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ESTIMATION OF STOREY STIFFNESS IN MULTI-STOREY BUILDINGS

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Abstract

Presence of stiffness irregularity, in conjuncture with strength irregularity, along building height leads to undesirable behavior during severe earthquake shaking, including localization of lateral deformations in select stories and initiation of storey collapse mechanism. Thus, seismic design codes recommend simple quantitative check using storey stiffness, to identify presence of stiffness irregularity along building height. This requires estimate of lateral stiffness of each storey along the height of the building, but the procedure to estimate the same is not specified in design codes. Consequently, in practice, several methods are used to estimate storey stiffness. In theory, there exists a unique value of stiffness of a given storey in a multi-storey building, but estimates using different methods give different results; the difference arise due to the inherent assumptions in the methods. Therefore, there is a need to compare and ascertain a method using which storey stiffness can be estimated with adequate accuracy. Storey stiffness estimates from seven available methods are compared, and their strengths and limitations discussed. A method involving use of fundamental natural mode of oscillation of structure seems to be most accurate, as it does not entails any simplifying assumption.

Keywords: Irregularity; Mode; Soft Storey; Vertical; Code

1. Introduction

Dynamic behavior of multi-storey building depends on two fundamental characteristics, namely seismic mass and stiffness. Traditionally, design lateral force on buildings ($V=ms_a=ks_d$) is estimated using seismic mass (m), because estimating seismic mass is relatively easier than estimating lateral translational stiffness (k); where, s_a and s_d are spectral acceleration and spectral displacement, respectively. Still, it is important to estimate lateral translational stiffness of each storey (storey stiffness) to ascertain presence of stiffness irregularity (if any) along the height of multi-storey buildings to minimize undesirable behavior, particularly during strong earthquake shaking.

Lateral translational stiffness irregularity along the height of multi-storied buildings can arise due to choice of structural configurations, including (i) discontinuity in lateral load resisting system, (ii) sudden change in size and length of structural members, and (iii) irregular distribution of un-reinforced masonry (URM) infill walls. In buildings meant to resist strong earthquake shaking, storeys with abruptly smaller stiffness, in conjuncture with weak storey strength, (a) attract large rotational demands on their flexural members [1], (b) result in decrease in deformation and energy dissipation capacities of buildings [2], and (c) increase likelihood to form undesirable collapse mechanism [3-4]. To minimize the damaging effects of stiffness irregularity, current seismic design codes categories storey as *acceptable*, *soft* or *extremely soft* depending on the change in stiffness of the storey relative to its adjoining upper storeys [5-7]. A storey is categorized *soft*, if lateral translational stiffness (K_i) of the considered storey is (a) less than 70% of that (K_{i+1}) of the storey immediately above it, i.e.,

$$\left[\frac{K_i}{K_{i+1}}\right] \leq 0.7 \text{ ; or} \tag{1}$$

(b) less than 80% of the average of those (K_{i+1}, K_{i+2}, and K_{i+3}) of 3 storeys immediately above it, i.e.,

$$\left[\frac{3K_i}{K_{i+1}+K_{i+2}+K_{i+3}}\right] \leq 0.8 . \tag{2}$$

Similarly, a storey is categorized as *extreme soft storey*, if lateral translational stiffness (K_i) of the considered storey is (a) less than 60% of that (K_{i+1}) of the storey immediately above it; or, (b) less than 70% of the average of those (K_{i+1}, K_{i+2}, and K_{i+3}) of 3 storeys immediately above it. Upon determining the category of each storey of the building, seismic deign codes recommend subsequent course of action, including increase in the design lateral force and/or improve the analysis to estimate design lateral force.

Thus, it is clear that estimates of stiffnesses of all storeys in a multi-storey building are essential for assessing stiffness irregularity (Eqs. 1-2). But, current seismic design codes do not recommend any specific method to estimate storey stiffness. Hence, designers choose any one of the several methods available to estimate the same. Therefore, comparison of strengths and limitations of commonly used methods are presented in this study, to aid designers to choose a method using which storey stiffness are estimated accurately.

2. Storey Stiffness

Presented in this section is a brief overview of seven methods that are available in literature, with their inherent assumptions, to estimate storey stiffness along the height of multi-storey buildings. Of the seven methods presented, the first three methods use simple closed-form equations, while the last four methods use results from linear elastic structural analyses, to estimate lateral translational stiffness of each storey in a multi-storey building. Further, the first three methods are applicable for buildings with moment frames as sole lateral load resisting system. Although the first three methods are seldom used in practice, it still presents a valid method to estimate storey stiffness. Hence, they are considered for the purpose of comparison in this paper.

2.1 Sub-Assemblage Method

This is one of the earliest methods to estimate storey stiffness in a multi-storey building [8]. In this method, all columns and beams in a storey are considered to resist equal magnitude of shear force and rotations (at both ends), respectively. In addition, this method does not differentiate between interior and exterior columns because it considers the frame to be a part of infinite array of members (Fig. 1). Therefore, the number of beams framing into the exterior column at top and bottom are assumed the same as that for interior columns. Thus, using these simplifying assumptions this method recommends storey stiffness (K_s) as the summation of lateral translational stiffness of individual columns present in the storey under consideration. The lateral translational stiffness of each column is estimated using slope-deflection equations and moment equilibrium of column sub-assemblage comprised of individual column and beams framing into the column at top and bottom (Fig 1). Thus, storey stiffness for any intermediate storey in a multi-storey building is given as,

$$K_s = \sum\left[\left(\frac{12E\,I_c}{H^3}\right)\left(\frac{\sum K_{bt} + \sum K_{bb}}{4K_c + \sum K_{bt} + \sum K_{bb}}\right)\right], \tag{3}$$

where, K_{bt} ($=I_{bt}/L$) and K_{bb} ($=I_{bb}/L$) are the flexural stiffness of the beams framing into columns at top and bottom of a storey, respectively, and K_c ($=I_c/H$) the flexural stiffness of the column; $E, I_c, I_{bt}, I_{bb}, L, H$ are the modulus of elasticity of concrete, second moment of area of columns, second moment of area of beam framing into the column at top, second moment of area of beam framing into the column at bottom, length of the beam and height of storey, respectively. Eq. (3) is applicable for all storeys except first storey, where there is a need to account for the effects of base fixity. Hence, an alternate equation to estimate storey stiffness of frames with fixed base is given as,

$$K_s = \sum\left[\left(\frac{12E_cI_c}{H^3}\right)\left(\frac{K_c + \sum K_{bt}}{4K_c + \sum K_{bt}}\right)\right], \tag{4}$$

where, all terms are same as defined in Eq. (3). Eq. (4) is determined considering the point of inflection at two-third the height of column measured from its base. Although this method presents simple closed form equation to estimate storey stiffness, considered assumptions, while deriving the same, may not be valid for all building; thus, the estimate of storey stiffness may not be accurate.

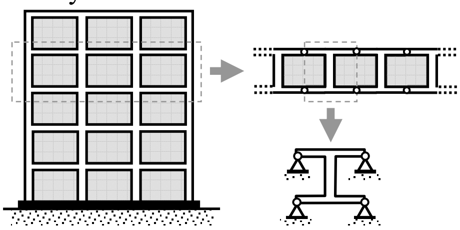


Fig. 1 – Each storey is composed of discrete beam-column sub-assemblages.

2.2 Storey Frame Method

In this method, each frame is first discretized into individual storeys and later into multiple interior and exterior sub-assemblages as shown in Fig. 2 [9]. As beams are considered common feature between two adjoining storeys, only one-half the second moment of area of the beam ($I_b/2$) is considered for the estimate of storey stiffness of each storey. By considering the point of inflection for beams and columns at mid length, each individual storey is discretized further into multiple interior and exterior sub-assemblages (as shown in Fig. 2). Lateral stiffness of each sub-assemblage is estimated using equilibrium equation after eliminating rotational degree of freedom by static condensation. Thus, storey stiffness is estimated as the combined lateral stiffness of each sub-assemblages present in a storey of a multi-storey building. If the difference between the interior and exterior column is ignored, the combined stiffness of all sub-assemblages present in a storey (or, storey stiffness) is given as,

$$K_s = \left(\frac{24}{H^2}\right)\left(\frac{1+C_s}{\frac{2}{\sum K_c} + \frac{1}{\eta_t \sum K_{bt}} + \frac{1}{\eta_b \sum K_{bb}}}\right) \tag{5}$$

where, K_{bt} (=EI_{bt}/L) and K_{bb} (=EI_{bb}/L) are the flexural stiffness of the beams framing into columns at top and bottom of a storey, respectively, and K_c (=EI_c/H) the flexural stiffness of the column; $E, I_c, I_{bt}, I_{bb}, L, H$ are as defined in Eq. (3); C_s is empirically determined correction factor that accounts for change in storey stiffness due to base fixity and discontinuity of members at top storey; and η_i is the correction factor that accounts for change in storey stiffness due to change in storey height of adjacent storeys. Like the previous method, closed form equation outlined in this study considers assumptions and empirical equations (correction factor, η_i) while may not be valid for all building; thus, the estimate of storey stiffness may not be accurate.

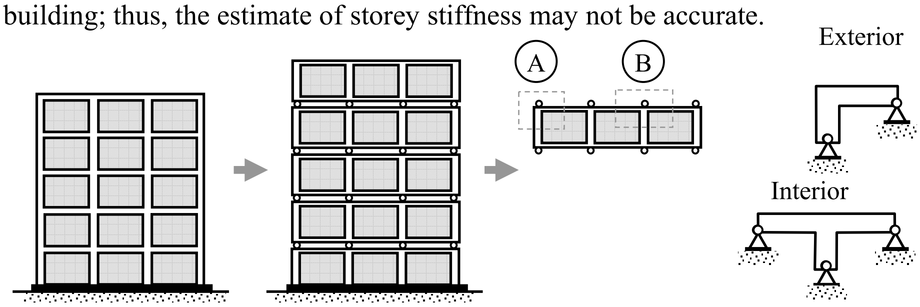


Fig. 2 – (a) Discretization of each storey from a frame and (b) Discretization each storey into interior and exterior sub-assemblages

2.3 Box Frame Method

In this method, storey stiffness is estimated using a representative one-bay one-storey frame which encompasses the combined stiffness of beams and column present in any particular storey of a individual frame as shown in Fig. 3 [10]. The stiffness of each column of the representative frame is one-half of the combined stiffness of all columns present in the particular storey (Fig. 3). Likewise, the stiffness of top beam and bottom beam of the representative frame is the cumulative flexural stiffness of the beams present at the top and bottom of the storey, respectively. Thus, storey stiffness of an equivalent frame of height H and bay length L is given as,

$$K_s = \left(\frac{12K_c}{H^2}\right)\left(\frac{K_c(K_{bb}+K_{bt})+6K_{bt}K_{bb}}{K_c^2+2K_c(K_{bb}+K_{bt})+3K_{bt}K_{bb}}\right) \tag{6}$$

where, K_c, K_{bt}, K_{bb}, and H are as defined in Eq. (5). Storey stiffness of the first storey of multi-storey building is estimated considering a very high value of K_{bb}. Unlike, the previous methods (2.1 and 2.2) this method does not recommend any correction factor to account for change in the storey stiffness due to base fixity and discontinuity of members at top storey. But, like the previous methods this procedure considers assumptions which may not be valid for all buildings; thus, the estimate of storey stiffness may not be accurate.

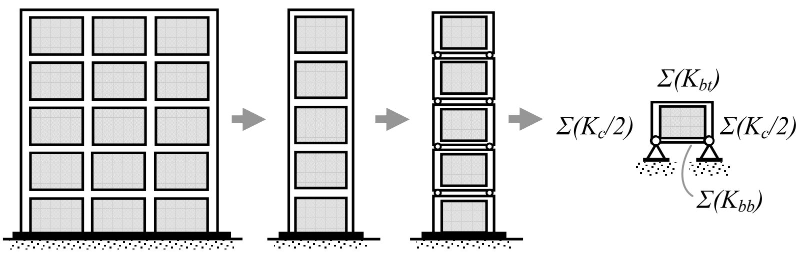


Fig. 3 – Discretization of a frame into multiple one-bay one-storey frame

2.4 Equivalent Stiffness Method

This method considers an n-storey frame composed of n lateral translational springs connected in series (Fig. 4). The stiffness of storey i is given by the lateral translational stiffness of the spring present in storey i. Lateral translational stiffness of first storey (i.e., first storey stiffness) is estimated as the lateral force that results in unit lateral translational deformation in that storey (Fig. 4). Lateral translational stiffness of all storey, except first storey, is estimated using equivalent storey stiffness ($K_{i,eq}$) and storey stiffness of all storeys below the considered storey and is given as,

$$K_i = \frac{1}{\left(\frac{1}{K_{i,eq}}\right) - \left(\sum_{j=1}^{j=(i-1)} \frac{1}{K_j}\right)} \tag{7}$$

where, K_i and $K_{i,eq}$ represents the stiffness of storey i and equivalent stiffness of all storey below storey i. Equivalent storey stiffness of a storey ($K_{i,eq}$) is estimated as the lateral force that results in unit lateral translational deformation in that storey (Fig. 4). Thus, this method requires n-additional analyses to estimate storey stiffness of an n-storey building. Hence, this method is considered cumbersome and time consuming.

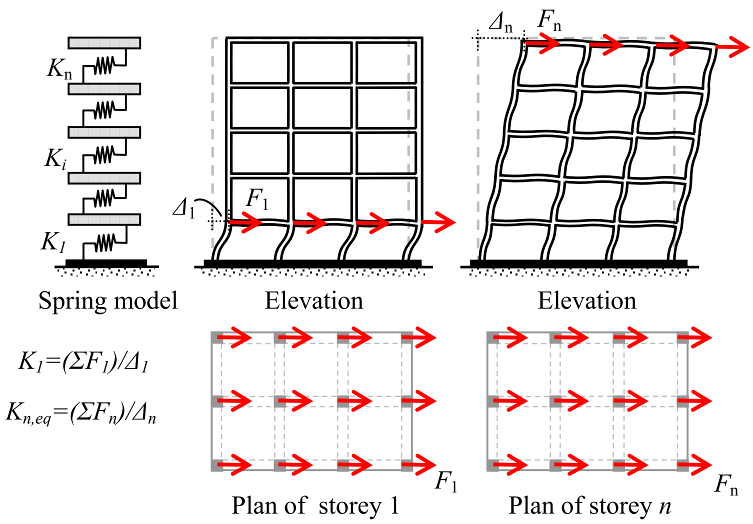


Fig. 4 – Idealized spring model of the building; method to estimate stiffness of first storey and equivalent stiffness of storey n

2.5 Single Storey Method

In this method, storey stiffness is estimated as the lateral force producing unit translational lateral deformation in that storey, with the bottom of the storey restrained from moving laterally, *i.e.*, only translational motion of the bottom of the storey is restrained while it is free to rotate. (Fig. 5) [2]. Like previous method (Equivalent stiffness method), this method requires n-additional analyses to estimate storey stiffness of an n-storey building. Hence, this method is also considered cumbersome and time consuming.

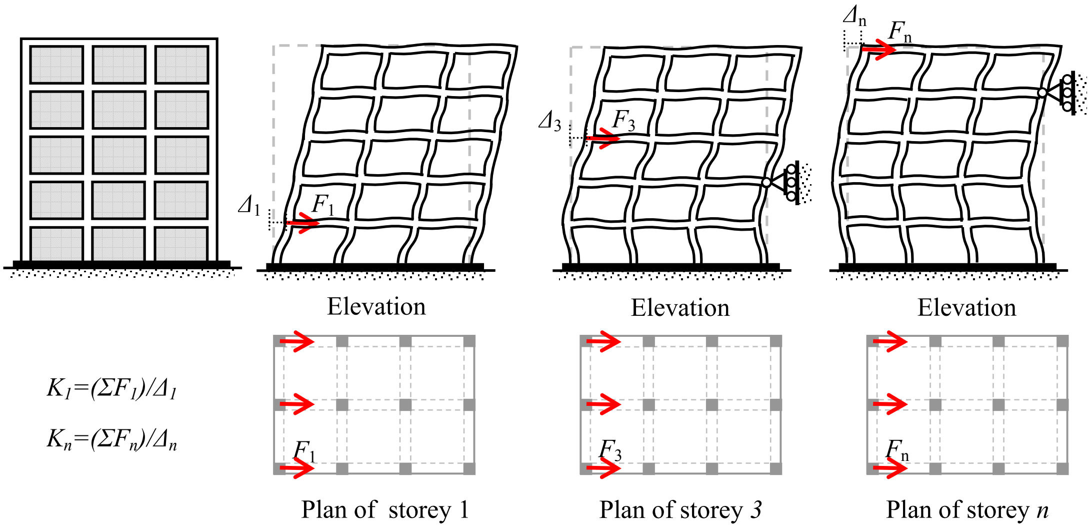


Fig. 5 – Method to evaluate storey stiffness of storey one, an intermediate storey, and top storey

2.6 Lateral Force-Deformation Method

In this method, results of structural analysis of building subjected to design earthquake loads are used to estimate storey stiffness as the ratio of cumulative storey shear force to the inter-storey lateral displacement (Fig. 6) [11]. This method does not require designer to perform additional analyses, other than that performed during analysis and design process, to estimate storey stiffness thereby saving considerable time and effort. But, the estimate of storey stiffness varies with the considered distribution of design lateral force along the height of the building [11].

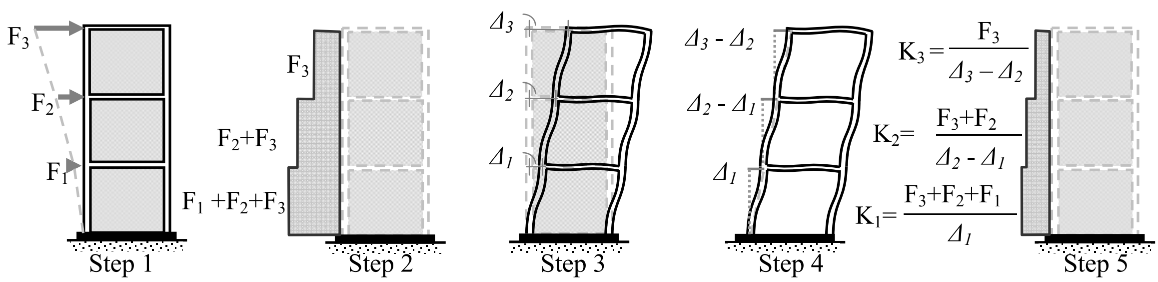


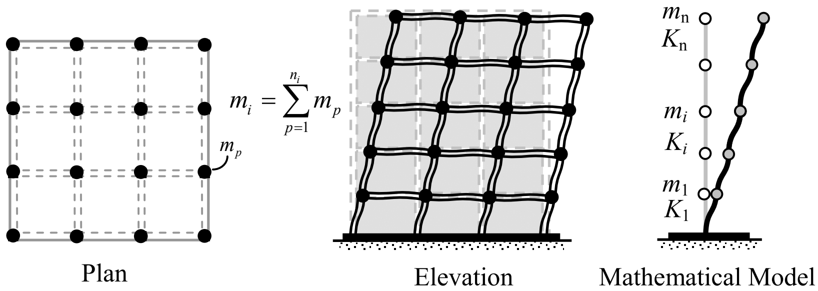
Fig. 6 – Method to Estimate of Lateral Storey Stiffness (adapted from [11])

2.7 Fundamental Lateral Translational Mode Shape Method

In this method, storey stiffness is estimated using seismic mass present at all storey levels and results of modal analysis of the building, namely the fundamental natural period and its associated mode shape. Like the previous method (lateral force-deformation method) this method does not require any additional structural analyses to be performed, as all required information is readily available during the analysis and design process of the building. By idealizing the building as a equivalent shear beam mathematical model (Fig. 7), this method presents a simplified closed form equation to estimate storey stiffness and is given as,

$$\{K_1;\ \ldots;\ K_{n-1}\ ;\ K_n\}^T = \left\{ \left[\frac{\omega^2 \sum_{i=1}^{n} m_i \phi_i}{\phi_1} \right];\ \ldots;\ \left[\frac{\omega^2 \sum_{i=n-1}^{n} m_i \phi_i}{\phi_{n-1} - \phi_{n-2}} \right];\ \left[\frac{\omega^2 m_n \phi_n}{\phi_n - \phi_{n-1}} \right] \right\}^T \tag{8}$$

where, K_i and m_i are the lateral translational stiffness and lumped seismic mass of storey i, respectively; $\{\varphi\}$ and ω are the fundamental lateral translational mode shape and fundamental lateral translational circular frequency, respectively. Since, this method uses dynamic characteristics (fundamental circular frequency ω and lateral translational mode shape ϕ) of the building along with storey mass m_i, the estimate of storey stiffness K_i determined using Eq. (8) is unique and does not change with the choice of input, such as distribution of lateral force as in the previous method. Further, storey stiffness of 3D buildings, along each principal direction, is estimated independently using corresponding lateral translational circular frequency ω, associated mode shape $\{\varphi\}$ and seismic storey mass m_i in each principal direction.



K_i : Lateral translational stiffness of storey i ;
m_p: Seismic mass lumped at each node p of storey i;
m_i : Seismic mass of storey i

Fig. 7 – (a) Numerical model plan, and (b) mathematical model

3. Strengths and Limitations

Listed in Table 1 are the strengths and limitations of the considered methods to estimate storey stiffness. Fundamental lateral translational mode shape method utilizes dynamic characteristics of the building to estimate storey stiffness. Consequently, the estimate of storey stiffness determined using this method could be closest to the actual value of storey stiffness. In addition, this method does not entail any simplifying assumption nor require results of additional analyses, other than that readily available at the end of analysis and design process, to estimate storey stiffness.

Table 1 – Strengths and limitations of different method to estimate storey stiffness

<table>
<tr><th>No.</th><th>Method</th><th>Strengths</th><th>Limitations</th></tr>
<tr><td>1.</td><td>Sub-Assemblage Method</td><td rowspan="3">1. Easy to estimate using closed form equations
2. Does not require results of structural analyses</td><td>1. Applicable for MRF with first storey column fixed at its base and NOT for Braced MRF and MRF with Structural walls
2. Considers ONLY flexural deformation
3. Effect of change in storey stiffness due to discontinuity of members at top storey not considered</td></tr>
<tr><td>2.</td><td>Storey Frame Method</td><td>1. Applicable for MRF with first storey column fixed at its base and NOT for Braced MRF and MRF with Structural Wall
2. Considers ONLY flexural deformation</td></tr>
<tr><td>3.</td><td>Box Frame Method</td><td>1. Applicable for MRF with first storey column fixed at its base and NOT for Braced MRF or MRF with Structural Wall
2. Considers ONLY flexural deformation
3. Does not specify correction factor for change in storey stiffness due to discontinuity of members at top storey</td></tr>
<tr><td>4.</td><td>Equivalent Stiffness Method</td><td rowspan="2">1. Applicable for all LLRS with any base fixity condition
2. Considers flexural, shear and axial deformation
3. Can considers flexibility of beam-column joint</td><td rowspan="2">1. Requires n-structural analysis to be performed which are not part of analysis and design process</td></tr>
<tr><td>5.</td><td>Single Storey Method</td></tr>
<tr><td>6.</td><td>Lateral Force-deformation Method</td><td>1. Applicable for all LLRS with any base fixity condition
2. Considers flexural, shear and axial deformation
3. Requires results of structural analysis; but, they are readily available at the end of analysis and design process
4. Can considers flexibility of beam-column joint</td><td>1. Estimate of storey stiffness varies with the assumed distribution of lateral force profile along the height of the building</td></tr>
<tr><td>7.</td><td>Fundamental Lateral Translational Mode Shape Method</td><td>1. Applicable for all LLRS with any base fixity condition
2. Considers flexural, shear and axial deformation
3. Requires results of structural analysis; but, they are readily available at the end of analysis and design process
4. Can considers flexibility of beam-column joint
5. Estimate of storey stiffness is based on dynamic characteristics of the building, and not on the distribution of lateral force profile</td><td>–</td></tr>
</table>

4. Numerical Study

In this section, estimates are presented for storey stiffness, of each storey of five (10-storey) RC study buildings, along with assessment of stiffness irregularity along the height of each study building (Fig. 8). Building A, regular in both plan and elevation, is considered as the benchmark building. Buildings B and D have flexible first storey arising from taller first storey column and distribution of masonry infill, respectively. Building C has a flexible seventh storey due to discontinuity of interior columns to facilitate column free space. And, Building E presents a viable solution, using RC structural wall as LLRS, to mitigate detrimental effects of stiffness irregularity stemming from distribution of masonry infill, as otherwise present in Building D. All buildings have four and three 6*m* long bays in each principle plan (X and Y) directions, respectively. All buildings have a uniform storey height of 4*m*, except first storey of building B, which is 6*m* tall. Columns present in first storey of all buildings are fixed at their base. Uniform size of beams (400*mm* × 600*mm*) and columns (600*mm* × 600*mm*) are assumed for all building, except columns present in first storey of building B (700*mm* × 700*mm*). Bare frames are considered for structural analysis of all buildings, except building D and E where masonry infills are considered to be present in all storeys except the first storey. Masonry infills, in these buildings, are modeled as diagonal struts with depth equal to 0.3 times the diagonal length of the panel and width equal to thickness of the wall (230*mm*). Structural walls in building E are modeled as equivalent frame element with length 6*m* and width of 200 *mm*. Grades of concrete and reinforcing steel considered are M25 and Fe415, respectively [12]. Modulus of elasticity of masonry is assumed to be 4500*MPa* [13]. Beam-column joint are assumed to be rigid. Effective second moment of area of beams, columns, structural walls and masonry infills are assumed to be $0.4I_{gross}$, $0.7I_{gross}$, $0.7I_{gross}$ and I_{gross} respectively, [14]. Design lateral force of 1,750 *kN* is applied on all buildings. Seismic weight of the building (40,000 *kN)* is assumed lumped uniformly at each storey of study building.

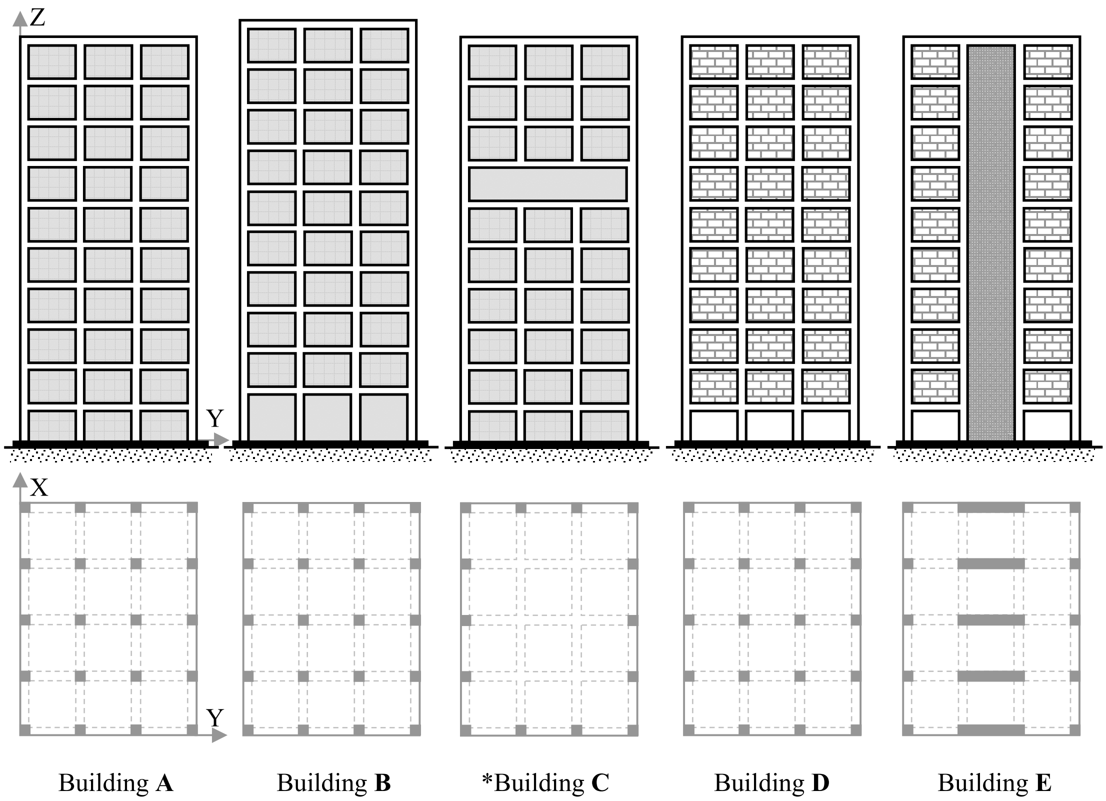


Fig. 8 – Elevation and plan of study buildings; * Plan of seventh storey of building C

In this study, results of all linear structural analysis and modal analyses are obtained using structural analysis program SAP 2000 [15]. For brevity, methods outlined in Sections 2.1, 2.2, 2.3, 2.4, 2.5, 2.6 and 2.7 are termed as Methods 1, 2, 3, 4, 5, 6 and 7, respectively. Estimate of stiffness of all storeys of building A using all seven methods is the same (=709 kN/mm), when all beams and columns present in the building are considered flexurally and axially rigid, respectively. Thus, any one of the seven Method can be used to estimate storey stiffness of such buildings. But, beams are seldom flexurally rigid, nor columns axially rigid. Hence, difference is expected, in the estimate of storey stiffness along the height of the building.

Listed in Table 2 is the stiffness estimate of each storey in building A, determined using all seven Methods. In principle, storey stiffness of benchmark building (building A) should decrease from the base to top of the building due to gradual increase in the flexibility. Such a trend is observed in the estimate of storey stiffness using Methods 4, 5, 6, and 7 alone. On the contrary, Methods 1, 2 and 3 indicates constant storey stiffness along the height of the building with the exception of first, second and top storey. Simplifying assumptions used in the first three methods is identified as the reason for the difference in the trend observed in the storey stiffness between the first three and the last four methods. Thus, in the subsequent discussion, only the last four Methods are considered. The estimate of storey stiffness using method 5 is significantly higher than those using all other methods. This is because (the deformed shape of the building along its height) during the estimation of storey stiffness, does not match the deformation profile with which buildings can deform during earthquake shaking (Fig. 5 and 6). Therefore, additional force is required to produce unit deformation at the desired storey. This results in a higher estimate of storey stiffness. Method 4 estimates higher first and second storey stiffness than those estimated using Methods 6 and 7. This could be due to end effects introduced due to proximity of first and second storey to the base of the building. Estimates of stiffness using Methods 6 and 7, for buildings considered, vary marginally (between 1 and 5%) (Table 3). But, the variation could increase with the choice of distribution of lateral force along the height of the building. It is evident from Table 3 that both Method 6 and Method 7 reflect the expected distribution of storey stiffness along all considered building.

Table 4 presents the assessment of stiffness irregularity using estimate of storey stiffness determined using method 7. As expected, the assessment indicates presence of *soft* seventh storey and *extreme soft first storey* in buildings C and D, respectively. Assessment of stiffness irregularity in building E does not indicate presence of either soft or extreme soft storey; thus, reaffirming the use of structural wall as plausible solution for vertical stiffness irregularity stemming from distribution of masonry infill.

Table 2 – Estimate of storey stiffness for the benchmark building (Building A) by all seven Methods

Storey	*Building A Storey Stiffness (kN/mm)*						
	Methods						
	1	*2*	*3*	*4*	*5*	*6*	*7*
10	144	103	151	93	247	90	83
9	144	113	113	102	276	106	101
8	144	113	113	104	278	108	105
7	144	113	113	105	279	108	107
6	144	113	113	107	280	108	108
5	144	113	113	108	281	109	109
4	144	113	113	110	283	110	110
3	144	113	113	117	287	113	114
2	144	132	113	144	294	126	127
1	237	242	236	392	411	230	232

Table 3 – Estimates of storey stiffness using Methods 6 and 7 of all five buildings

Storey	*Method 6*					*Method 7*				
	Storey Stiffness (kN/mm)					*Storey Stiffness (kN/mm)*				
	A	*B*	*C*	*D*	*E*	*A*	*B*	*C*	*D*	*E*
10	90	90	92	898	891	83	82	84	688	773
9	106	105	109	1484	1513	101	101	105	1236	1378
8	108	107	109	1890	1988	105	105	107	1687	1884
7	108	108	75	2209	2375	107	107	75	2084	2323
6	108	108	108	2490	2726	108	108	107	2462	2731
5	109	109	110	2783	3092	109	109	110	2859	3175
4	110	109	110	3093	3523	110	110	111	3263	3659
3	113	111	113	3758	4191	114	112	114	4095	4397
2	126	119	126	3262	5830	127	120	127	3413	6162
1	230	134	231	457	4403	232	135	233	460	4517

Table 4 – Assessment of stiffness irregularity in study buildings conforming to condition stated in Seismic Design Code using Method 7 of all five buildings

Storey	(K_i/K_{i+1})					$(K_i/[(K_{i+1}+K_{i+2}+K_{i+3})/3])$				
	A	*B*	*C*	*D*	*E*	*A*	*B*	*C*	*D*	*E*
10	-	-	-	-	-	-	-	-	-	-
9	1.22	1.22	1.24	1.80	1.78	-	-	-	-	-
8	1.04	1.04	1.02	1.36	1.37	-	-	-	-	-
7	1.02	1.02	0.70	1.24	1.23	1.11	1.11	0.76	1.73	1.73
6	1.01	1.01	1.43	1.18	1.18	1.04	1.04	1.12	1.48	1.46
5	1.02	1.01	1.03	1.16	1.16	1.02	1.02	1.14	1.38	1.37
4	1.01	1.01	1.01	1.14	1.15	1.02	1.02	1.14	1.32	1.33
3	1.03	1.02	1.03	1.26	1.20	1.04	1.03	1.04	1.43	1.38
2	1.12	1.07	1.12	0.83	1.40	1.14	1.09	1.14	1.00	1.65
1	1.83	1.13	1.83	0.14	0.73	1.98	1.19	1.98	0.13	0.95

5. Summary

Seismic design codes internationally, use lateral translational storey stiffness to assess stiffness irregularity. In literature, several methods are available to estimate storey stiffness. The objective of this study is to ascertain the Method using which storey stiffness is estimated reasonably and accurately. Storey stiffness estimates are determined from, seven commonly used methods, namely Sub-Assemblage Method, Storey Frame Method, Box Frame Method, Equivalent Stiffness Method, Single Storey Method, Lateral Force Deformation Method and Fundamental Lateral Translational Mode Shape Method. Among these methods, the first three methods use closed form equations to estimate storey stiffness, while the other four use results from structural analysis to estimate storey stiffness. Strengths and limitations of each of the methods indicate that the Fundamental Lateral Translational Mode Shape method is the most appropriate method to estimate storey stiffness. This is because fundamental lateral translational mode shape method uses dynamic characteristics of the building to estimate storey stiffness, and does not entail any simplifying assumption, nor does it require any additional analysis, apart form that performed during the analysis and design process.

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