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LATERAL STIFFNESS OF FRAMED STRUCTURES FOR LATERAL LOADS

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Abstract - *In the last few years the awareness about the importance of the building's regularity and non-structural damage prevention for frame systems located in seismic areas has grown significantly, especially after the observation of disastrous effects of seismic events. During the pilot design of an RC building located in a seismic zone, having a swift but dependable analytical measurement of storey stiffness is helpful in order to check the fulfilment of damage limit state and stiffness regularity in elevation required by seismic design codes. Most of the seismic codes have provisions to prevent stiffness irregularities in structures, but none of them has proposed the method to calculate the storey stiffness. Most of the research on stiffness has been focused on approximate methods and accurate methods have been studied less. Comparison of different approximate methods to calculate the stiffness of storey shows that the results lead to a good approximation when the structure is close to the shear model, but the results are different when the structure is close to the flexural model. Thus, to evaluate the method to calculate storey stiffness which is closer to reality and easy for engineers to compute a detailed study is proposed. This proposed study presents various accurate methods, to calculate the stiffness of a storey by using FEM models using analytical Software.*

Key Words: **Storey stiffness; Soft storey; Calculation methods; Earthquake; Seismic codes**

1. INTRODUCTION

In the last few years, the awareness about the importance of the buildings regularity and nonstructural damage prevention for frame systems located in seismic areas has grown significantly, especially after the observation of disastrous effects of seismic events. Therefore, the most recent building codes (e.g. I.S. 1893: 2016 [12], ASCE 7-10 [6], NZS 1170.5 (New Zealand Standard) [17], and Standard No.2800 (Iranian standard) [21], discourage design of irregular buildings by not allowing the engineers to embrace some simplifications in relations of structural model and analysis technique, generally valid for regular structures. Moreover, they impose larger magnitudes of lateral forces, compared to regular frame, through imposing a penalizing value of so-called 'behaviour factor' commonly used for linear analyses.

Tabeshpour and Noorifard (2016) [14] have focused on calculating storey stiffness by accurate methods using analytical software. Their paper includes four common methods in the professional society of civil engineers and two proposed ones for accurate calculation of storey stiffness.

After defining the material and section properties, boundary conditions and assigning the loads at the appropriate points depending on the method under consideration, we perform the analysis of the frames in order to get the displacements of individual storeys from which the storey drifts are calculated. The storey drift is the difference of storey displacements of adjacent storeys. And from the storey drifts, the stiffness for each storey is calculated using the relation of

$$\mathbf{F = K.\Delta.} \qquad (1)$$

Where **F** is the applied lateral force, **K** is the storey stiffness and **Δ** is the storey drift obtained.

1.1 Scope

Having a large probability of occurrence during the life-cycle of a building, the most recent earthquake resistant design codes emphasize the importance of limiting damage under low to medium intensity seismic events. Owing to the fact that probable damage derives from frame displacements, limiting inter-storey drifts leads to limit expected losses.

Besides the structural issues, non-structural components of buildings also play a significant role in performance-based earthquake engineering, especially in the case of critical facilities that provide vital emergency assistance to the communities when earthquakes happen.

Thus, new codes emphasize the importance of limiting non-structural damage through limiting inter-storey drifts at given values, depending on the non-structural element's features and on the way, they interact with structural deformations.

The stiffness regularity in elevation, defined as a continuous variation of the storey stiffness along with the height of the building without abrupt changes, reduces the likelihood of dangerous concentrations of plastic deformations in a few (more flexible) stories. One of the most common vertical structural irregularities is due to a large open space or car-parking (with fewer partition walls than the upper stories) located at the bottom of the building.

The earthquake energy concentrates on highly demanded columns and walls at the more flexible stories where, as a consequence, the mechanism known as 'soft-storey' or 'weak-storey' may develop.

International codes define the vertical stiffness regularity based on the percentage variation between the lateral stiffness of two adjacent stories. For example, according to the I.S. 1893: 2002 [11], soft-story is a condition of vertical regularity, where the lateral stiffness of each storey is less than 70% of that in the storey above or less than 80% of the typical stiffness of the three storeys above. Though latest revision of I.S. 1893: 2002 defines a soft-storey as a storey whose lateral stiffness if less than the storey above.

Most of the research on stiffness has been focused on approximate methods and accurate methods have been studied less. So, it is important to know the answers for the following three questions –

1. Which methods are used to calculate the storey stiffness?
2. Which calculation method of storey stiffness is closer to reality?
3. Which calculation method of storey stiffness is more accurate and much easier for a structural designer?

1.2 Objective

The proposed study will include the study of the definition of stiffness and lateral stiffness, calculation of stiffness of the frame.

Further, as the main scope, the proposed study will explore the comparative study of accurate methods to evaluate lateral inter-storey drifts and stiffnesses during the preliminary design of a given RC frame structure.

2. METHODOLOGGY

A G+3 reinforced concrete framed structure is considered. Then position beam, columns, and slabs were decided to form a structural layout. The model was analyzed using analytical software.

Assumptions made for the analytical model are as follows:
For beams, columns, foundation M30 grade concrete will be used and HYSD (Fe 415) grade steel will be used. For slabs, Staircases M20 grade concrete along with HYSD (Fe 415) grade steel will be used.

The height of the structure is 18.8m, floor to floor height is 4.5 m, width is 58.11m, the length is 37.37m and the total Built-up Area: 1985.92 square meters.

Design codes and standards applied belong to

1. IS 456-2000 "Code of practice for Plain and Reinforced Concrete"
2. IS 875-Part 1 "Unit weights of materials"
3. IS 875-part 2 "Design loads for building and structure".

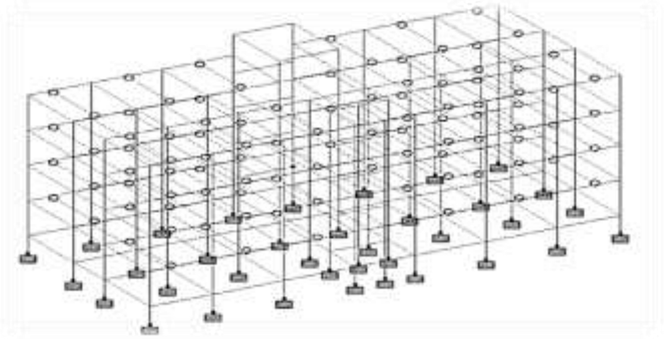

Fig -1: Analysis performed on the model using analytical software

2.1 Design of structural elements

The results obtained from the analysis of structure were utilized to find out the critical sections. The design of the structure was prepared manually using limit state method of reinforced concrete design referring to IS 456:2000. The slabs of all floors were designed as continuous slabs one-way and two-way wherever required as specified in structural layout.

The design of the staircase is done as dog-legged staircase providing equal numbers for risers on both flights. Primary beams were designed for both sagging and hogging moments developed at mid-span and near-end supports. Secondary beams were designed as simply supported for avoiding torsion induction in the primary beams at their ends.
Columns were designed and checked for biaxial bending including the ultimate load.

Isolated pad footings were provided assuming the hard rock strata and depth of foundations as 800KN/m^2 and 2.5 m

2.2 Stiffness Calculation

Finite Element based, Models of 2D, RC Bare Frames were prepared out of the framed structure modelled and designed using analytical software. The models have variables in the form of the number of bays, the number of storeys, modulus of elasticity of frame members and support of frame members. Thus, two model frames were analyzed using 6 different methods and 4 different load intensities thus a total of 48 different models were analyzed for the study.

The frame was given the section properties as per the design obtained by manual calculation.
For the first analysis frame along XX and YY direction are considered and the following methods are applied to get the results.

The deflection obtained in each case is calculated. The total stiffness of Frame is calculated by using the stiffness equation. $F = K.\Delta$

Linear Static Analysis is proposed for various 6 load application modules.

Module A - Force is applied to the centre of mass of the last storey and by calculating the drift of any storey, the stiffness of that storey is obtained.

Module B - The force is applied to the centre of the rigidity of each storey individually and by calculating the drift of that storey, the storey stiffness is obtained.

Module C - The force is applied to the centre of the rigidity of considered storey and equal force in the opposite direction is applied to the centre of the rigidity of lower storey. By calculating the drift of considered storey, the storey stiffness will be obtained

Module D- Here pinned supports are added to the upper and lower storey of considered one to eliminate the horizontal displacement and the force is applied to the centre of the rigidity of considered storey. By calculating the drift of the storey, the total stiffness of two adjacent storeys is calculated. The stiffness of the last storey is just for one storey, by subtracting the stiffness of upper storey respectively, the stiffness of each storey is obtained

Module E - The forces with a triangular distribution similar to seismic force distribution are applied to the centre of mass of all storeys and by calculating the drift of any storey, the stiffness of that storey is obtained.

Module F - All the storeys which are located above the considered storey are deleted and the bottom of columns is constrained. By applying the force to the centre of the rigidity of considered storey, storey stiffness will be calculated.

3. RESULTS AND OBSERVATION

The graphs of storey stiffness versus the storey level were plotted to understand the variation of the stiffness along with the total height of the structure under consideration

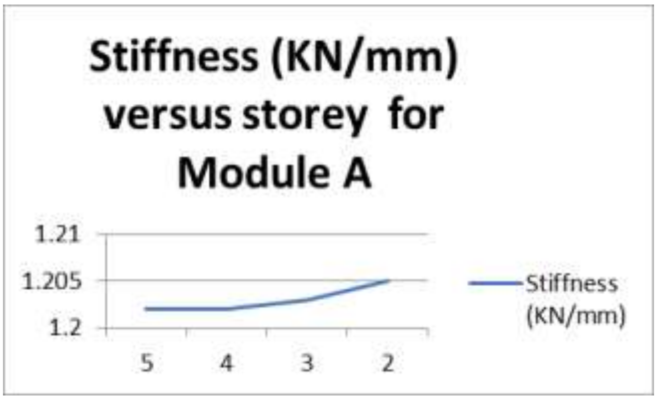

Chart -1: Stiffness plot for Module A

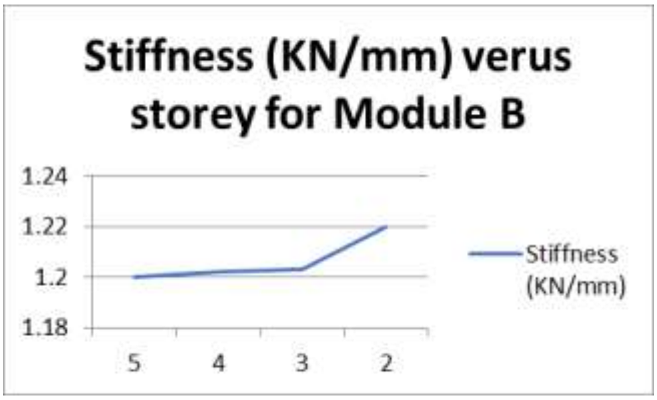

Chart -2: Stiffness plot for Module B

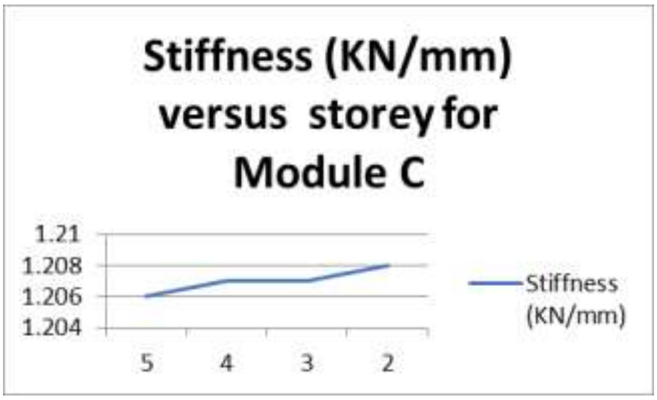

Chart -3: Stiffness plot for Module C

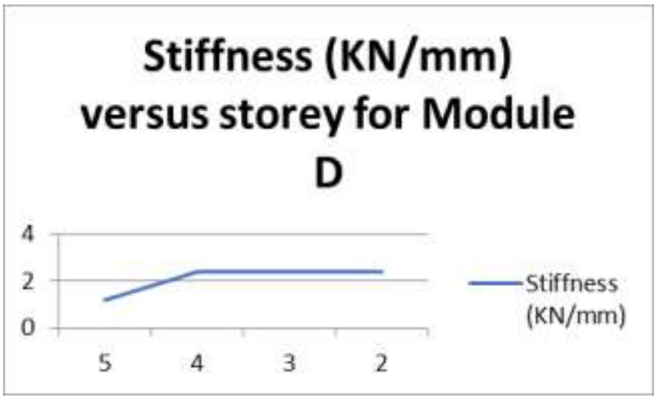

Chart -4: Stiffness plot for Module D

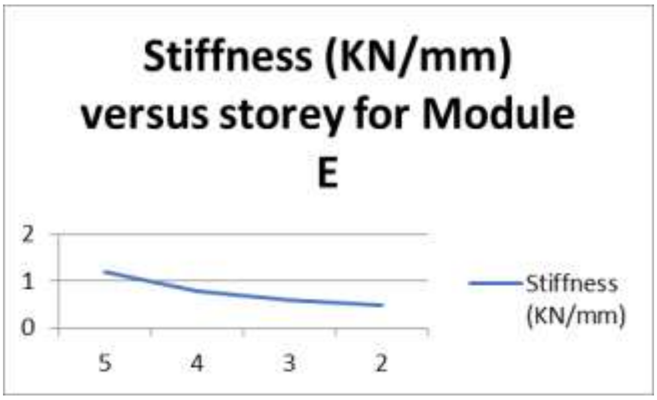

Chart -5: Stiffness plot for Module E

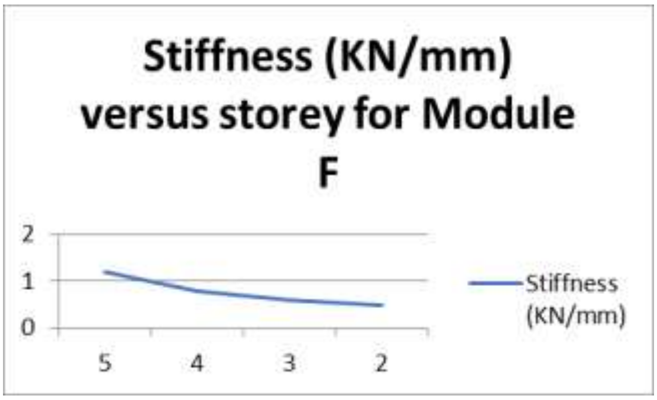

Chart -6: Stiffness plot for Module F

4. CONCLUSION

The results showed that all the investigated methods for assessing storey stiffness led to a good approximation when the frame is closer to a shear type. Divergent results have been obtained from different methods as the frame approaches the flexural type. Out of which 3rd and 5th are close to reality. Using the analysis one can find the lateral stiffness of a frame and structure as it is mentioned to be calculated in almost every design code. It is suggested that the stiffness variations in the structure are to avoided as far as lateral forces such as earthquake forces are concerned. The stiffness of frame plays an important role in limiting the deflections of the structure resulting in a way to judge the serviceability requirements of a structure.

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