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Simplified Analytical Method to Determine Lateral Stiffness and Identify the Presence of Soft Story in RC Buildings

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Abstract

Discontinuity of walls in any floor causes stiffness differences and creates soft story problems. Proposed Bangladesh National Building Code (BNBC 2015 final draft), American Society of Civil Engineers (ASCE7-05) and Indian Standard 1893 (IS-2002) have the same definition and use stiffness difference as the criteria to define a soft story. Soft story elements need special attention during design and have to be designed for 2.5 times greater story shear force than bare frame analysis.

Lateral stiffness of any story subjected to lateral load due to earthquake is a function of story shear and inter story displacement. Computer aided software like ETABS can estimate building's response and story displacement under earthquake loading by elastic analysis. Design base shear, which is the total design lateral force, or shear due to earthquake at the base of a structure, is distributed among the stories and can be calculated as per seismic design code of BNBC-2015 final draft. In this study, a six storied RC building with open ground system located at seismic zone-III (Peak Ground Acceleration 0.28*g*) was analyzed both for bare frame and with considering the infill masonry. Infill masonry was represented in the model by equivalent diagonal strut.

This paper aims to develop a simplified analytical procedure to calculate lateral stiffness and identify the presence of soft stories in RC buildings according to BNBC-2015 final draft and seismic code of Japan.

Key Words: Soft Story, Lateral Stiffness, Story Shear, Inter Story Drift.

1. Introduction

Scarcity of land in many developing countries has compelled to construct multi storied buildings with open ground to be used as vehicle parking, stores or other facilities. Like other many countries, brick masonry is used in Bangladesh as infill material due to its easy construction, local availabilities and low cost. However, using masonry infill as nonstructural element in the upper stories keeping building's ground floor open results in lateral stiffness difference. This lateral stiffness difference causes vulnerabilities associated with soft first story. The structural configuration with a soft first story proved to be very vulnerable and performed poorly during past earthquakes such as the 1995 Kobe earthquake, the 1999 Turkey earthquake, the 2001 Bhuj earthquake, the 2003 Algeria earthquake and 2015 Nepal earthquake.

The common practice of structural design in many countries including Bangladesh to design the RC buildings is done without considering the effects of infill masonry. This practice of bare frame analysis leads to inappropriate estimation of structure's actual capacity and cannot address the

problem of soft first stories. Earlier in Bangladesh, there was no guideline about consideration of soft story effects in the seismic design code of BNBC-1993, which is now included in the new seismic design code of BNBC-2015 final draft. So, in Bangladesh most of the soft first story buildings are designed without considering the soft story effect. But, according to the new proposed code (BNBC 2015 final draft,), soft story elements need special attention during design and have to be designed for 2.5 times greater story shear than bare frame.

It is very important to identify the presence of soft story in any RC building to be designed based on the guidelines described in the new seismic codes. One of the major challenges to define any story as soft story is the calculation of lateral stiffness, which is the criteria to define it. This paper aims to develop a simplified analytical procedure to calculate lateral stiffness and identify vertical irregularity in terms of soft stories. This methodology can be very useful to determine the existence of vertical irregularity like soft story in RC buildings. After identifying the soft stories, the soft story elements can be considered for designed by 2.5 times greater story shear force as mentioned in the seismic codes.

2. Definition of Soft Story and Lateral Stiffness

2.1 Soft Story

In RC frame structures, discontinuity of walls in some floors causes stiffness differences. The presence of infill walls makes the stories stiffer than its lower stories without infill. This flexible/ less stiff floor will experience large horizontal displacement beyond the elastic limit during an earthquake. In case of Open Ground System (OGS), often known as a structure with a soft first story behaves as an inverted pendulum. As the upper part of the structure has more stiffness due to presence of infill walls, which works as a block, and the lateral drift is concentrated in open ground columns. If any story has less stiffness than upper stories in certain percentage, it is called soft story.

The definition of soft story varies from different seismic codes around the world. Bangladesh National Building Code (2015) final draft, American Society of Civil Engineers (2005) and Indian Standard 1893(2002) have the same definition and use stiffness difference as the criteria to define a soft story. According to the definition of these codes, a soft story is one in which the lateral stiffness is less than 70% of that in the story above or less than 80% of the average lateral stiffness of the three stories above irregularity.

An extreme soft story is defined where its lateral stiffness is less than 60% of that in the story above or less than 70% of the average lateral stiffness of the three stories above. In Figure 1, the definition of soft story according to BNBC-2015 final draft is illustrated.

According to New-Zealand building code, a soft story is the story where the ratio of inter story deflection divided by product of the story shear and story height exceeds 1.4 times the corresponding ratio for the story immediately above this level.

According to the seismic design code of Japan, the ratio of lateral stiffness of each floor to mean stiffness of all floors must be equal or greater than 0.6. If the condition does not satisfy this criteria, the floor will be called as a soft story.

2.2 Lateral Stiffness

The term stiffness of any story used in this paper is the lateral stiffness. The lateral stiffness of a story is generally defined as the ratio of story shear to story drift displacement as shown in Eq. (1). However, story drift displacement, defined as the difference in the lateral displacements of floors bounding a story, is affected by vertical distribution of lateral loads, i.e., there is a unique displaced profile for each type of lateral load distribution. Consequently, the lateral stiffness of a story is not a stationary property, but an apparent one that depends on lateral load distribution (Schult *et al.*, 1992). Definition of lateral stiffness of any story is illustrated in Figure 2.

The seismic code for buildings in Japan defined lateral stiffness as the story height divided by the story drift caused by the lateral seismic shear for a moderate earthquake motion (Figure 3). This definition is expressed as Eq. (2).

$$Lateral\ stiffness = \frac{Story\ shear\ (Vi)}{Inter\ story\ drift\ displacement\ (di)} \tag{1}$$

$$Lateral\ stiffness = \frac{story\ height}{Inter\ story\ drift}, \text{(Seismic code, Japan)} \tag{2}$$

3. Concept of Story Shear Calculation as per BNBC-2015 Final Draft

3.1 Design Base Shear

Design base shear is the total design lateral force or shear due to earthquake at the base of a structure. The seismic design base shear force in a given direction shall be determined from the following Eq. (3):

$$V = S_a W \tag{3}$$

where,

S_a= Lateral seismic force coefficient (BNBC 2015 final draft, section 2.5.4.3). It is also called design spectral acceleration (in units of *g*) corresponding to building period *T*(s) (BNBC -2015final draft, section 2.5.7.2).

W = Total seismic weight of the building (BNBC -2015 final draft, section 2.5.7.3).

The earthquake ground motion for which the building has to be designed is represented by the design response spectrum (Figure 4). This spectrum represents the spectral acceleration for which the building has to be designed as a function of the building period, taking into account the ground motion intensity. The spectrum is based on elastic analysis but in order to account for energy dissipation due to inelastic deformation and benefits of structural redundancy, the spectral accelerations are reduced by the response modification factor *R*. For important structures, the spectral accelerations are increased by the importance factor *I*. The design basis earthquake (DBE) ground motion is selected at a ground shaking level that is 2/3 of the maximum considered earthquake (MCE) ground motion. The effect of local soil conditions on the response spectrum is incorporated in the normalized acceleration response spectrum C_s (Manual of BNBC-2015 final draft). The spectral acceleration for the design earthquake is given by the following equation:

$$S_a = \frac{2}{3}\frac{ZIC_s}{R} \geq \frac{2}{3}ZI\beta \tag{3}$$

where, S_a = design spectral acceleration, β = coefficient used to calculate lower bound for Sa. recommended value for β is 0.2, *Z* = seismic zone coefficient, *I* = structure importance, *R* = response reduction factor which depends on the type of structural system. C_s = normalized acceleration response spectrum which is a function of structure (building) period and soil type. The ratio I/R < 1.

3.2 Vertical Distribution of Lateral Seismic Force

The lateral seismic forces (F_x) induced at any floor level shall be determined from the following equations:

$$F_x = V\ \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k} \tag{4}$$

where, *Fx* = part of base shear force induced at level *x*, kN (or kip).w_i and w_x= part of the total effective seismic weight of the structure (*w*) assigned to level *i* or *x* (kN) (or kip). h_i and h_x= the height from the base to level *i* or *x*, m (or ft). k = 1 for structure period ≤ 0.5s or k = 2 for structure period ≥ 2.5s or k = linear interpolation between 1 and 2 for other periods and n = number of stories.

3.3 Story Shear

The design story shear V_x, at any story x is the sum of the forces F_x in that story and all other stories above it, given by following equation:

$$V_x = \sum_{i=1}^{n} F_i \tag{4}$$

where, F_i= Portion of base shear induced at level i

4. Representation of Infill Masonry in ETABS

4.1 Equivalent Strut Method

Behavior of a RC frame structure with infill brick masonry during earthquakes is very complex. Many researches and experiments are being conducted to find out the factual failure mode and behavior. According to El-Dakkhakhni *et al.*(2003), five types of failure modes of infill masonry within RC frames are observed during lateral load. The failure modes are: corner crushing mode, sliding shear mode, diagonal compression mode, diagonal cracking mode and frame failure mode. Al-Chaar (2002) presented the behavior of infill within RC frame buildings during lateral load. According to him, the transfer of lateral forces across infilled frames causes non uniform stress distribution within the infill and frame elements. As the lateral forces increase, the stress distribution varies until failure of the infill occurs. Failure of the infill occurs when either its shear or compressive strength is reached.

Lateral load carrying capacity of masonry infill within RC frames is dependent on lots of parameters such as masonry strength, mortar, concrete, reinforcement and properties of RC frames. It is very difficult to represent all the parameters in nonlinear finite element program. So, a simplified method known as equivalent strut method was proposed to represent the infill masonry.

4.2 Strut Geometry

Equivalent struts to represent infill masonry consist of three parameters such as: depth, width and thickness of strut as shown in Figure 5. The depth of strut is calculated by Eq. (5). The thickness of strut is considered as same as the thickness of infill masonry.

The equivalent strut width, a, depends on the relative flexural stiffness of the infill to that of the columns of the confining frame. The formula presented in Eq. (6) suggested by Paulay & Priestley (1992) is used to calculate an equivalent strut width as this formula gives good results in comparison with test results.

$$D = \sqrt{l^2 + h^2} \tag{5}$$

where, D is the total depth of strut, l and h are length and height of infill masonry within RC frame.

$$a = 0.25 * d_m \tag{6}$$

where, a = strut width and d_m= depth of the strut.

4.3 Material Properties of Equivalent Strut

Two important parameters such as compressive strength of masonry prism (f'_m) and modulus of elasticity (E_m) are needed to represent the infill masonry in finite element model. The compressive strength of masonry prism (f'_m) can be calculated by the equation proposed by Paulay and Priestley in 1992 as shown in Eq. (7).

$$f'_m = \frac{f'_{cb}\,(f'_{tb} + \alpha * f'_j)}{U_u\,(f'_{tb} + \alpha * f'_{cb})} \qquad (7)$$

where, f'_{cb} = Compressive strength of the brick, f'_{tb} = tensile strength of the brick (= 0.1* f'_{cb}), f'_j = compressive strength of the mortar, j = mortar joint thickness, h_b = height of masonry unit, U_u = stress non-uniformity coefficient (=1.5).

The maximum allowable compressive strength of a strut is calculated by multiplying compressive strength by the cross sectional area of the strut. To represent the strength reduction due to opening in the infill masonry, a reduction factor is used to consider the decreased lateral strength. Ghassan Al-Chaar *et al.*(2002) proposed the following reduction factor formula as shown in Eq. (8) after conducting a large scale experiment.

$$\lambda_{op} = 0.6 * \left(\frac{A_0}{A_p}\right)^2 - 1.6 * \left(\frac{A_0}{A_p}\right) + 1 \qquad (8)$$

The modulus of elasticity (E_m) of masonry prisms has been investigated by many researchers. After conducting many experiments, FEMA 273 proposed Eq. (9), Paulay and Priestley (1992) proposed Eq. (10) to calculate modulus of elasticity of masonry prisms of clay bricks.

$$Clay\ brick, E_m = 550 * f'_m \qquad (9)$$

$$Clay\ brick, E_m = 750 * f'_m \qquad (10)$$

BNBC-2015 final draft adopted the same formula as suggested by Paulay and Priestley (1992) in Eq. (10) with limiting value of 15,000 N/mm^2.

5. Outline of the Analyzed Building

The target building is a six storied RC building located in seismic zone –III (as per proposed BNBC-2015 final draft) and designed by following the building design code BNBC-1993. The building has open ground which is used for car parking and brick infill masonry in the upper floor having thickness of 125 mm and 250 mm. Individual footing is used as foundation. The building is designed by analyzing only bare frames and consideration of brick infill masonry in the upper floor is not done. So, effects of the soft first story on RC building were neglected in this building, as there was no guideline to design soft story in

BNBC-1993. Some important features of the target building are presented in Table 1. The column schedule is presented in Table 2.

Architectural plans of the ground floor, the first floor and elevation 01-01 and D-D of the building are presented through Figure 6 to Figure 8.

5.1 Calculation of Lateral Stiffness and Identifying the Presence of Soft Story

The compressive strength (f_m') of the masonry prism which is represented in the model as equivalent diagonal strut can be calculated as per the formula presented in Eq. (07). By this equation the compressive strength (f_m') is calculated as 3.00 Mpa considering the properties of the commonly used bricks and mortar in Bangladesh and presented below:

$$f_m' = \frac{f_{cb}' \, (f_{tb}' + \alpha * f_j')}{U_u \, (f_{tb}' + \alpha * f_{cb}')}$$

$$f_m' = \frac{5 \, (0.5 + 0.03252 * 3)}{1.5 \, (0.5 + 0.03252 * 5)} = 3.006 \text{ Mpa}$$

where, f'_{cb} = compressive strength of the brick = 5.0 Mpa, f'_{tb} = tensile strength of the brick (0.1* f'_{cb}) = 0.5 Mpa, f'_j = compressive strength of the mortar = 3 Mpa, j = mortar joint thickness = 10mm, h_b = height of masonry unit = 75 mm, U_u = Stress non-uniformity coefficient (=1.5),α = j/(4.1h_b) = 0.03252.

The geometric properties of the equivalent diagonal strut including strut depth, opening reduction factor according to Al-Chaar *et al.*(2003), reduced width and thickness are presented in Table 3. At first, the building is analyzed for its bare frame (Figure 9) according to existing sectional properties and reinforcement detailing of columns and beams. Then the same building is analyzed considering the infill masonry by equivalent diagonal strut according to the real construction (Figure 10). The inter story drift displacement, story shear force and lateral stiffness of each story are calculated for both cases according to the method described in the above sections. It should be noted that, the building has infill masonry in the upper floors with open ground system but structural design is conducted only by analyzing bare frame.

The stiffness difference of each story with upper floors for both bare frames and considering infill masonry are shown in Table 4 and Table 6 (X-direction) and Table 5 and Table 7 (Y-direction). The graphical representations are shown in Figure 11 (X-direction) and Figure 12 (Y-direction). It is observed that, when infill masonry is considered, the lateral stiffness difference of the first floor with upper floor is more then (-) 30% for both direction. However, in case of bare frame, no story has experienced such lesser stiffness difference. As per the definition of Bangladesh National Building Code final draft (2015), American Society of Civil Engineers (2005) and Indian Standard 1893(2002), the first floor (when masonry infill in the upper floor is considered in the model) has vertical irregularity and can be defined as soft first story.

The lateral stiffness of each story according to the seismic code of Japan is also presented in Table 4 and Table 6 (X-direction) and Table 5 and Table 7 (Y-direction). The graphical representations are shown in Figure 13 (X-direction) and Figure 14 (Y-direction). According to the definition of the seismic code of Japan, if the ratio is less than 0.6, then vertical irregularity or soft story is present. It is observed from the Figure 13 and Figure 14, the first floor is soft story when infill is considered in upper floors. But no such condition is observed when bare frame analysis is done.

It can be concluded that, any RC building with an open ground system cannot be judged or evaluated whether it has soft story or not if only bare frame analysis is done.

6. Conclusions

Lateral stiffness is an important parameter to define any story as soft story or determine vertical irregularity in RC building. It is necessary to determine the existence of soft story in RC building to understand whether the story elements are to be designed for 2.5 times shear force as per the present seismic codes. This paper presents a simplified analytical method of calculating inter story drift displacement, story shear force and lateral stiffness of each story in RC building. Method to model RC buildings considering infill masonry by equivalent diagonal strut in ETABS is also presented. This method can be very useful to determine whether any soft story is present or not after preliminary structural design or evaluating any existing RC building. It can be concluded that, any RC building with an open ground system cannot be judged or evaluated whether it has soft story or not if only bare frame analysis is done. Consideration of infill masonry in modeling is mandatory to evaluate whether any soft story or vertical irregularity is present or not.

7. Acknowledgement

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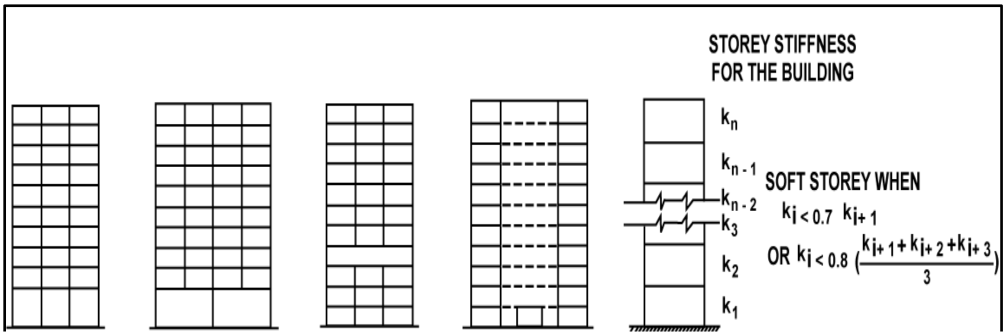

Figure 1. Definition of soft story (BNBC 2015 final draft).

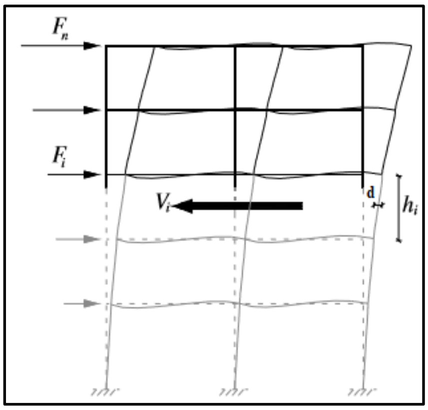

Figure 2. Definition of lateral stiffness. (Schult *et al.*, 1992)

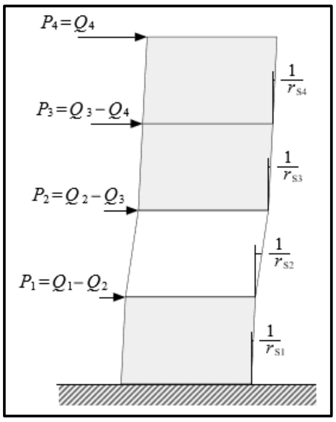

Figure 3. Definition of lateral stiffness in seismic code for building, Japan.

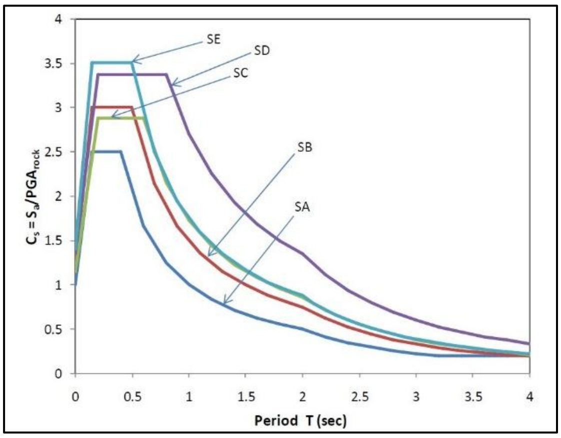

Figure 4. Normalized design acceleration response spectrum for different site classes (SA-SE) based on average soil properties (Shear Wave Velocity, Standard Penetration Value and Undrained Shear strength) in top 30 meters. (BNBC-2015 final draft).

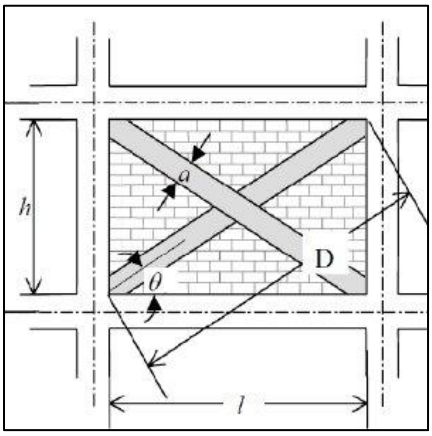

Figure 5. Geometry of equivalent strut.

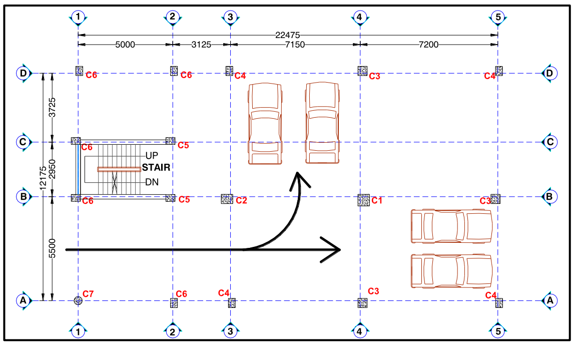

Figure 6. Ground floor plan.

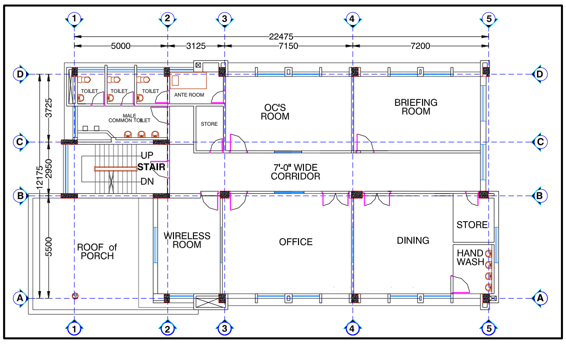

Figure 7. First floor plan.

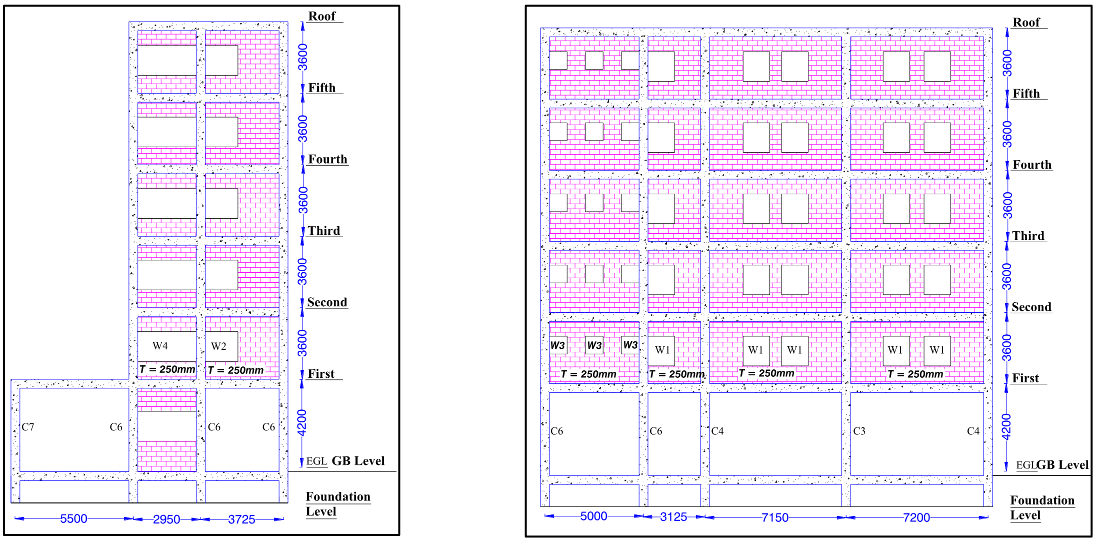

Figure 8. Elevation 01-01 and D-D.

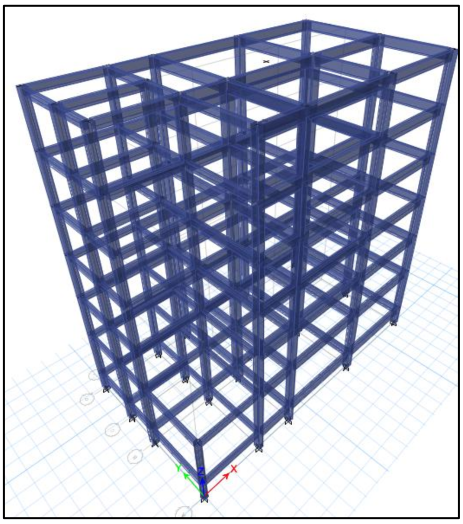
Figure 9. Bare frame modeling

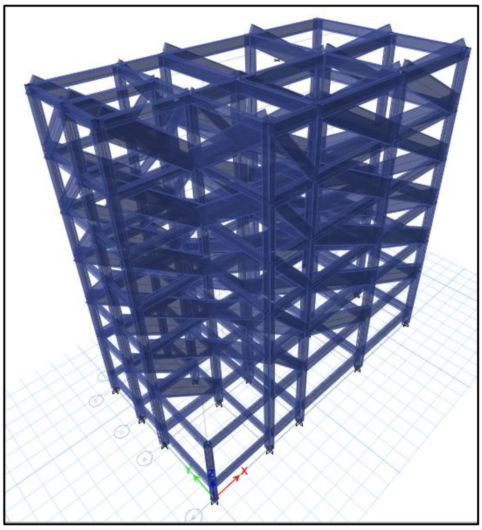
Figure 10. Modeling considering masonry infill by equivalent diagonal strut

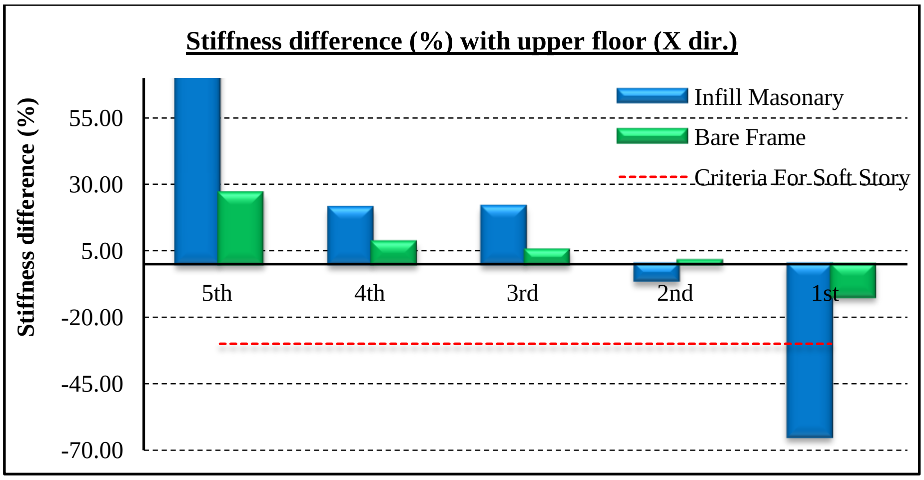

Figure 11. Lateral stiffness difference in X-direction.

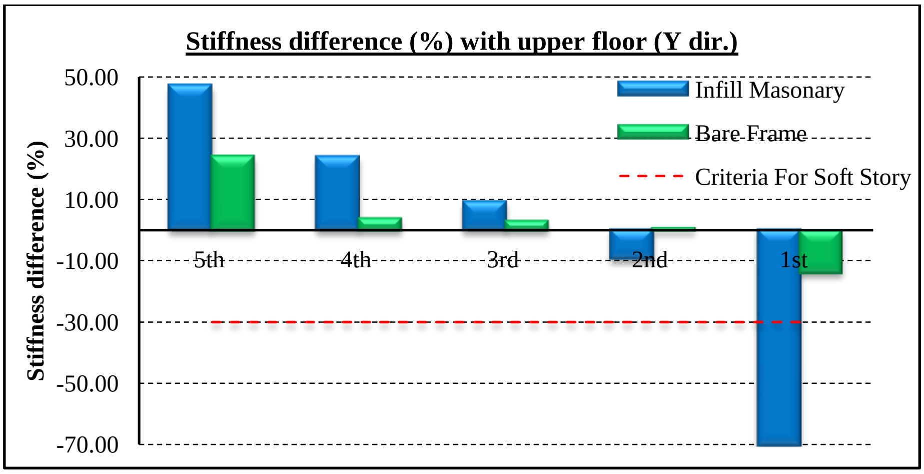

Figure 12. Lateral stiffness difference in Y-direction.

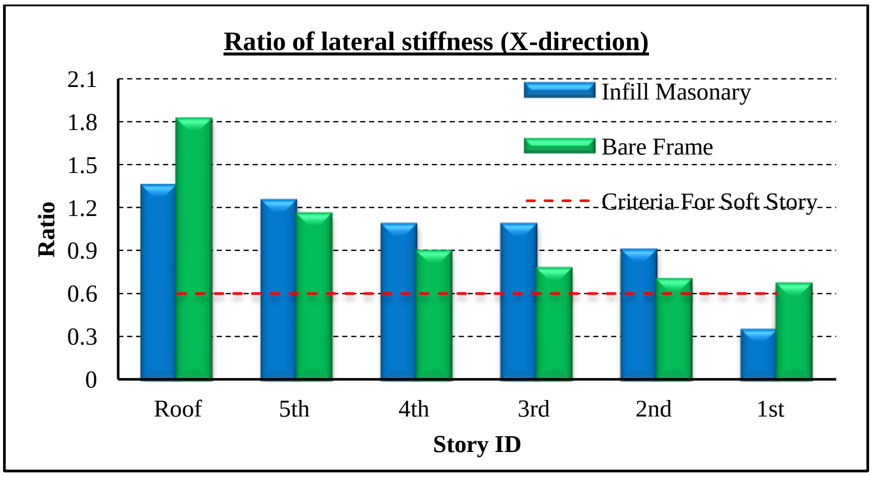

Figure 13. Lateral stiffness ratio (as per seismic code of Japan) in X-direction.

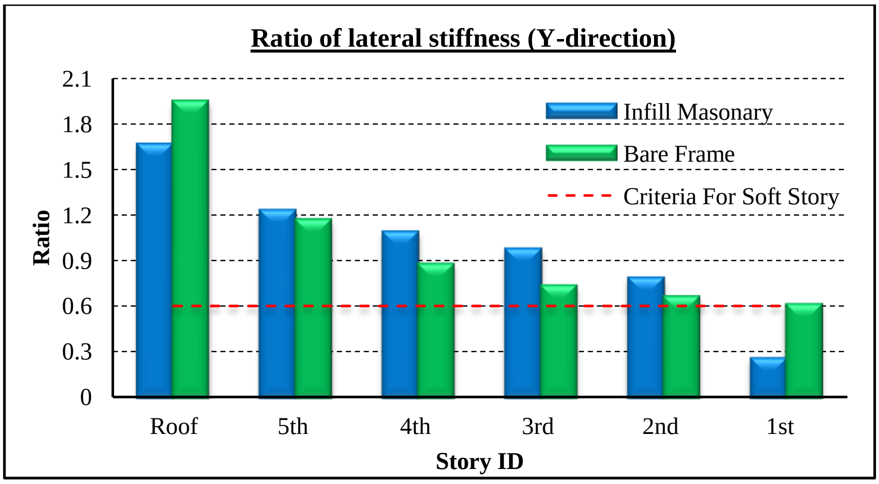

Figure 14. Lateral stiffness ratio (as per seismic code of Japan) in Y-direction.

Table 1. Important features of the analyzed building.

Basic Information			**Load Consideration**	
Name of the building	Police Station		Live Load	2.873 KN/m^2
Number of story	Six (06)		Floor finish	1.2 KN/m^2
Year of construction	2013		Partition wall (Typical)	3.0 KN/m^2
Structure type	RC		Partition wall (Roof)	1.2 KN/m^2
Occupancy category	IV		Slab thickness	162.5 mm
Importance factor	1.5		Concrete strength	20.68 Mpa
Soil type	SC		Steel	415 Mpa

Table 2. Column schedule of the analyzed building.

Column ID	**Column size**		**Reinforcement of column**	
	Below G.L	**Above G.L**	**Ground to 2nd floor**	**3rd to roof**
C1	675 x 675	625 x 625	20-20mm dia	8-20mm + 8-16mm dia
C2	675 x 550	625 x 500	16-20mm dia	16-16mm dia
C3	550 x 550	500 x 500	16-20mm dia	16-16mm dia
C4	425 x 550	375 x 500	16-20mm dia	16-16mm dia
C5	425 x 550	375 x 500	14-20mm dia	4-20mm + 10-16mm dia
C6	425 x 550	375 x 500	12-20mm dia	12-16mm dia
C7	500 Dia	450 Dia	10-20mm dia	Up to porch slab

Table 3. Property of equivalent diagonal strut.

Infill ID	Length (mm)	Height (mm)	A, opening (m^2)	A, infill (m^2)	Opening ratio, r%	Depth, infill (mm)	Strut width (mm)	Opening Reduction Factor	Reduced strut width a, (mm)	Thickness of strut, (mm)
A/2-3	2625	3100	2.03	8.14	24.88	4062	1016	0.64	649	250
A/3-4	6650	3100	4.05	20.62	19.65	7337	1834	0.71	1300	250
A/4-5	6700	3100	4.05	20.77	19.50	7382	1846	0.71	1312	250
B/1-2	4500	3100	0	13.95	0.00	5464	1366	1.00	1366	250
B/2-3	2625	3100	2.52	8.14	30.97	4062	1016	0.56	571	125
B/3-4	6650	3100	8.41	20.62	40.82	7337	1834	0.45	820	125
B/4-5	6700	3100	5.94	20.77	28.60	7382	1846	0.59	1092	125
C/1-2	4500	3100	0	13.95	0.00	5464	1366	1.00	1366	250
D/1-2	4500	3100	2.43	13.95	17.42	5464	1366	0.74	1010	250
D/2-3	2625	3100	2.02	8.14	24.88	4062	1016	0.64	649	250
D/3-4	6650	3100	4.05	20.62	19.65	7337	1834	0.71	1300	250
D/4-5	6700	3100	4.05	20.77	19.50	7382	1846	0.71	1312	250
1/B-C	2450	3100	3.67	7.60	48.39	3951	988	0.37	362	250
1/C-D	3225	3100	2.47	10.00	24.76	4473	1118	0.64	716	250
2/A-B	5000	3100	2.02	15.50	13.06	5883	1471	0.80	1178	250
2/B-C	2450	3100	2.52	7.60	33.18	3951	988	0.54	529	125
2/C-D	3225	3100	4.32	10.00	43.21	4473	1118	0.42	470	125
3/A-B	5000	3100	2.02	15.50	13.06	5883	1471	0.80	1178	125
3/B-D	6175	3100	8.41	19.14	43.96	6909	1727	0.41	713	125
4/A-B	5000	3100	2.02	15.50	13.06	5883	1471	0.80	1178	125
4/B-D	6175	3100	6.61	19.14	34.56	6909	1727	0.52	896	125
5/A-B	5000	3100	2.02	15.50	13.06	5883	1471	0.80	1178	250
5/B-D	6175	3100	4.05	19.14	21.16	6909	1727	0.69	1189	250

Table 4. Lateral stiffness of the analyzed building for bare frame (X-direction).

Story ID	Total story shear (KN)	Displacement (mm)	Drift displacement (mm)	Lateral stiffness (KN/mm)	Stiffness difference (%)	Story drift	Lateral stiffness (Japan code)	Average of stiffness	Ratio
Roof	290.71	45.9	3.5	83.06		0.00097	1028.57	567.19	1.813
5th	577.69	42.4	5.5	105.04	26.46	0.00152	654.55		1.154
4th	807.60	36.9	7.1	113.75	8.29	0.00197	507.04		0.894
3rd	982.33	29.8	8.2	119.80	5.32	0.00227	439.02		0.774
2nd	1104.25	21.6	9.1	121.35	1.29	0.00252	395.60		0.697
1st	1182.89	12.5	11.1	106.57	**-12.18**	0.00264	378.38		**0.667**

Table 5. Lateral stiffness of analyzed building for bare frame (Y-direction).

Story ID	Total story shear (KN)	Displacement (mm)	Drift displacement (mm)	Lateral stiffness (KN/mm)	Stiffness difference (%)	Story drift	Lateral stiffness (Japan code)	Average of stiffness	Ratio
Roof	291.56	61.1	4.3	67.81		0.00119	837.21	440.09	1.902
5th	579.69	56.8	6.9	84.01	23.90	0.00192	521.74		1.185
4th	810.87	49.9	9.3	87.19	3.78	0.00258	387.10		0.879
3rd	987.05	40.6	11	89.73	2.91	0.00306	327.27		0.743
2nd	1110.70	29.6	12.3	90.30	0.63	0.00342	292.68		0.665
1st	1191.63	17.3	15.3	77.88	**-13.75**	0.00364	274.51		**0.623**

Table 6. Lateral stiffness of analyzed building with infill masonry (X-direction).

Story ID	Total story shear (KN)	Displacement (mm)	Drift displacement (mm)	Lateral stiffness (KN/mm)	Stiffness difference (%)	Story drift	Lateral stiffness (Japan code)	Average of stiffness	Ratio
Roof	290.71	13.90	1.2	242.25	-	0.00033	3000		1.35
5th	577.69	12.70	1.3	444.38	83.44	0.00036	2769		1.24
4th	807.60	11.40	1.5	538.40	21.16	0.00042	2400		1.08
3rd	982.33	9.90	1.5	654.88	21.63	0.00042	2400	2222	1.08
2nd	1104.25	8.40	1.8	613.47	-6.32	0.0005	2000		0.90
1st	1182.89	6.60	5.5	215.07	**-64.94**	0.0013	764		**0.34**

Table 7. Lateral stiffness of target building with infill masonry (Y-direction).

Story ID	Total story shear (KN)	Displacement (mm)	Drift displacement (mm)	Lateral stiffness (KN/mm)	Stiffness difference (%)	Story drift	Lateral stiffness (Japan code)	Average of stiffness	Ratio
Roof	291.56	27.80	1.7	171.51		0.0005	2118		1.66
5th	579.69	26.10	2.3	252.04	46.96	0.0006	1565		1.23
4th	810.87	23.80	2.6	311.87	23.74	0.0007	1385		1.09
3rd	987.05	21.20	2.9	340.36	9.13	0.0008	1241	1273	0.98
2nd	1110.70	18.30	3.6	308.53	-9.35	0.001	1000		0.79
1st	1191.63	14.70	12.8	93.10	**-69.83**	0.003	328		**0.26**

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