Effect of Damping on Multistory Frame using Response Spectrum

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Abstract: The absolute response of the multi-storey frame is ensured by elastic and damping forces. The peak structural response of the frame is obtained using response spectrum analysis under linear range to obtain the lateral forces developed in the structure situated at zone V. In this paper the influence of damping ratio on irregular multi-storey frame on elastic response spectra have been investigated. The analytical results show that the impact of damping ratio and modal response combination are significant on the shape of response spectra. The impacts on storey drift and storey displacement parameters are also studied for gradual increase in damping ratios.

Introduction

The substantial elastic strain energy is released by the unexpected slip at the fault so that seismic waves move throughout the body and also along the surface, causing a violent shaking of the Earth. The seismic motions are caused by the generation of seismic waves with violent energy release that ruptures at the fault causes ground shaking on the Earth's surface. These waves arrive at various times, have varying amplitudes, and convey varying amounts of energy. As a result, motion at every point on the ground is random in nature, with amplitude and direction changing at random times [1]. Technology has evolved in order to combat these calamities, such as establishing disaster warning systems and implementing preventative measures. It occurs suddenly for a few seconds, depending on the severity of the earthquake, and causes minor, moderate, or significant loss of life and property. It's manageable, but not entirely eradicated. As a result, today's global worry is a reduction approach. The visual representation and precision of earthquakes have been used to assess the seismic quality of building complexes on several occasions [2]. Structural engineers confront non-convergence and a number of difficulties when endeavouring to assess the seismic quality of building complexes [3]. Adding viscous dampers may be done using a CSM-based design process. Despite its flaws, their technique is useful for determining the optimal damping ratio [4]. In recent years, several papers have been published on analytical approaches for estimating earthquake's physical damage depending on the energy input to the structure. These concepts are, however, only applied in a few real-world structural design applications [5]. In seismic layout and structure study, response spectrum analyses are often utilised. Typically, a nominal critical damping of 5% is used to develop seismic ground motion response spectra [6]. These damping techniques are referred to as viscous damping for the sake of convenience. Both viscous and hysteretic damping is included in the concept of essentially equivalent viscous damping in seismic analysis and design [7]. The direct displacement-based techniques have been developed for focussing a structural seismic layout and analysis research in recent years. The direct displacement method works by replacing a multi degree of freedom structure with an equivalent single degree of freedom structure, referred as replacement structure. They are distinguished by viscous damping and secant stiffness (elastic and hysteretic damping) that correspond to the optimal displacement response [8]. The viscous damping of replacement structure generally has critical damping greater than 5%. Heat transfer devices have been used to improve the seismic performance of critical structures on several occasions. In the first mode response of a structural system, frictional sliding, metal yielding, viscoelastic material deformation, fluid orificing, and metal phase change can all supply up to 40% critical damping. Despite the fact that various supplemental damping devices' energy dissipation qualities are not perfect viscous, they may be linked to an equal damping ratio [9]. Response spectra for damping levels more than 5% can be calculated using response spectrum prediction methods, which can estimate the spectral ordinate for a variety of damping levels directly. They also can be created by converting current prediction equations or code-based response spectra with different damping ratios utilising response spectrum damping modification factors. The second alternative may have multiple drawbacks, and ground motion prediction equations for varying degrees of damping require a large amount of research [10]. Although there is a little possibility that a structure would be subjected to ground motion from a large earthquake in its lifetime, it will be prone to structural damage if it can respond in the elastic range when exposed to inertia forces induced by a massive earthquake [11].

The design life of a construction might be anything from 50 to 100 years. It may be uneconomical to construct a structure to withstand a greater earthquake that strikes once every 500 years in such a situation. As a result, the structure is designed to withstand base shear forces that are far lower than the actual seismic load. This makes it possible to utilize strength reduction parameters to reduce elastic strength capacity while increasing inelastic drift demand. To obtain lower elastic design force or design base shear, the Indian seismic code divides the seismic reaction by the response reduction factor (R) [12]. The percentage of over strength that can be achieved depends on the construction type and ground motion parameters [13]. When rigid connections are replaced with semi-rigid connections, the over strength factor lowers by roughly 50% while the ductility factor increases greater than 25% [14]. Previously, researchers looked at a variety of factors that influence building performance in a significant ground motion, emphasising the importance of over-strength in structure performance during a severe earthquake [15]. The structure's durability becomes increasingly important as the building's height rises. Tall constructions become more sensitive to a variety of loading events as the number of storeys grows, including extremely high loading values induced by lateral forces such as earthquakes. These guidelines should be followed, and every engineer should make great effort to ensure that the structure is stable and strong enough to bear lateral loads. When the number of floors is reduced, the torsional irregularity coefficient rises [16].

ETABS is used to analyse a G+26 storey RC structure under seismic loads for various damping ratios in Zone-V locations using the response spectrum method. By combining the features of numerous independent ground motion recordings, the response spectrum shows an interaction between ground acceleration and the structural system. In line with IS 1893 (Part 1):2002, a variety of dead and live load combinations have been observed. The earthquake loads on a structure of various heights are calculated. When lateral systems are used, the displacement, shear, and moment of the structure reduces, enhancing the structure's stiffness to resist lateral stresses [17]. This paper focuses on the impacts of various damping ratios and modal combinations for the G+26 storey RC building located in Zone-V under response spectrum analysis.

Analytical Investigation

The response spectrum has been analysed using linear dynamic analysis. Response spectrum calculates vibration in each mode and then combines the responses from numerous mode to get the overall response. Deformation and acceleration are two examples of responses. The response spectrum is determined by plotting the highest response against the natural period. ETABS is used to do the analysis for a G+26 level multi-story structure. The plan of the G+26 RC building with its elevation is shown in Fig. 1 & 2.

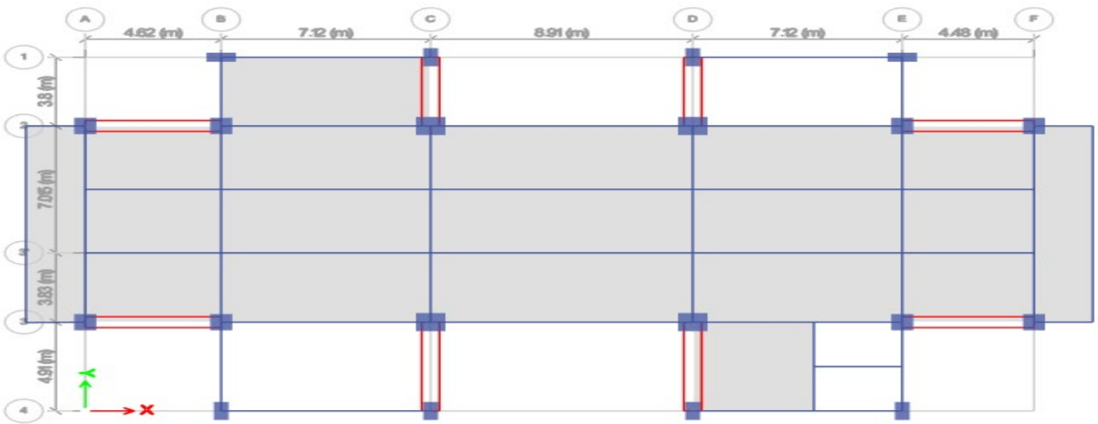

Fig 1. Plan of the G+26 RC building for first floor

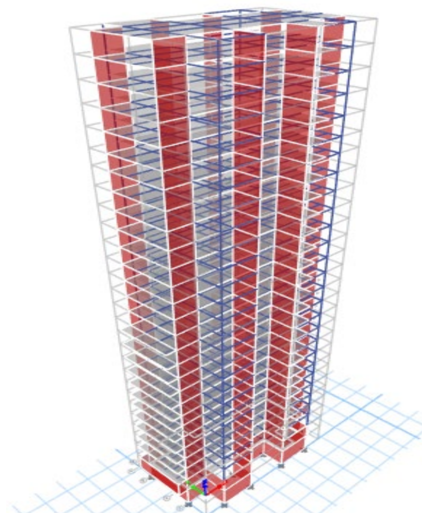

Fig 2. Elevation of the G+26 RC building

Modal Combination

Complete quadratic combination (CQC)

Traditional Response Spectrum Analysis using the CQC rule implies the following steps: (1) solving the real-values eigen problem to produce the modal matrix and accompanying spectral matrix; (2) picking the structure's number of vibrational modes (m); (3) finding the interest's generic structural response y(t) is a combination of the m modal responses, according to Eq. 1.

$$y(t) = \sum_{i=1}^{m} e_{i}\, \theta_{i}(t) \qquad \text{Eq. 1}$$

where θi(t)= qi(t)/Γi, ei, is the influence coefficient that contribute the i-th mode shape to the response quantity of interest affected by the i-th participation factor [for example ei= ϕri Γi when the r^{th} structural displacement has to be evaluated, that is y(t) = ur(t)]. The term i(t) denotes the solution to the following differential equation, $\ddot{\theta} i(t) + 2\zeta\omega i\dot{\theta}(t) + \omega_i^2\theta i(t) = \ddot{u}_g(t)$ (4) Applying the CQC rule as given in Eq. 2 to the design value of y(t):

$$y^{CQC} = \sqrt{\sum_{i=1}^{m} \sum_{k=1}^{m} \rho_{ik}\, e_{ie_k} \frac{A_{e(T_i,\xi_i)}}{\omega_i^2} \frac{A_{e(T_i,\xi_i)}}{\omega_k^2}} \quad \text{Eq. 2}$$

Where ρik is the correlation coefficient between the i-th and k-th modes of vibration, which is calculated assuming zero-mean stationary seismic acceleration [18]. In terms of pseudo-acceleration, $Ae(T_i,\zeta i)$ is the i-th ordinate of the response spectrum. This value is determined by the vibration durations Ti= 2π/ωi and the viscous damping ratios ζi of the m modes of vibration.

Square root of sum of squares method (SRSS)

In the SRSS approach, the maximum response is calculated by calculating the square root of the sum of squares of responses in each vibration mode and expressing it as shown in Eq. 3

$$r = \sqrt{\sum_{i=1}^{n} r_i^2} \quad \text{Eq. 3}$$

The SRSS technique of combining maximal modal responses is fundamentally sound when the modal frequencies are well spaced. This approach, on the other hand, delivers disappointing results when the frequencies of significant contributing modes are close together.

Absolute Sum Method (ABSSUM)

The ABSSUM approach adds the peak responses of all modes algebraically, assuming that all modal peaks occur at the same time. Eq. 4 calculates the system's maximum response.

$$r = \sum_{i=1}^{n} |r_i| \quad \text{Eq. 4}$$

The ABSSUM method gives a much more conservative estimate of the total response peak value as well as an upper bound on the final response quantity.

Structural configuration

The Commercial building is considered for the analysis using response spectrum analysis to predict the behaviour of structural elements. Various damping ratios and their percentage are shown in Table 1 and the structural parameters taken for study of response spectrum analysis are shown in Table 2 and. In this study, analysis of G + 26 storey RC building for zone V has been carried out. The earthquake forces as specified by code IS: 1893-2002 (Part I) has been followed.

Table 1. Damping Ratio with Percentage

Damping percent (%)	Damping ratio
2	0.02
5	0.05
7	0.07
10	0.1
15	0.15
20	0.2
25	0.25
30	0.3

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Table 2. Structural parameters

Description	Parameters
No.of Storeys	G+26
Typical floor height	3.6m
Ground floor height	5.1m
Total height of building	93.85m
Plan dimension	20m
Grades of concrete	M50, M35
Types of sreel	Fe500, Fe250
Dead load	2.5KN/m^2
Live load	3KN/m^2
Thickess of slab	225 mm
Sizes of beam	400mmX750 mm
	450mmX900mm
Sizes of column	1000mmX1000mm
	1000mmX500mm
	900mmX750mm
	500mmX1000mm
Type of zone	V
Zone factor	0.36
Importance factor	1
Type of structure	SMRF
Response reduction factor	5

Results and discussion

A. Storey displacement

When displacement compared to base of the structure is said to be storey displacement. Storey displacement is a critical parameter to consider when seismic force affects the structure. It is determined by the structure's height. The storey displacement for G+ 26 storeys RC building in Zone-V for various damping ratios like 0.02, 0.05, 0.07, 0.1, 0.15, 0.20, 0.25 and 0.30 are obtained for both X and Y direction. Analysis was done using response spectrum using CQC, SRSS and ABSSUM methods. The values of displacement at top storey are higher than at bottom storey. Hence the storey displacement for 26th storey for 5% and 25% of damping ratio using response spectrum analysis in X-direction is shown in Fig.3 and Fig.5. The storey displacement for 26th storey for 5% and 25% of damping ratio using response spectrum analysis in Y-direction is shown in Fig.4 and Fig.6.

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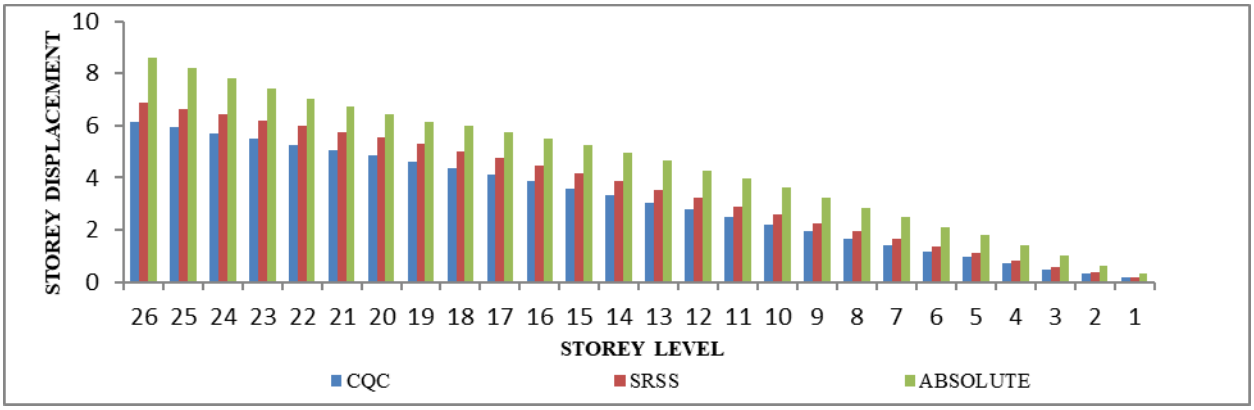

Fig 3. Displacement for 5% damping ratio using Response spectrum analysis in X - direction

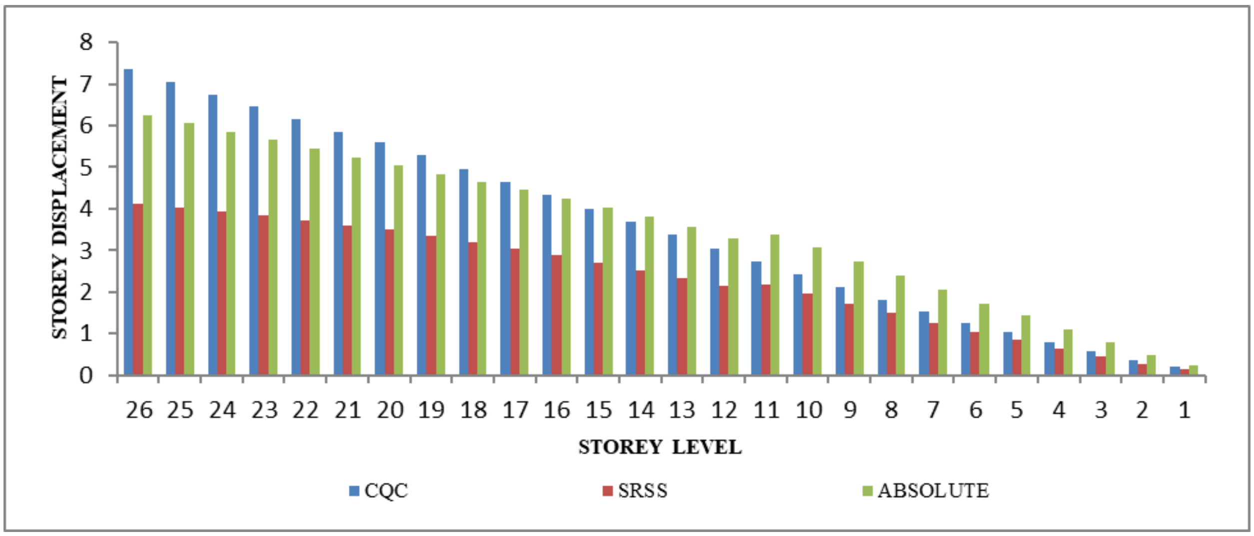

Fig 4. Displacement for 5% damping ratio using Response spectrum analysis in Y - direction

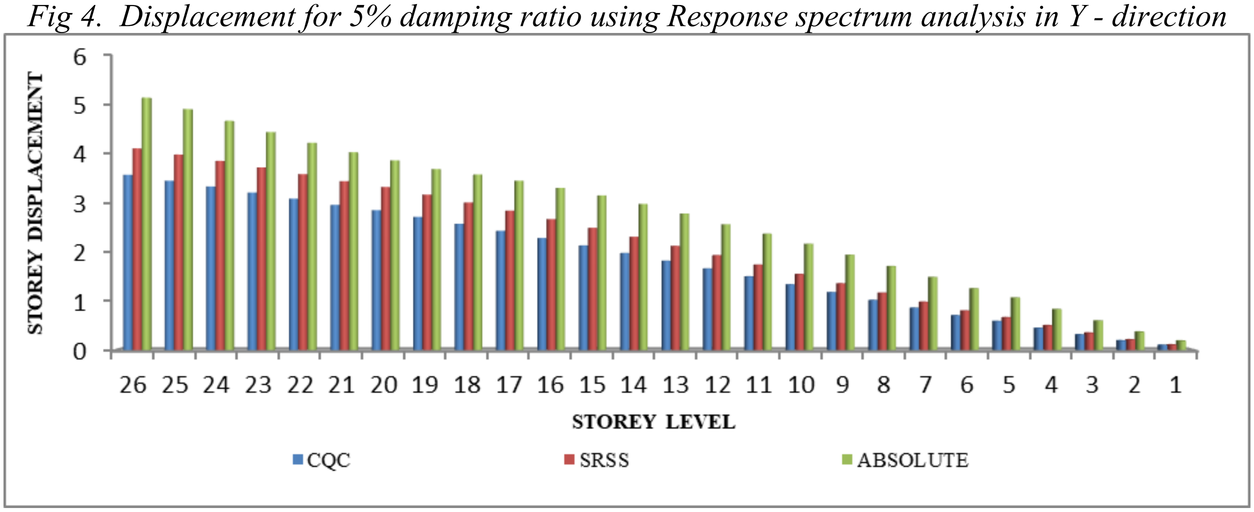

Fig 5. Displacement for 25% damping ratio using Response spectrum analysis in X – direction

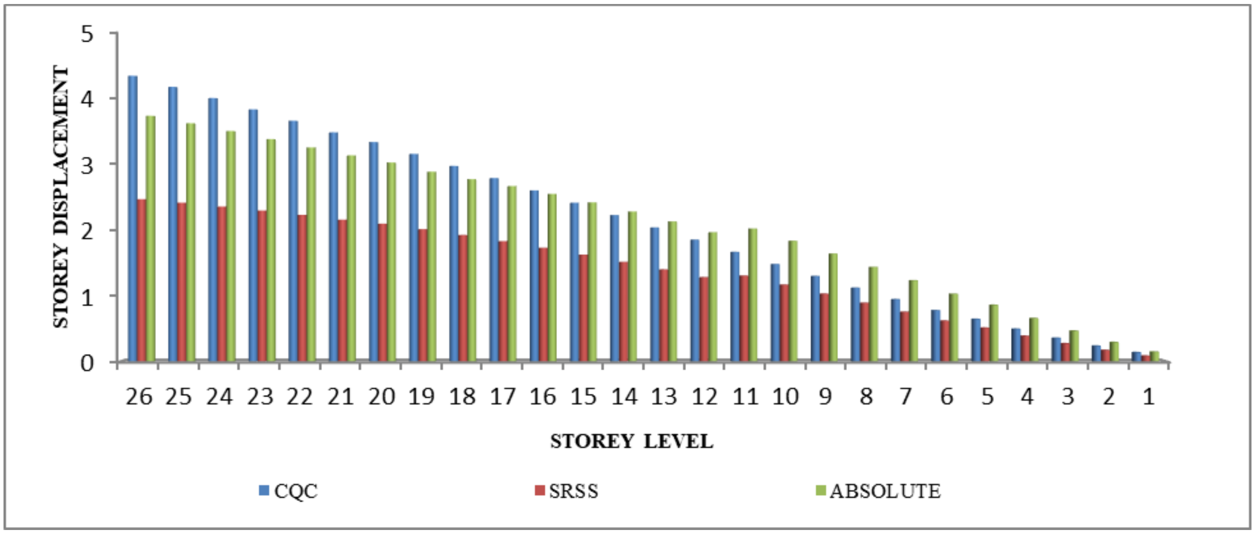

Fig 6. Displacement for 25% damping ratio using Response spectrum analysis in Y - direction

B. Storey Drift

Storey drift is defined as a storey's displacement in relation to the next storey. Its maximum value should be equal to 0.004 of the storey's height. In general, the value of drift is greatest at the building's H/2 height. The storey drift for G+ 26 storeys RC building in Zone-V for various damping ratios like 0.02, 0.05, 0.07, 0.1, 0.15, 0.20, 0.25 and 0.30 are obtained for both X and Y direction. Hence the storey drift for 26th storey for 5% and 25% of damping ratio using response spectrum analysis in X-direction is shown in Fig.7 and Fig.9. The storey displacement for 26th storey for 5% and 25% of damping ratio using response spectrum analysis in Y-direction is shown in Fig.8 and Fig.10.

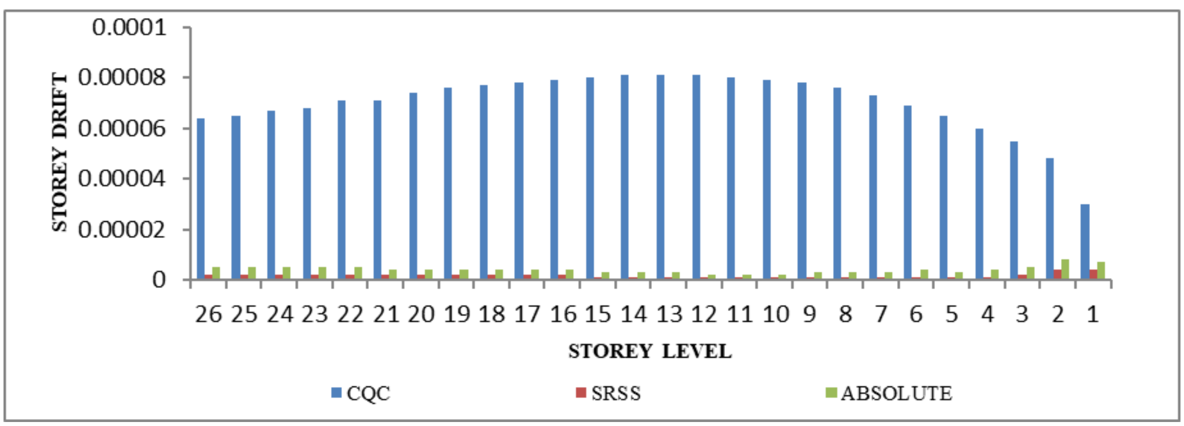

Fig 7. Drift for 5% damping ratio using Response spectrum analysis in X-direction

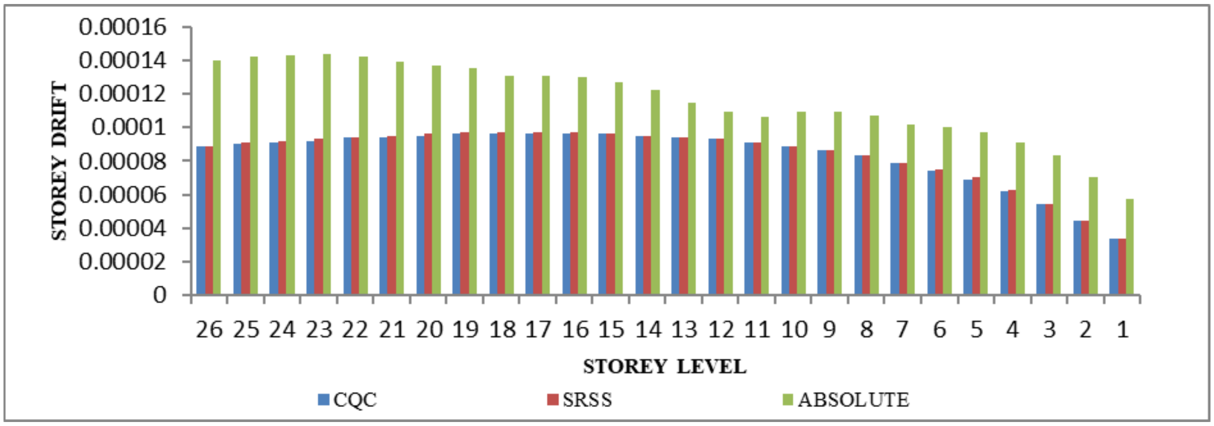

Fig 8. Drift for 5% damping ratio using Response spectrum analysis in Y-direction

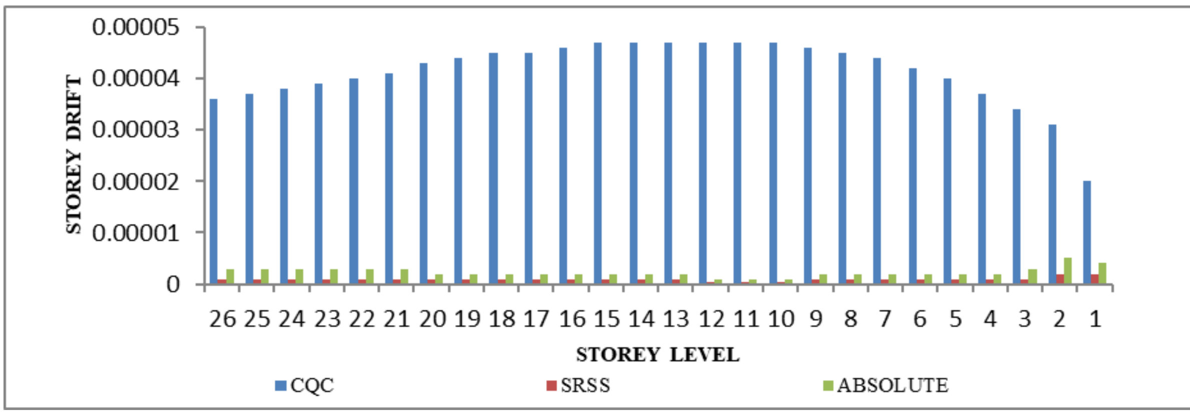

Fig 9. Drift for 25% damping ratio using Response spectrum analysis in X-direction

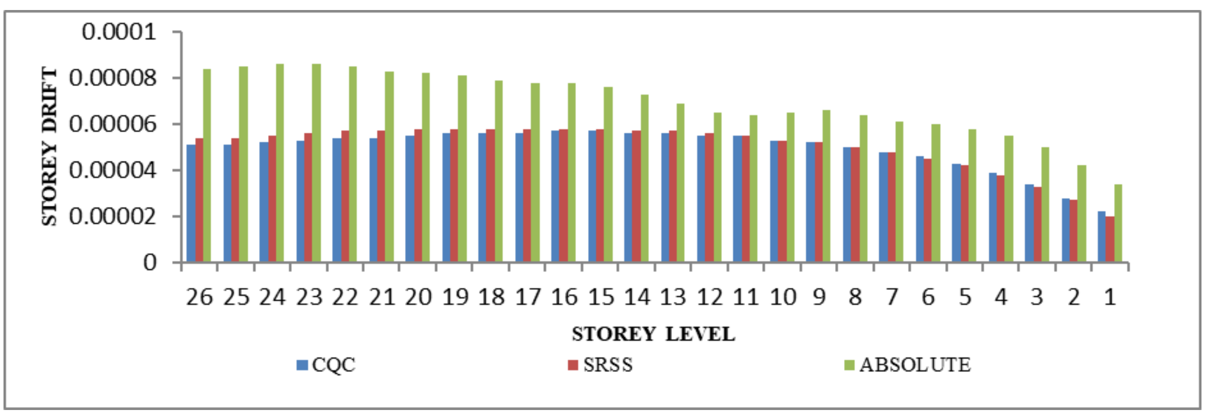

Fig 10. Drift for 25% damping ratio using Response spectrum analysis in Y-direction

C. Storey Shear

Base shear refers to the seismic force at the building's base. Storey shear refers to the lateral forces experienced by different floors as a result of an earthquake. Its value is highest at the bottom storey and lowest at the top storey. The storey shear for G+ 26 storeys RC building in Zone-V for various damping ratios like 0.02, 0.05, 0.07, 0.1, 0.15, 0.20, 0.25 and 0.30 are obtained for both X and Y direction. Analysis was done using response spectrum method. For both directions shear values are same hence storey for 26th storey and Base shear for 5% and 25% of damping ratio are shown in the Fig.11, Fig.12, Fig.13 and Fig.14.

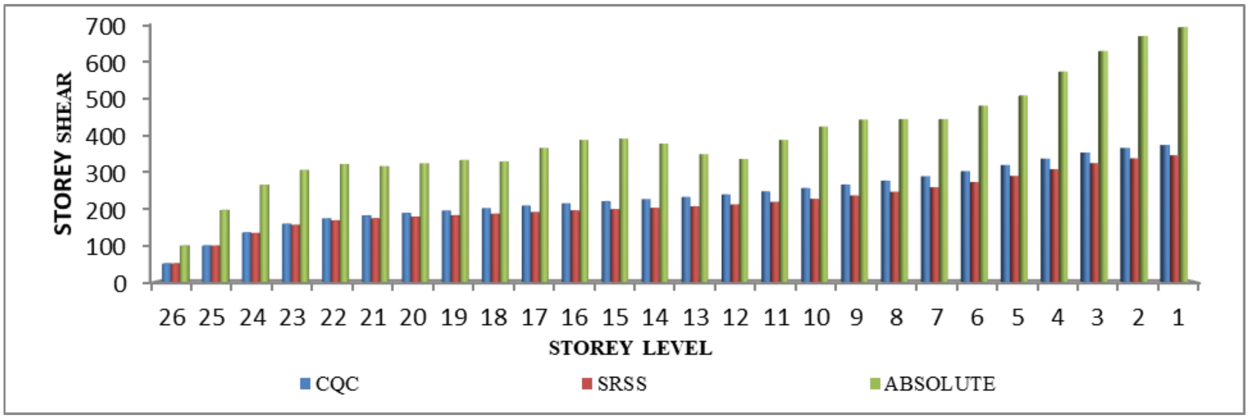

Fig 11. Shear for 5% damping ratio using Response spectrum analysis in X-direction

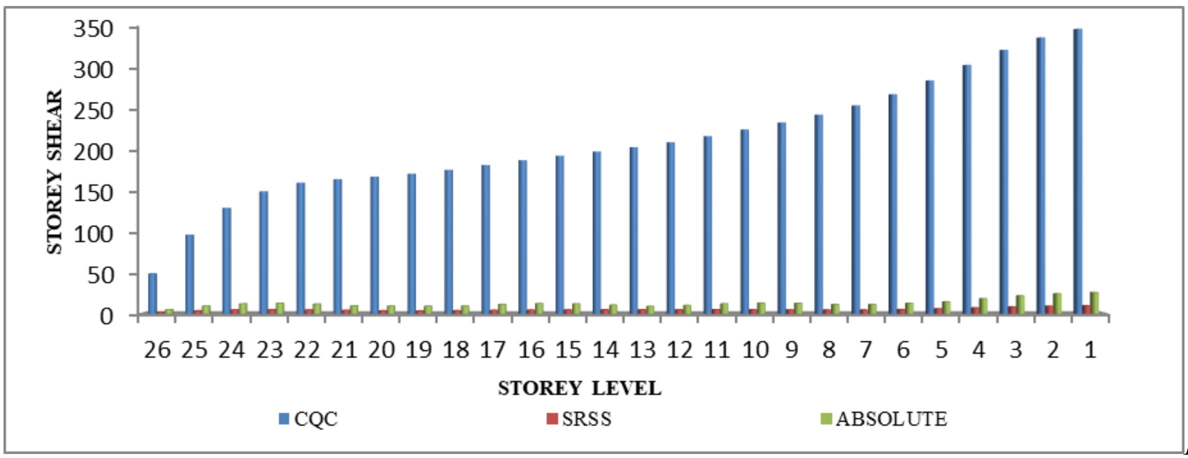

Fig 12. Shear for 5% damping ratio using Response spectrum analysis in Y-direction

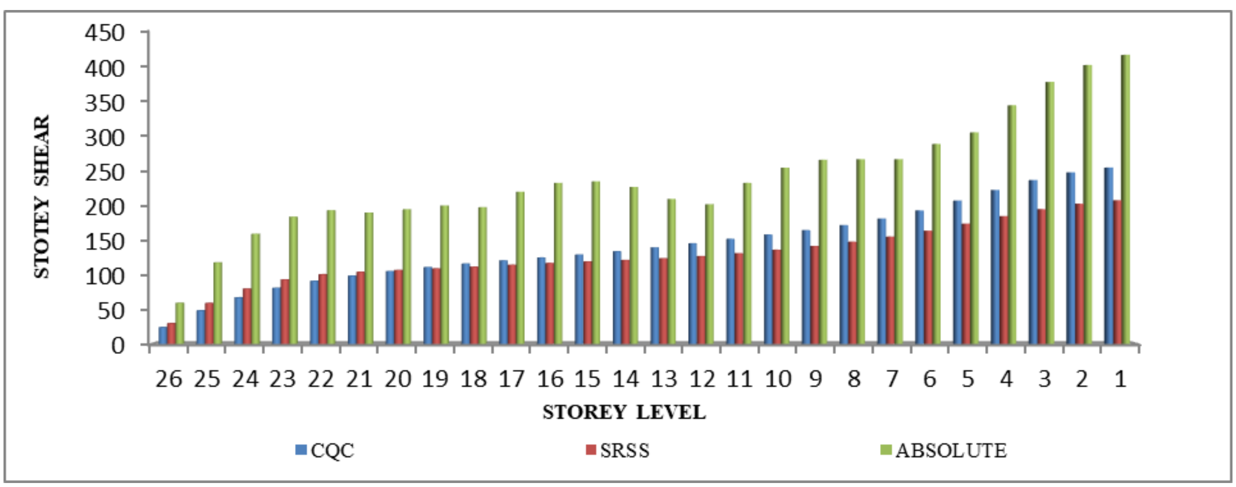

Fig 13. Shear for 25% damping ratio using Response spectrum analysis in X-direction

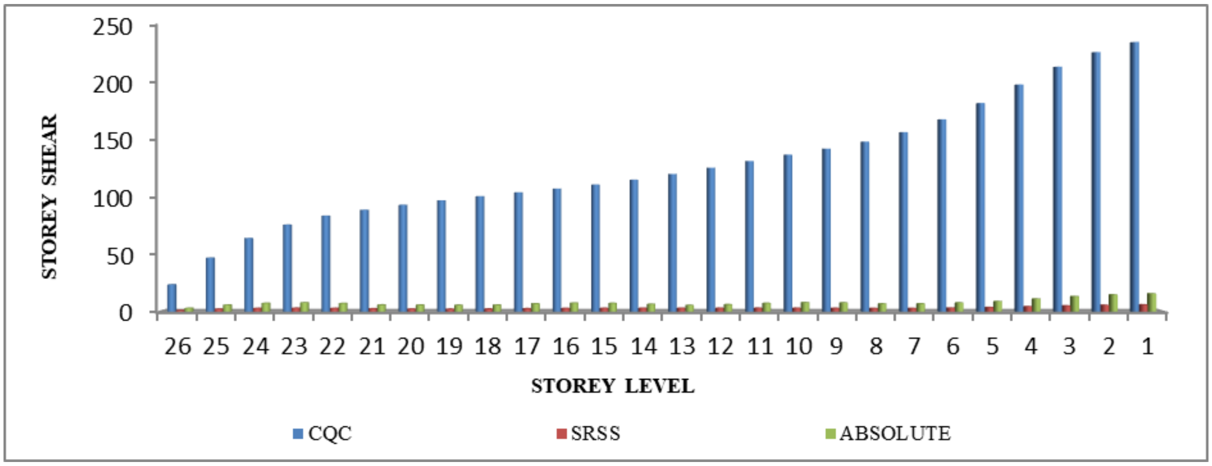

Fig 14. Shear for 25% damping ratio using Response spectrum analysis in Y-direction

Conclusions

1. From the analysis it is concluded that the storey displacement for G+ 26 storeys RC building in Zone-V is maximum for 0.02 damping ratio and in 0.05 damping ratio storey displacement value is average.
2. When analysis is done using Response spectrum method in both X and Y directions the storey drift is found to be maximum at 15th and 17th storey for all damping ratios
3. The storey shear in Response spectrum method for both directions is maximum at the ground when compared top storeys.
4. It is noted that when increasing the damping ratio parameters like storey displacement, storey drift and storey shear values are decreasing for Zone V region.
5. Hence by using the higher damping ratio we can significantly reduce the storey displacement, storey drift and storey shear values.

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