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Comparative Analysis of Set-back Buildings as per IS 1893 (Part 1): 2002 and IS 1893 (Part 1): 2016

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Abstract—*A set-back is a step like recession in the profile of a high-rise building. The design code, IS 1893 (Part 1): 2002, was not clear about the definition of building height for computation of fundamental natural period of set-back buildings. The bay-wise variation of height in set-back buildings made it difficult to compute the fundamental natural period of such buildings. But a method is introduced in IS 1893 (Part 1): 2016 for arriving at the approximate fundamental natural period of buildings with basements, set-back buildings and buildings on hill slopes. With this background it is found essential to study the effect of set-backs on the fundamental natural period of buildings. Also, to study the performance of empirical equation given in IS 1893 (Part 1): 2016 for the estimation of fundamental natural period of set-back buildings. This is the primary motivation underlying the present study. The dynamic analysis is carried out using STAAD.Pro software. In total five models are made, one for normal building and four different models are made for set-back buildings. Equivalent Static Method and Response Spectrum Method are used for the dynamic analysis of the buildings. The different parameters selected for the comparison are Height, Time Period, Design Acceleration Coefficient, Design Seismic Acceleration, Base Shear, Average Deflection at Top Storey, Storey Drift, Lateral Force and Scale Factor.*
Keywords— *Dynamic Analysis, Equivalent Static Method, Response Spectrum Method, Set-back Building, Vertical Geometric Irregularity*

I. Introduction

During an earthquake, failure of the structure starts at the points of weakness [9]. This weakness arises due to discontinuity in mass, stiffness and geometry of the structure [9]. Such discontinuities between storeys are often associated with sudden variations in the frame geometry along the height [9]. Height-wise changes in mass, stiffness and geometry render the dynamic characteristics of these buildings different from the regular building [9]. Hence, symmetry and regularity are usually recommended for a sound design of earthquake resistant structures [9]. However, in many cases, these two requirements cannot be met. The structures having this discontinuity are termed as Irregular structures [9].

As per IS 1893 (Part 1): 2016, there are two types of irregularities:

1. Plan Irregularities
2. Vertical Irregularities

Irregular structures contribute a large portion of the urban infrastructure [9]. Vertical irregularities are one of the major reasons for failures of structures during earthquakes [9]. So, the effect of vertical irregularities in the seismic performance of structures becomes really important [9]. Height-wise changes in mass, stiffness and geometry render the dynamic characteristics of these buildings different from the regular building [9].

The set-back irregularity is one of the most common types of vertical geometric irregularity in the modern buildings. A set-back is a step like recession in a wall [1]. Set-backs were initially used for structural reasons, but now are often mandated by land use codes, or are used for aesthetical reasons [1]. In densely built-up areas, set-backs also help get more daylight and fresh air to the street level [1]. Importantly, a set-back helps lower the building center of mass, making it more stabilized [1].

In many cities, building set-backs add value to the interior real estate adjacent to the set-back by creating usable exterior spaces [1]. These set-back terraces are prized for the access they provide to fresh air, skyline views, and recreational uses such as gardening and outdoor dining [1]. In addition, set-backs promote fire safety by spacing buildings and their protruding parts away from each other and allow for passage of firefighting apparatus between buildings [1].

II. Equivalent Static Method

As per this method, first, the design base shear V_b shall be computed for the building as a whole [4]. Then, this V_b shall be distributed to the various floor levels at the corresponding centers of mass [4]. And, finally, this design seismic force at each floor level shall be distributed to individual lateral load resisting elements through structural analysis considering the floor diaphragm action [4]. This method shall be applicable for regular buildings with height less than 15 m in Seismic Zone II [4].

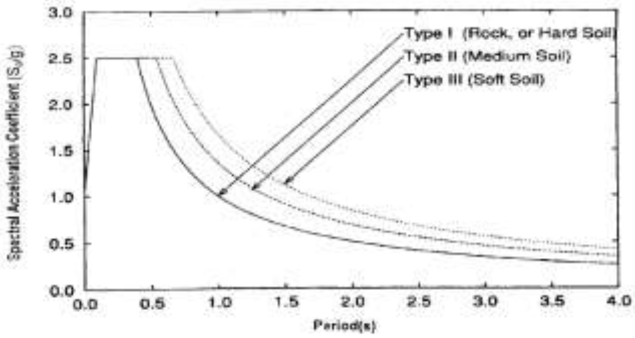


Fig. 1: Spectra for Equivalent Static Method as per IS 1893 (Part 1): 2002 [3]

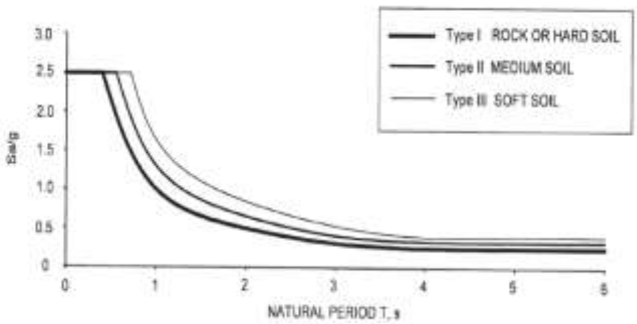


Fig. 2: Spectra for Equivalent Static Method as per IS 1893 (Part 1): 2016 [4]

III. Dynamic Analysis Methods

Linear dynamic analysis shall be performed to obtain the design lateral force (design seismic base shear, and its distribution to different levels along the height of the building, and to various lateral load resisting elements) for all buildings, other than regular buildings lower than 15 m in Seismic Zone II [4].The analytical model for dynamic analysis of buildings with unusual configuration should be such that it adequately represents irregularities present in the building configuration [4].

Dynamic analysis may be performed by either the Time History Method or the Response Spectrum Method. When either of the methods is used, the design base shear V_b estimated shall not be less than the design base shear $\overline{V_b}$ calculated using a fundamental period Ta, where T_a is as per clause 7.6.2 of IS 1893 (Part 1): 2016 [4].

When V_b is less than $\overline{V_b}$, the force response quantities shall be multiplied by $\overline{V_b}$/ V_b [4].

3.1. Response Spectrum Method

Response spectrum method may be performed for any building using the design acceleration spectrum specified in clause 6.4.2 of IS 1893 (Part 1): 2016, or by a site-specific design acceleration spectrum mentioned in clause 6.4.7 of IS 1893 (Part 1): 2016 [4].

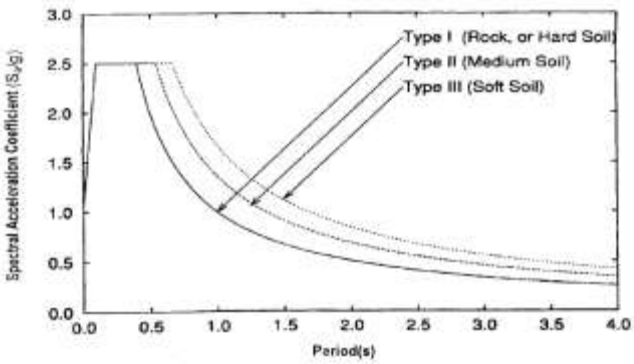


Fig. 3: Spectra for Response Spectrum Method as per IS 1893 (Part 1): 2002 [3]

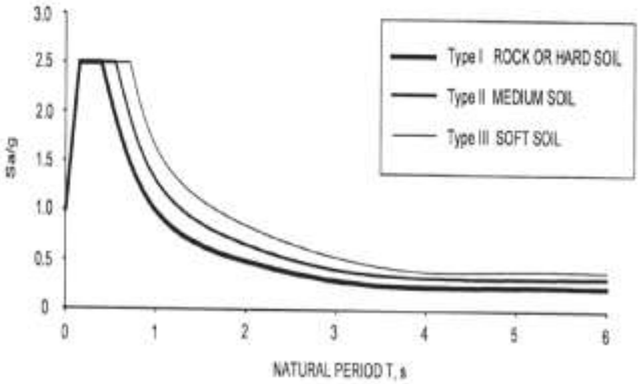


Fig. 4: Spectra for Response Spectrum Method as per IS 1893 (Part 1): 2016 [4]

IV. Provision for Calculation of Height of Set-back Buildings in IS 1893 (Part 1): 2016

As per IS 1893 (Part 1): 2016, the height of set-back building is calculated as follows:

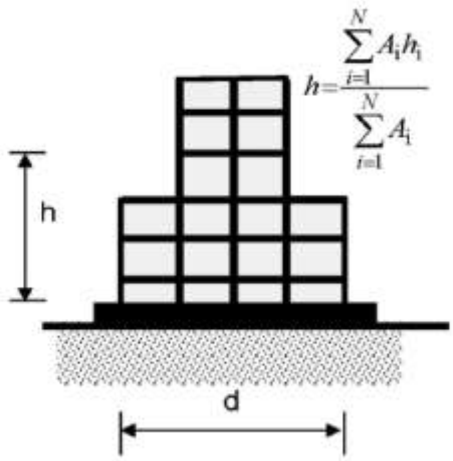


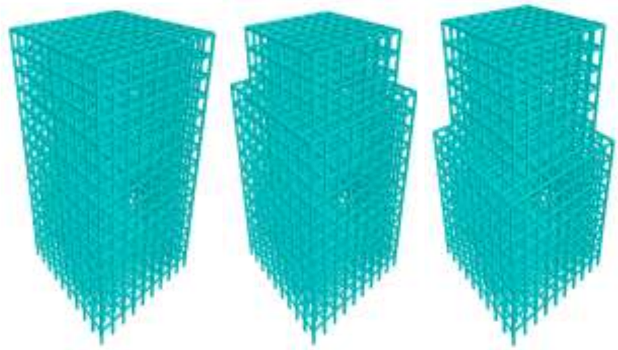
Fig. 5: Provision for Height of Set-back Buildings in IS 1893 (Part 1): 2016 [4]

Where,
N = Number of portions of Plan Area at Base of Building
A_i = Plan Area of i[th] Portion
h_i = Total Height of i[th] Portion
$\sum_{i=1}^{N} A_i$ = Total Plan Area at Base of Building

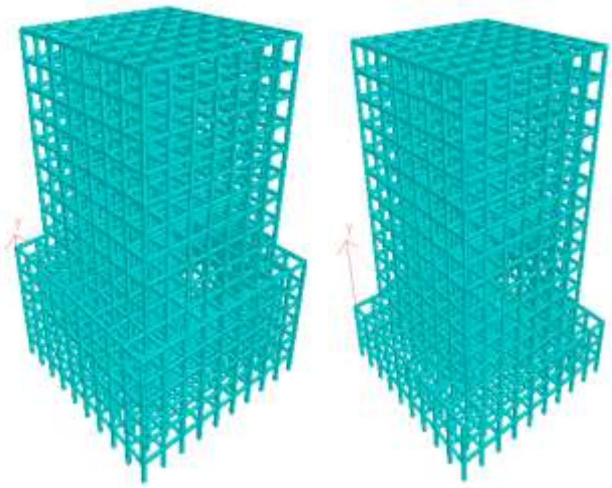
V. Methodology

In the present work, total five models are made as follows:
1. Normal Building without set-back. (N)
2. Set-back at 1 Bay from all 4 sides and at 80% height of building. (1B80H)
3. Set-back at 1 Bay from all 4 sides and at 60% height of building. (1B60H)
4. Set-back at 1 Bay from all 4 sides and at 40% height of building. (1B40H)
5. Set-back at 1 Bay from all 4 sides and at 20% height of building. (1B20H)

All models were analyzed using STAAD.Pro software. Equivalent Static Method and Response Spectrum Method are used for the dynamic analysis of all buildings. Complete Quadratic Combination (CQC) Method is used for the combination of the responses of different modes. The parameters calculated are Height, Time Period, Design Acceleration Coefficient, Design Seismic Acceleration, Base Shear, Average Deflection at Top Storey, Storey Drift, Lateral Force and Scale Factor. The results are obtained and compared for IS 1893 (Part 1): 2002 and IS 1893 (Part 1): 2016.



1 (N) 2 (1B80H) 3 (1B60H)



4 (1B40H) 5 (1B20H)

Fig. 6: Models made in STAAD.Pro Software

VI. Loadings

The loads applied on models are as follows:
1. Earthquake load in X-direction
2. Earthquake load in Y-direction
3. Dead Load: It includes,
   Self-weight of structure
   Outer brick wall load (0.23 m thick)
   Inner brick wall load (0.115 m thick)
   Parapet load (1 m high, 0.115 m thick)
   Slab load (0.15 m thick)
   Floor finish load (0.75 kN/m^2)

4. Live load on floors (4 kN/m^2)
5. Live load on roof (2 kN/m^2)
6. Response Spectrum Load as per IS 1893 (Part 1): 2016 with CQC method of combination
7. Serviceability load combinations as per IS 456: 2000
8. Collapse load combinations as per IS 1893 (Part 1): 2016

The density of concrete is taken as 25 kN/m^3 and the density of brick wall is taken as 18.85 kN/m^3 as per IS 875 (Part 1): 1987.

VII. Analysis and Results

Table No. 1: General Data for all models

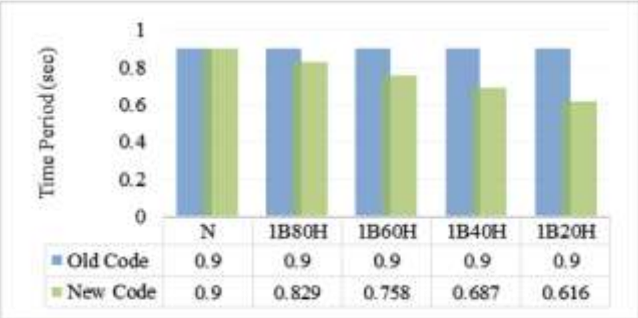
Building	G + 13
Height of One Floor	4 m
Depth of Foundation	4 m
Number of Bays in X-direction	9
Bay Spacing in X-direction	4 m
Number of Bays in Z-direction	9
Bay Spacing in Z-direction	4 m
City	Nagpur (ƶ = 0.1)
Response Reduction Factor	Special RC Moment Resisting Frame (R = 5)
Importance Factor	Public Building (I = 1.5)
Soil Type	Medium
Type of Structure	Building with Brick Infill
Damping	5%
Grade of Concrete	M35
Grade of Steel	Fe500

Table No. 2: Optimized Dimensions for all models

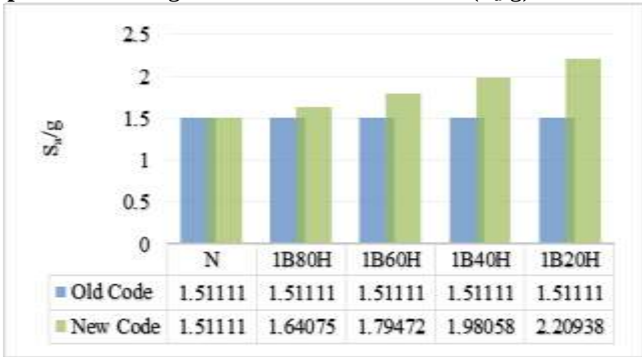
Model Number	Columns in first 3 storeys (mm)	Columns in all other storeys (mm)	Beam Dimensions (mm)
1 (N)	550 x 550	500 x 500	350 x 500
2 (1B80H)	550 x 550	500 x 500	350 x 500
3 (1B60H)	550 x 550	500 x 500	350 x 550
4 (1B40H)	525 x 525	475 x 475	350 x 550
5 (1B20H)	500 x 500	450 x 450	350 x 550

Graph No. 1: Height of building for all models

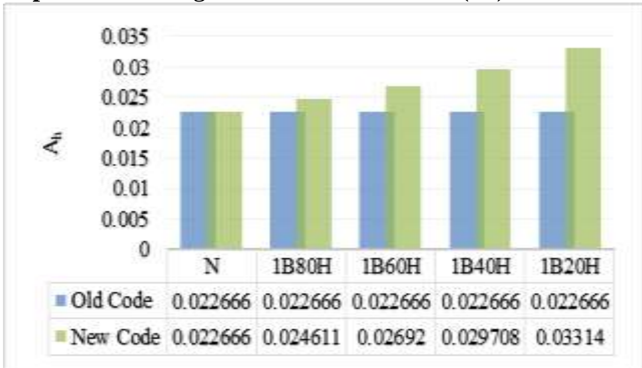
Graph No. 2: Time Period of Building for all models



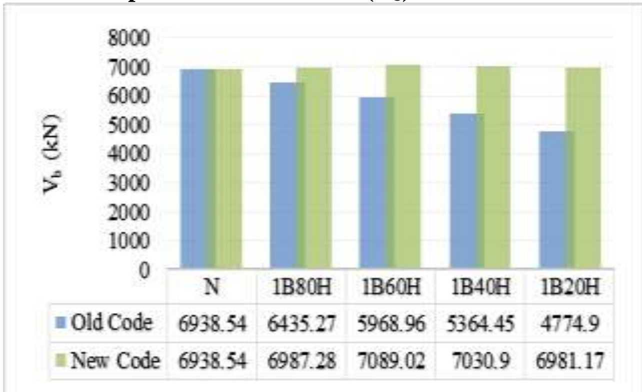
Graph No. 3: Design Acceleration Coefficient (S_a/g) for all models



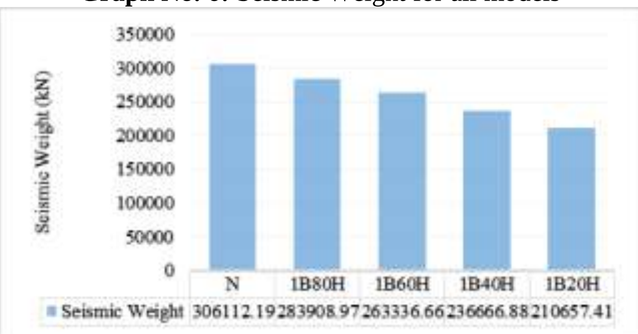
Graph No. 4: Design Seismic Acceleration (A_h) for all models



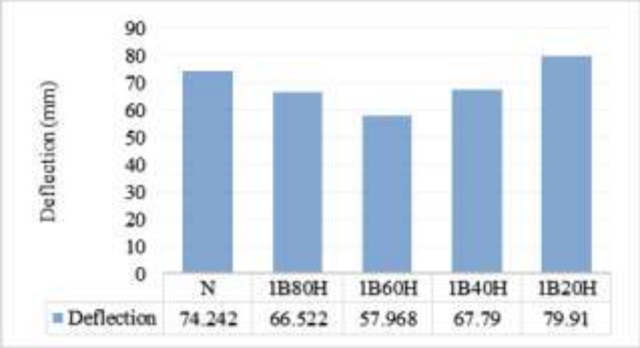
Graph No. 5: Base Shear (V_b) for all models



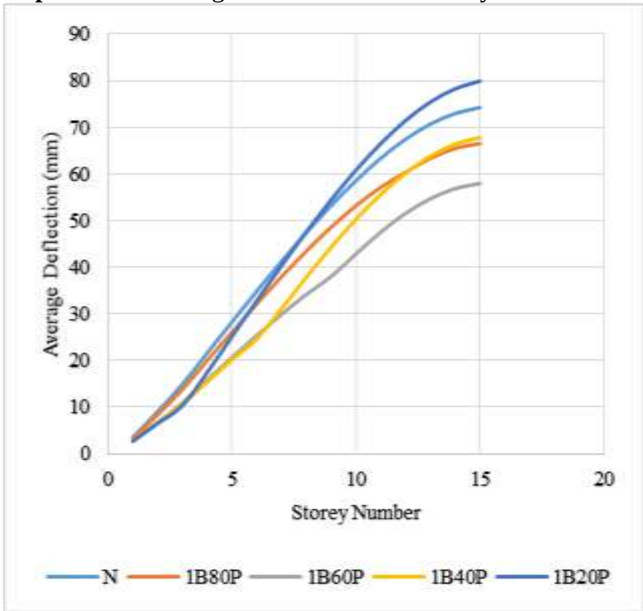
Graph No. 6: Seismic Weight for all models



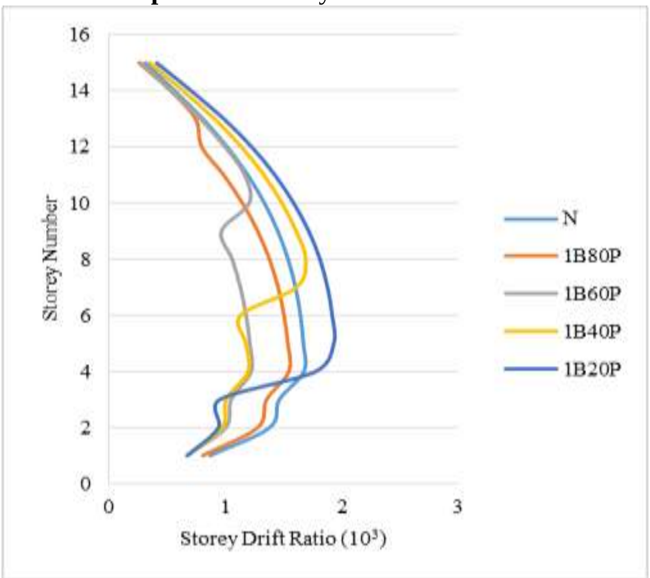
Graph No. 7: Average Deflection at Top Storey for all models



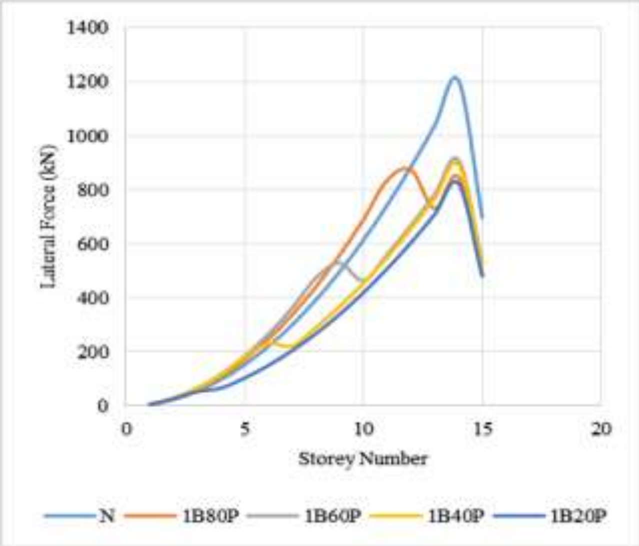
Graph No. 8: Average Deflection in all Storeys for all models



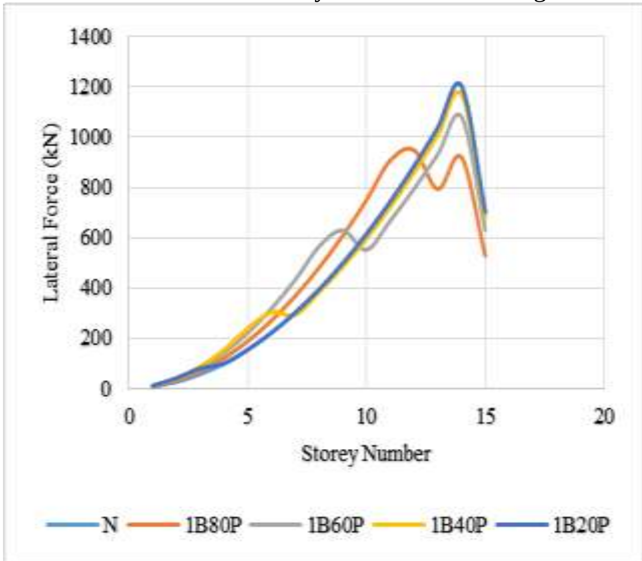
Graph No. 9: Storey Drift for all models



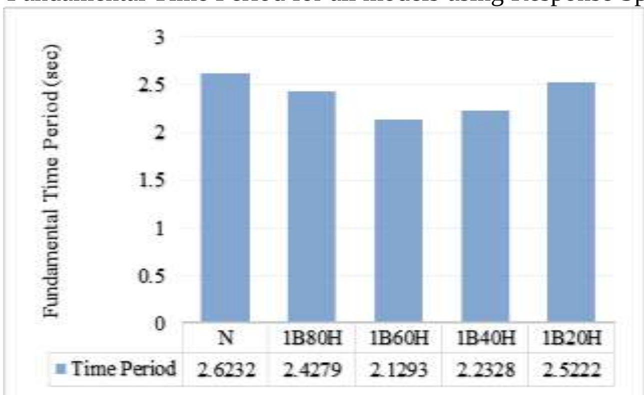
Graph No. 10: Lateral Force in each Storey for all models using IS 1893 (Part 1): 2002



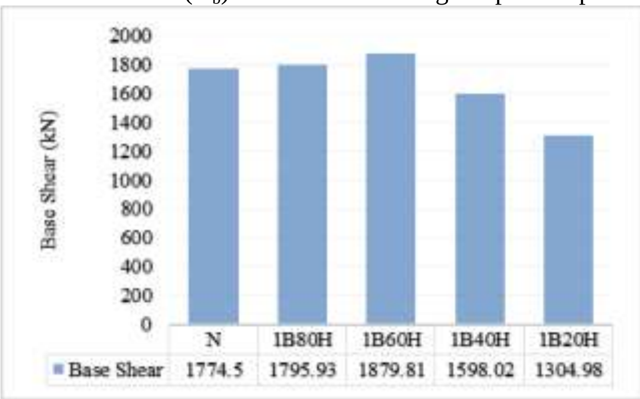
Graph No. 11: Lateral Force in each Storey for all models using IS 1893 (Part 1): 2016



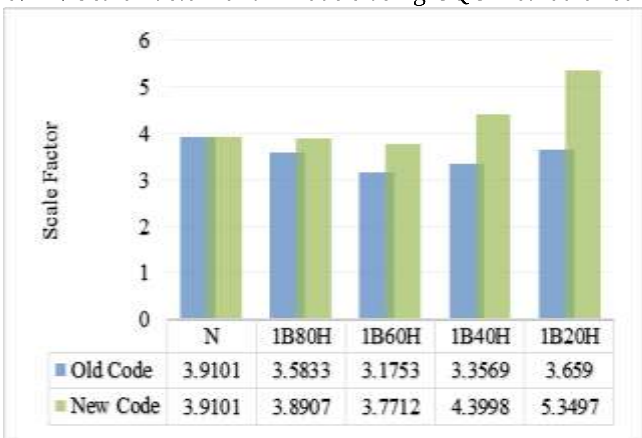
Graph No. 12: Fundamental Time Period for all models using Response Spectrum Method



Graph No. 13: Base Shear (V_b) for all models using Response Spectrum Method



Graph No. 14: Scale Factor for all models using CQC method of combination



VIII. Conclusion and Discussion

Based on the above work, the conclusions obtained are as follows,

1. There is a huge increase in shear force and bending moment at the level of set-back irregularity. Hence, heavier sections for beams are required at the top of base portion and at the bottom of tower portion.
2. The dimensions for beam are minimum for regular building. And the dimensions for beam increases with increase in tower height.
3. The dimensions for column are maximum for regular building. And the dimensions for columns decrease with increase in tower height.
4. The height of the building is constant for all models as per IS 1893 (Part 1): 2002. But the building height decreases for set-back buildings as compared to normal building as per IS 1893 (Part 1): 2016. Also, the building height decreases with increase in tower height.
5. The time period of the building is constant for all the models as per IS 1893 (Part 1): 2002. But the time period decreases for set-back buildings as compared to normal building as per IS 1893 (Part 1):2016. Also, the time period decreases with increase in tower height.
6. The decrease in building height and time period for set-back buildings are in same proportion.
7. The value of design acceleration coefficient (S_a/g) is constant for all the models as per IS 1893 (Part 1): 2002. But the value of S_a/g increases for set-back buildings as compared to normal building as per IS 1893 (Part 1): 2016. Also, S_a/g increases with increase in tower height.
8. The value of Design Seismic Acceleration (A_h) is constant for all the models as per IS 1893 (Part 1): 2002. But the value of A_h increases for set-back buildings as compared to normal building as per IS 1893 (Part 1): 2016. Also, A_h increases with increase in tower height.
9. The increase in S_a/g and A_h values are in same proportion.
10. The base shear for set-back buildings is less as compared to normal building as per IS 1893 (Part 1): 2002. Also, the base shear decreases with increase in tower height. But the base shear is more for set-back buildings as compared to normal building as per IS 1893 (Part 1): 2016.
11. The seismic weight for set-back building is less as compared to normal building. Also, the seismic weight decreases with increase in tower height.

12. The average deflection at top storey for set-back buildings first decreases as compared to normal building when the height of tower portion is less and then it again starts to increase when the height of tower portion is more. It is found maximum for 1B20H model.
13. For normal building, the storey drift graph is similar to regular RCC building. For set-back buildings, the storey drift graph shows a notch at the level of set-back irregularity. The graph clearly has two different portions, one for base portion and other for tower portion. Both base portion and tower portion curves are similar to regular RCC building.
14. The storey drift is more for tower portion as compared to base portion.
15. The storey drift for base portion decreases with increase in tower height and the storey drift for tower portion increases with increase in tower height.
16. The storey drift for base portion of set-back building is less as compared to normal building and the storey drift for tower portion of set-back building is more as compared to normal building.
17. The lateral force in the levels of base portion of set-back buildings is more as compared to the same levels of normal building. The lateral force suddenly decreases at the level of set-back and the lateral force in the levels of tower portion is less as compared to same levels of normal building.
18. The values of lateral force in each storey are higher for IS 1893 (Part 1): 2016 as compared to IS 1893 (Part 1): 2002.
19. As per Response Spectrum Method, the time period for set-back buildings first decreases as compared to normal building when the height of tower portion is less and then it again starts to increase when the height of tower portion is more. It is found maximum for normal building.
20. The base shear from Response Spectrum Method is less than the base shear from Equivalent Static Method for all models.
21. As per Response Spectrum Method, the base shear for set-back buildings first increases as compared to normal building when the height of tower portion in less and then it starts to decrease when the height of tower portion is more. It is found minimum for 1B20H model.
22. As per IS 1893 (Part 1): 2002 and IS 1893 (Part 1): 2016, the scale factor for set-back buildings first decreases as compared to normal building when the height of tower portion is less and then it again starts to increase when the height of tower portion is more. It is found maximum for normal building as per IS 1893 (Part 1): 2002 and for 1B20H model as per IS 1893 (Part 1): 2016.

Note: The above results and conclusions are only applicable for buildings with time period between 0.55 sec to 4.0 sec.

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