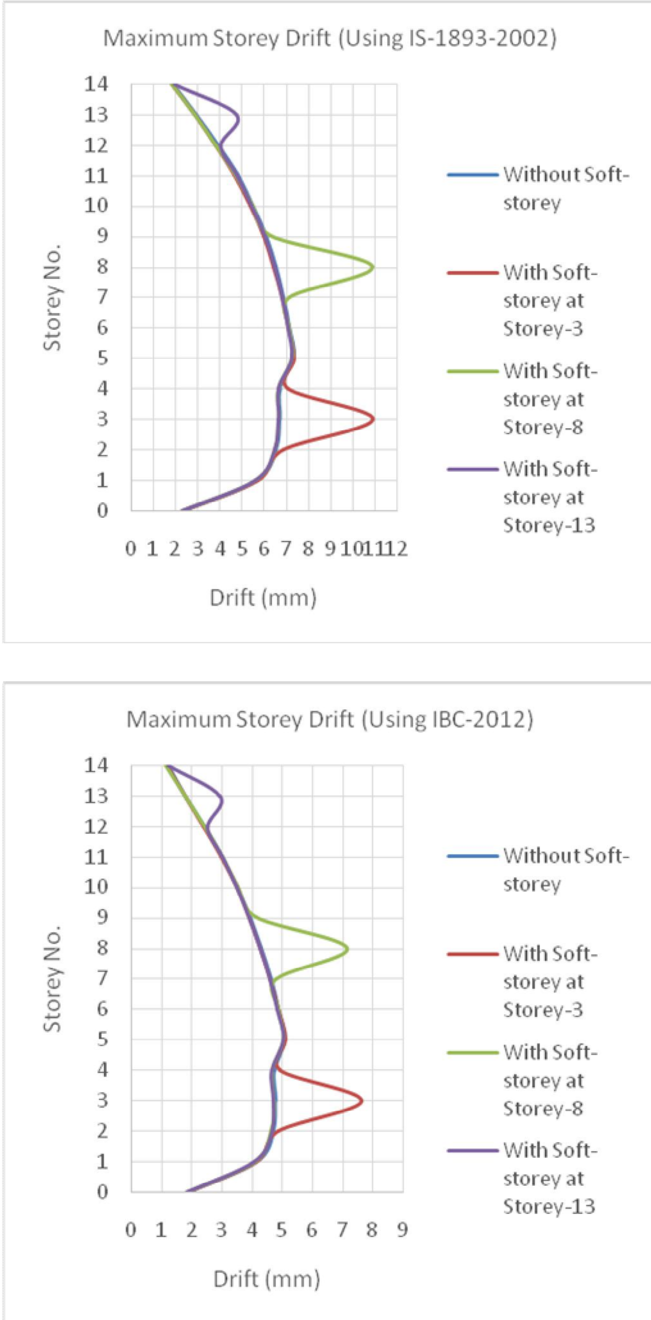


Fig. 11 Maximum Storey Drift

From the Fig. 10, it is cleared, that maximum displacement at top floor for Model-2 & Model-3 having soft-storey at Storey-3 and Storey-8 respectively, is equal. Displacement of Model-4 which have soft storey at Storey-13 is lesser than Model-2 and Model-3 and its displacement is about equal to the model without irregularities (Model-1) up to soft-storey, but for soft-storey it is a little increased.The displacement as per IS-1893-2002 is higher as compared to IBC-2012.

From Fig.11 above, it is observed, that three models having soft-storey, the storey drift of soft-storeys is increased suddenly as compared to the model without soft-storey. Generally, due to soft-storey the drift of soft-storey and adjacent storeys is increased, but the drift of other storeys is decreased. Also from this figure it is cleared, the soft-storey drift of models having soft-storey at lower part of the building is higher as compared to model (Model-4) having soft-storey at upper part of the building.The storey drift in case of using IS-1893-2002 is more than using IBC-2012 code.

IV. CONCLUSION

In this study, G+13 storey RC building has been selected for dynamic analysis. The selected building has been analyzed with two type irregularities (mass & stiffness irregularities). In first case the heavy mass was added to the building at three different locations along the height of building. Four models were prepared, Model-1 was without mass irregularities, Model-2 had heavy mass at second floor (Storey-3), Model-3 had heavy mass at 7th floor (Storey-8) and Model-4 had heavy mass at 12th floor (Storey-13) and in second case for the same selected building, stiffness irregularities were considered at three different locations along the height of building. Four models were prepared, Model-1 was without stiffness irregularities, Model-2 had soft-storey at second floor (Storey-3), Model-3 had soft-storey at 7th floor (Storey-8) and Model-4 had soft-storey at 12th floor (Storey-13). The analysis has been done by Time History Analysis Method using both (IS-1893-2002 & IBC-2012) codes. The results of the analysis are concluded as under:

1. Based on the results, the location of heavy mass at upper storeys of building is affected more on performance of building, because lateral load and torsional moment in the upper storeys are much higher and displacement & storey drift are also higher in this case.
2. From result, it is cleared, that location of soft-storey at upper storeys of building is better than that located at lower storeys of the building and soft-storey effects on building at upper storeys are lesser. Because the displacements in this case are less, the storey drift of soft-storey is reduced significantly and lateral load and torsional moment are not considerably changed.
3. In case of soft-storey the storey drift is increased suddenly in soft-storey, but in case of heavy mass the storey drifts are increased for all storeys. Therefore, the effects stiffness irregularities are larger than mass irregularities.
4. Displacement, storey drift, moments and shear forces in beams, axial force and moments in columns, support reactions in results of using IS-1893-2002 are increased when it is compared with results of using IBC-2012 code. IS-1893-2002 is conservative as compared IBC-2012.
5. The using of IS-1893-2002 code is simple, someone can easily understand and does not need more calculation, but IBC-2012 code is more complicated and needs more study and calculation.

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