

EARTHQUAKE RESPONSE ANALYSIS OF A MULTISTORIED RC BUILDING UNDER EQUIVALENT STATIC AND DYNAMIC LOADING AS PER BANGLADESH NATIONAL BUILDING CODE 2006

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Abstract: In the history of civil engineering, the structures were usually designed considering only static load factor. Later due to research in the civil engineering field, it was explored that the structures are also acted upon by several other loads which included seismic loads, wind loads, snow loads and many others depending upon the dimensions of the structure, location of the structure, type of the ground profile, etc. Hence this brought in the process of analyzing a structure for different types of loads and designing the structure for the critical load case of which dynamic load is considered as one of the important load for which the structure should be analyzed and designed. The main aim of this research work is to investigate the seismic performance of a multistoried reinforced concrete moment resisting framed building under static and dynamic loading as per Bangladesh National Building Code (BNBC, 2006). Static seismic load has been applied to the structure according to Equivalent static force (ESF) method. On the other hand, response spectrum (RS) method has been performed for the application of dynamic loading. The present study focuses on investigating the variation of storey-displacement and storey drift for each storey, base shear, bending moments and shear forces in columns at different storey level. Finally, a comparative study has been carried out between static and dynamic analysis. Based on computing modeling output data, it has been found that the base shear obtained from RS analysis is less compared to ESF method. Maximum storey-displacement obtained from dynamic RS analysis is about 78% of that of static analysis. At the same time, in case of maximum bending moment in an interior column, the dynamic value is approximately 87% of the static value.

Keywords: *Equivalent static force method, response spectrum analysis, story drift, base shear.*

1.0 Introduction

Earthquakes, caused by movements on the earth surface, result in different levels of ground shaking leading to damage and collapse of buildings and civil infra-structures, landslides in the case of loose slopes (Paz and Leigh, 2004). Several major earthquakes

having magnitude greater than 5 with epicenters within Bangladesh and part of India which are close to Indo-Bangladesh have occurred. Table 1 provides the list of the major earthquakes that affected Bangladesh and its surroundings.

Table 1: List of Major Earthquakes affecting Bangladesh

<i>Date Of Occurrence</i>	<i>Name</i>	<i>Magnitude</i>	<i>Epicentral Distance from Dhaka</i>
10 Jan, 1869	Cachar Earthquake	7.5	250
14 Jul , 1885	Bengal Earthquake	7.0	170
12 Jun, 1897	Great Indian Earthquake	8.7	230
08 Jul, 1918	Srimangal Earthquake	7.6	150
02 Jul, 1930	Dhubri Earthquake	7.1	250
15 Jan, 1934	Bihar-Nepal Earthquake	8.3	510
15 Aug, 1950	Asam Earthquake	8.5	780
08 May, 1997	Sylhet Earthquake	6.0	210
21 Nov,1997	Chittagong Earthquake	5.5	264
22 Jul, 1999	Moheshkhal Earthquake	5.2	300
27 Jul, 2003	Chittagong-Rangamati Earthquake	5.9	290

Furthermore, Bangladesh is divided into three zones determined from the earthquake magnitude for various return periods and acceleration attenuation relationship namely zones 1, 2, 3 being most to least severe gradually. The historical seismicity data of Bangladesh and adjoining areas indicate that Bangladesh is vulnerable to earthquake hazards (Jihan, 2014). As Bangladesh is one of the world's most densely populated area, any future earthquake shall affect more people per unit area than any other seismically active regions of the world. Both of the above factors call for evaluation of seismic hazard of Bangladesh so that proper hazard mitigation measure may be undertaken before it is too late. Traditionally, seismic design approaches are stated, as the structure should be able to ensure the minor and frequent shaking intensity without sustaining any damage. The assessment of the seismic vulnerability of structures is a very complex issue due to the nondeterministic characteristics of the seismic action. The major

developments in earthquake engineering have occurred in last four decades. This has been possible as a result of combination of factors such as installation of strong motion instruments in active seismic areas, as a result sizeable amount of ground motion data is available, development of basic principles of seismic design, design for strength and ductility, and basic concepts of design response spectrum, developments in mathematical modeling and dynamic linear and nonlinear analysis, shake table testing, quasi-static and pseudo dynamic testing, response control, seismic isolation and energy dissipating devices. Besides, study of behavior of structures and their performance in past earthquakes have provided a wealth of information on earthquake protection and safety. A research work was carried out on the seismic analysis of symmetric RC Frame using Response Spectrum Method and time history method (Harshitha *et al.*, 2014). Another study was pertinent to the response spectrum analysis of asymmetrical building (Shirule and Mahajan, 2013). and the seismic analysis of high-rise building by response spectrum method (Patil *et al.*, 2013).

At present, three common types of structural analysis are used to analyze high rise buildings subjected to earthquakes and those are equivalent static force method (ESFM), response spectrum (RS) analysis and time history analysis. In this study, the first and second method of analysis has been carried out. The objective of the present study is to provide a comparative study between the two seismic design methods recommended by BNBC (2006) namely, Equivalent Static Force (ESF) method and the dynamic Response spectrum (RS) analysis. Seismic load has been applied to the structure according to Equivalent Static Force Method as per BNBC (2006) which is considered as static load. For dynamic analysis, Response Spectrum (RS) method has been performed. Before performing RS analysis, modal analysis technique has been performed and for modal analysis, different mode shapes with different natural period of vibrations have been considered. The results obtained from both static and dynamic analysis are presented in the form of storey sway, storey drift, base shear, shear forces and bending moments in columns at different story levels and finally a comparative study has been done.

2.0 Response Spectrum Method

A response spectrum represents the response of single DOF systems to a time-history loading function. It is actually a graph of response versus frequency where the response might be spectral displacement, velocity, acceleration or force. Response spectrum of any building gives us a plot of peak or steady state response of a series of oscillators of a varying natural frequency, that are forced into motion by the same base vibration or shock. The resulting plot can then be used to pick off the response of any linear system, given its natural frequency of oscillation. The method involves the calculation of only the maximum values of the displacements and member forces in each mode using smooth design. Response spectra can also be used in assessing the response of linear systems with multiple modes of oscillation (multi-degree of freedom systems). Before

performing Response spectrum analysis, Modal analysis is performed to identify the modes, and the response in that mode are picked from the response spectrum (Khan, 2010). The peak responses are then combined to estimate a total response. Typical combination methods are the absolute sum of squares (ABS), square root of the sum of the squares (SRSS), complete quadratic combination (CQC) method etc. The main limitation of response spectra is that they are only universally applicable for linear systems. Response spectra can be generated for non-linear systems, but are only applicable to systems with the same non-linearity, although attempts have been made to develop non-linear seismic design spectra with wider structural application (Harshitha *et al.*, 2014).

3.0 Modeling and Analysis Approach

In the present study, a ten storied reinforced concrete (RC) multistoried building has been modeled and then analyzed using ETABS 2015 software package. The building is designed for residential use. The location of the building is assumed to be at Dhaka city of Bangladesh. The total height of the building above ground level considered for the study is 30m. Typical floor height is 3m and all the floors are considered as typical floors. The plan area of the structure is 30m × 30m with columns spaced at 5m from center to center in both directions. Material properties of the model are given in Table 2. Linear behavior of all materials have been considered in the analysis. For the purpose of modeling the real behavior of the slabs, they are modeled using shell elements to ensure adequate stiffness in all directions and transfer mass of slab to columns and beams. A rigid diaphragm is assumed at all floor levels.

Table 2:Material Properties

Name of the Material	Parameter	Values	Unit
Concrete	Mass per unit volume	2.4×10^{-9}	ton/mm ³
	Modulus of Elasticity	2×10^4	N/mm ²
	Poisson's ratio	0.2	---
	Compressive strength of Concrete, f'_c	27.58	N/mm ²
Steel	Yield strength of Steel, f_y	413.79	N/mm ²

Table 3: Geometric properties of the building model

Structural Components	Value	Unit
Corner Column	335 × 335	mm × mm
Exterior Column	385 × 385	mm × mm
Interior Column	485 × 485	mm × mm
All Beams	470 × 370	mm × mm
Slab Thickness	125	mm

There are different dimensions of structural components used for this building. Different section dimensions are presents in Table 3. Typical floors plan and isometric view of the ten storied building are presented in Figure 1 and 2 respectively. Three-dimensional analysis is carried out under static and dynamic seismic analysis in both X and Y directions, which are known to be orthogonal directions. Equivalent static force method (ESFM) and response spectrum method (RSM) have been used for performing static and dynamic analysis respectively.

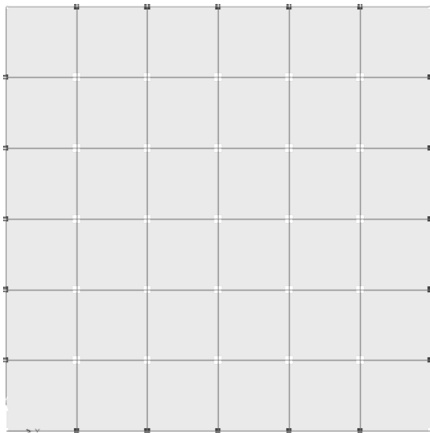


Figure 1: Typical floor plan of the studied ten-storied building

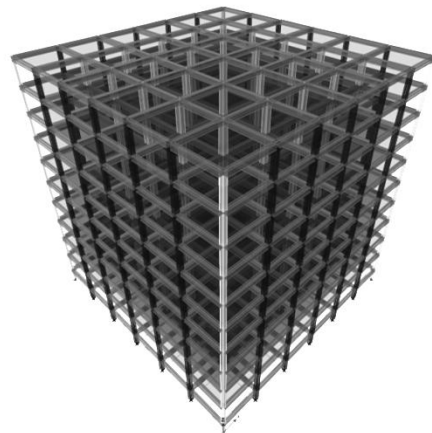


Figure 2: Isometric view of ten-storied building

3.1 Equivalent Static Force Method (ESFM)

Earthquake loads are applied according to equivalent static force method and analyzed with the help of ETABS V.2015 software package considering linear elastic behavior. Generally any structure is subjected to simultaneous ground motion in three orthogonal directions. In this analysis method, only one components of motion are accounted for the analysis as the structure is symmetric and regular shaped.

3.2 Response Spectrum (RS) Analysis

The seismic movement of the ground causes the structure to vibrate and causes structural deformity in the building. Different parameters regarding this deformity like frequency of vibration, time period and amplitude are of significant importance and defines the overall response of the structure. This overall response also depends on the distribution of seismic forces within the structure which again depends on the method used to calculate this distribution. Different methods of three dimensional dynamic analysis of structures have become more efficient in use along with the development of technology. The major advantage of using the forces obtained from a dynamic analysis as the basis for a structural design is that the vertical distribution of forces may be significantly different from the forces obtained from an equivalent static load analysis. Modal analysis is a pre-requisite to response spectrum analysis. The number of requested modes can be selected such that their combined participating mass is at least of 90% of the total effective mass in the structure (Chopra, 1995). In this analysis, the total numbers of modes are taken twelve. The goal of modal analysis in structural mechanics is to determine the natural mode shapes and frequencies of an object or structure during vibration. It must be ensured that the total number of modes extracted should be enough to characterize the structure's response in the frequency range of interest. Some of the modal shapes with corresponding natural period of vibration have been shown in Figure 3.

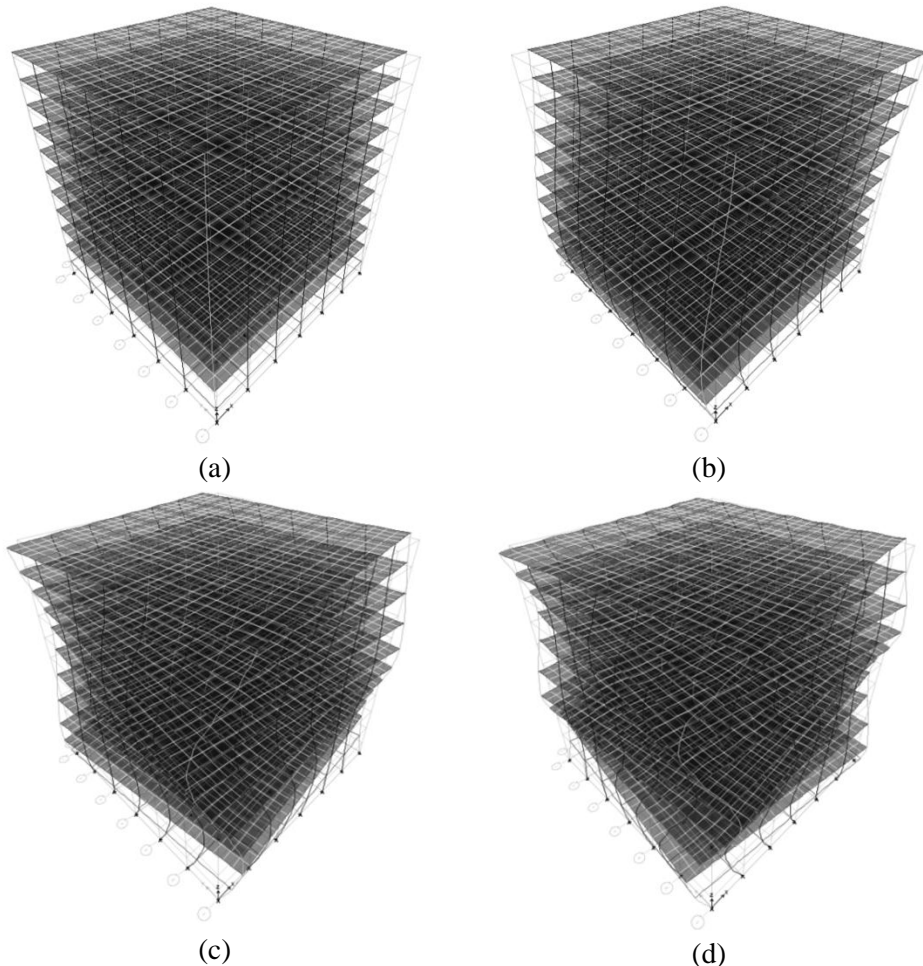


Figure 3: Different modes of vibration of the building with corresponding time period (a) First modal shape ($T = 1.52$ sec), (b) Fifth modal shape ($T = 0.493$ sec) , (c) Ninth modal shape ($T = 0.274$ sec), and (d) Twelfth modal shape ($T = 0.189$ sec).

The response spectrum analysis procedure provides maximum responses of the structure when it is vibrating in each of its significant normal modes. However, because these maximum modal responses will not occur at the same time during earthquake ground motion, it is necessary to use approximate procedure to estimate the maximum composite response of structure. Such procedures are typically based on an approximate combination of maximum individual modal responses (Ansary *et al.*, 2000). The square root of sum of squares (SRSS) of the maximum modal values is one of the popular methods. Another two methods namely, sum of the absolute of the modal response values (ABS) and the CQC are also used for peak response computation (Bagheri *et al.*, 2012). In order to account for the modal damping effect, the complete quadratic

combination (CQC) technique, which takes into account the statistical coupling between closely spaced modes caused by modal damping, is used for modal combination. This relatively new method of modal combination method was first published in 1981 (Kiureghian,1981). In RSA, the size of the problem is reduced to finding only the maximum response of a limited number of modes of the structure, rather than calculating the entire time history of responses during the earthquake. This makes the problem much more tractable in terms both of processing time and size of computer output. It is assumed here that the duration of the earthquake shaking is long when compared to the fundamental period of the structure and the design response spectrum exhibits slowly varying amplitudes over a wide range of periods that include the dominant modes of the structure.

There are two types of response spectrum analysis. One is Single-point response spectrum and the other one is Multi-point response spectrum. Here single-point response spectrum analysis is performed. The single-point response spectrum curve is shown in Figure 4. From this figure, it is observed that only one spectrum curve is specified at all supports of the model. In the present study, the spectral value, s is considered as spectral acceleration. Most importantly, for soil type 2 (deep cohesion less or stiff clay solids) and damping ratio of 5%, the normalized response spectra according to BNBC (2006) has been used at all supports of the building model which has been shown in Figure 5. Here a scale factor gZ has been used for the input dynamic seismic loading.

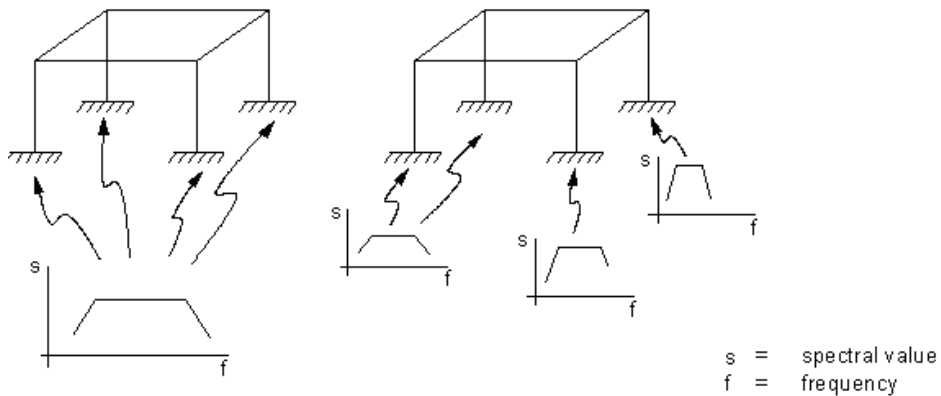


Figure 4. Single-Point and Multi-point Response Spectra

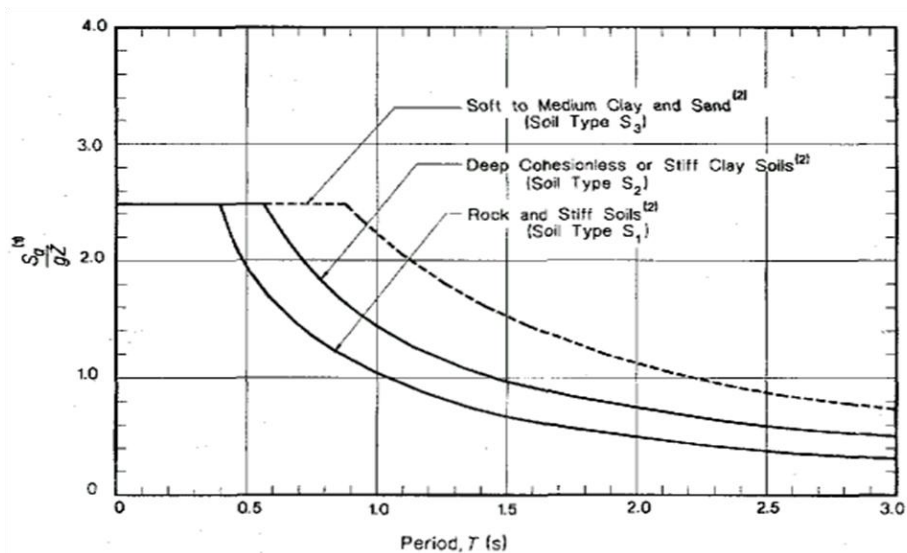


Figure 5: Normalized Response Spectra for 5% Damping Ratio (BNBC, 2006)

4.0 Results and Discussions

The comparison of lateral story displacement, story drift, base shear, shear forces, bending moments at corner, exterior and interior columns obtained from equivalent static force method and dynamic response spectrum analysis has been shown in the following Figures from 6 to 12.

4.1 Lateral Story Displacement

From Figure 6, it has been clearly observed that maximum story sway occurs at top story level for both analyses. It has been found here that the maximum sway obtained from dynamic RS analysis is about 78% of that of static ESFM. Mahmoud and Abdallah (2014) carried out a research work on analysis of multi-Storey RC Buildings under equivalent static and dynamic loads according to Egyptian code. The study shows that the maximum storey displacement obtained from static ESFM is about 18% higher than that of dynamic RS analysis. Likewise, in the present study, it has been found that in case of ESFM, maximum storey displacement is nearly 28% higher than that of RS analysis.

4.2 Storey Drift

From the following Figure 7, it has been observed that the storey drift for the building under dynamic earthquake load is greater than that of static load case.

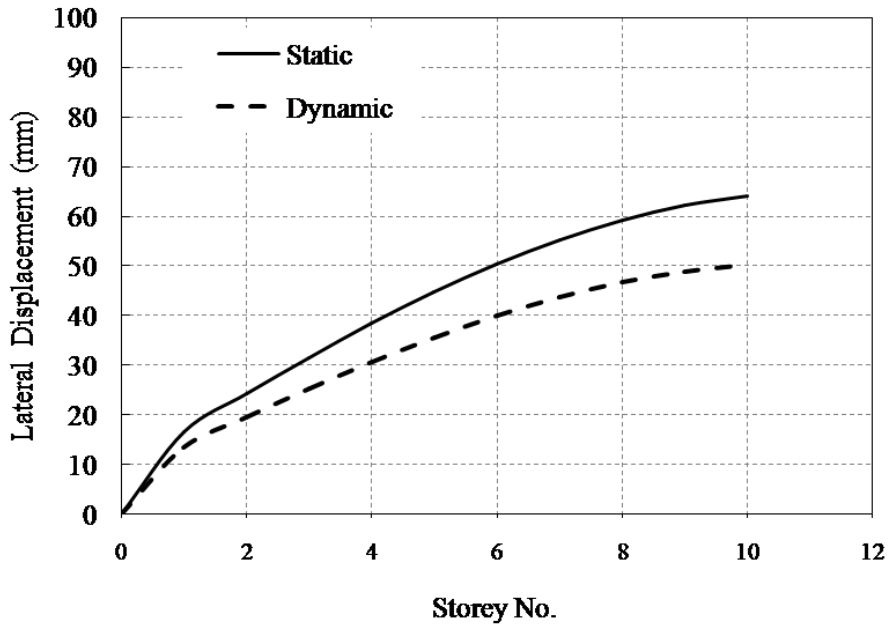


Figure 6: Lateral displacement along X direction at different storey level

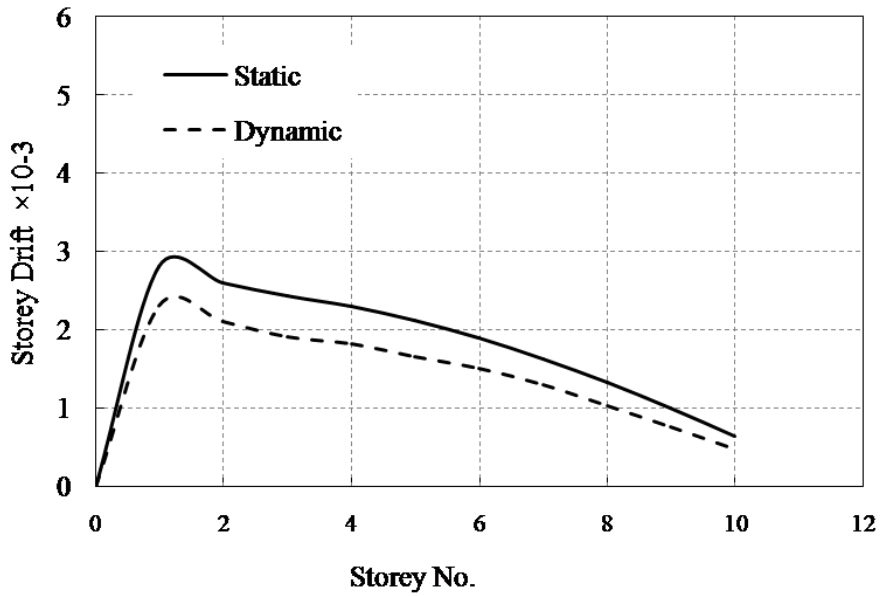


Figure 7 : Lateral Story drift along X direction at different storey level

Story drifts show a decreasing tendency with increasing the height of the building in both cases. Khaled *et al.* (2010) carried out a research work on the evaluation of seismic performance of multistory buildings designed according to Egyptian code. The study shows that the maximum storey drift obtained from static ESFM is about 44% higher than that of dynamic RS analysis. Likewise, in the present study, it has been found that in case of ESFM, maximum storey drift is nearly 34% higher than that of RS analysis.

4.3 Base Shear

Total base shear is a very important parameter for earthquake resistant design of buildings. In this study, total base shear obtained from dynamic RS analysis is about 85% of static ESFM analysis result which can be seen from the following Figure 8. The study (Mahmoud and Abdallah, 2014) shows that the total base shear obtained from static ESFM is about 8% higher than that of dynamic RS analysis. Likewise, in the present study, it has been found that in case of ESFM, the base shear is nearly 17% higher than that of RS analysis. In addition, for the purpose of comparisons and also as per BNBC code for loads requirements, if the shear at base determined by dynamic RS analysis is less than that specified by ESF procedure, it has to be scaled to the static base shear determined by ESF procedure. Similarly, if the dynamic base shear obtained from a dynamic RS analysis is of higher value compared to the static base shear, it may be scaled down as per BNBC code.

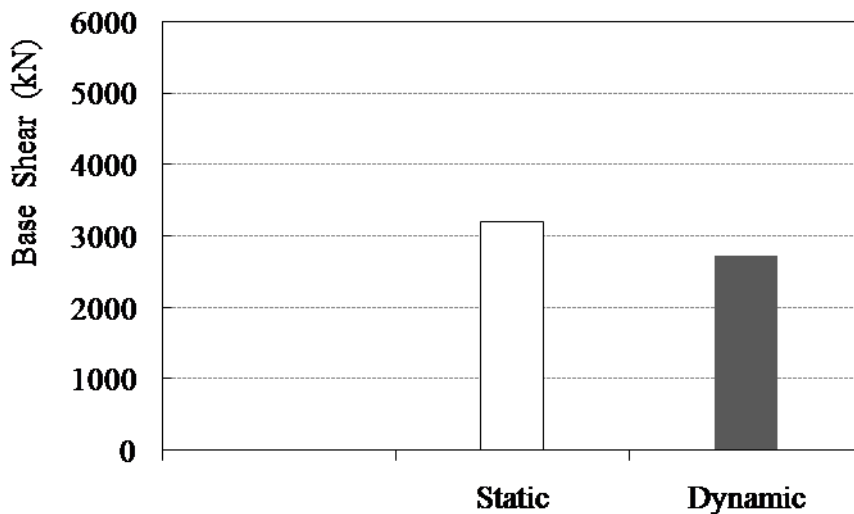


Figure 8: Comparison bar graph of Total Base Shear

Figure 8 shows the obtained base shear using both ESF and RS procedures before scaling and it has been seen that the dynamic RS analysis produces base shear lower

than the one obtained from static force procedure. As per BNBC code (2006), for all regular structures, design base shear must not less than 90 percent of the base shear determined by ESFM. In this case, a scaling factor of 1.06 is applied to dynamic base shear for the load requirements as per code.

4.4 Shear Forces in Columns

From Figure 9, it has been clear that the difference of shear forces in an interior column between ESFM and dynamic RS analysis is highest at the ground floor in which dynamic result is about 84% of the static value. But the differences of the shear forces are decreasing gradually with increasing the height of the structure. Furthermore, Figure 10 shows the comparison of maximum shear forces in corner, exterior and interior columns. It has been found here that the Maximum Column shear forces obtained from dynamic analysis is about 87% of the static value.

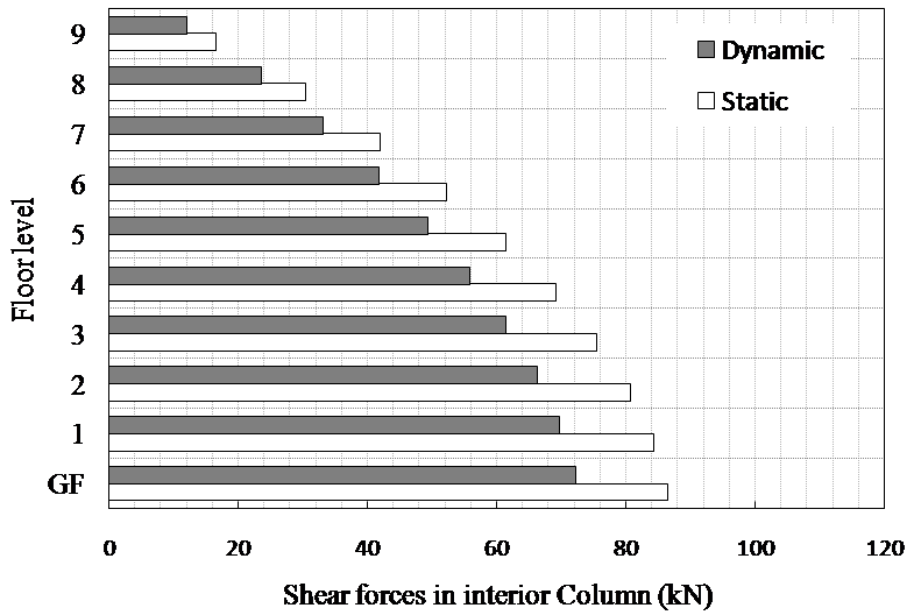


Figure 9: Comparison of Shear forces in Interior column at different story level

4.5 Bending Moments in Columns

Figure 11 represents the comparative study of exterior column bending moments between static and dynamic analyses. The difference of column bending moments is higher at lower floor levels and at the ground floor, the dynamic value is approximately 82% of static value. But the differences of the column bending moments are decreasing gradually with increasing the height of the structure.

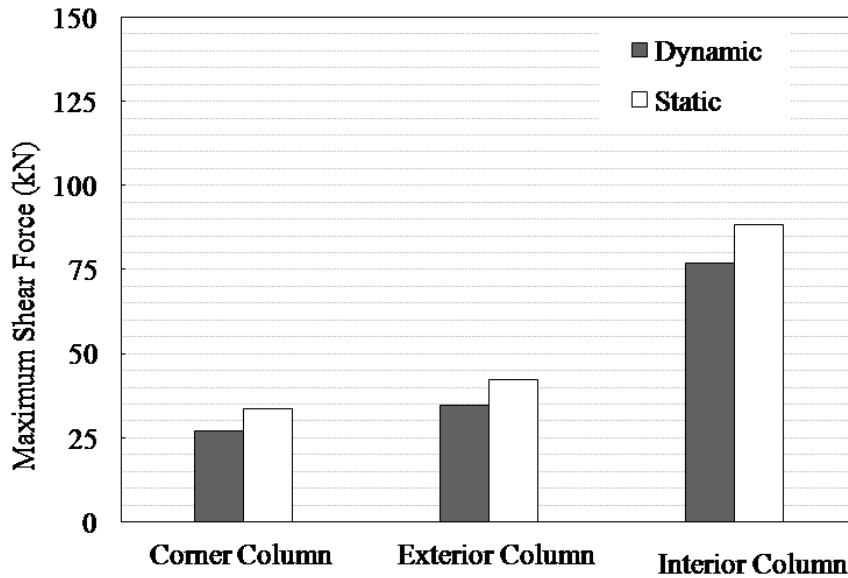


Figure 10. Bar graph for Maximum Column Shear forces at different columns

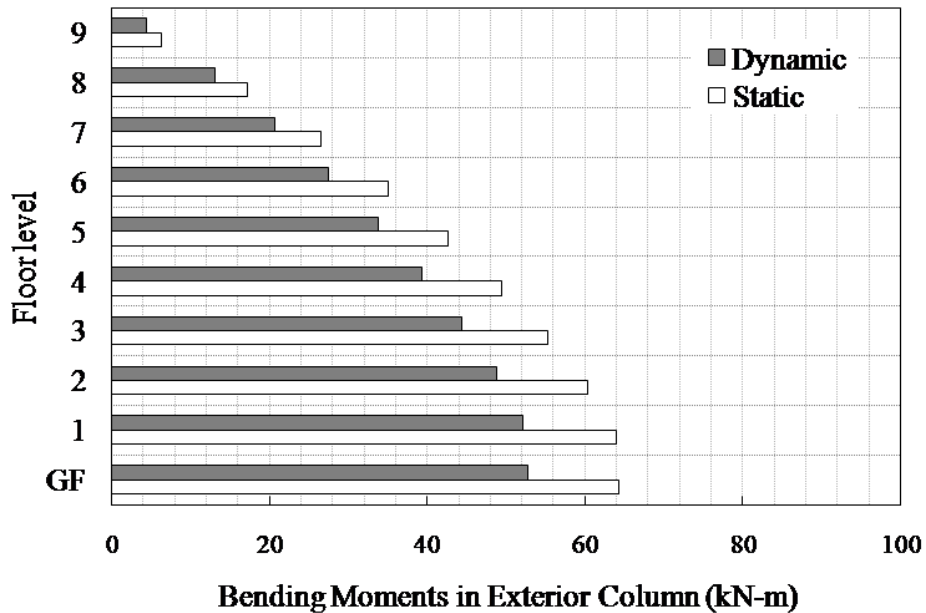


Figure 11: Comparison of Bending Moments in Exterior column at different story level

In addition, Figure 12 shows the comparison of maximum bending moments at corner, exterior and interior columns. It has been found here that in case of corner column the maximum bending moment obtained from dynamic analysis is about 81% of the static result. In case of exterior column and interior column, the dynamic values are almost 82% and 83% of those of static values respectively.

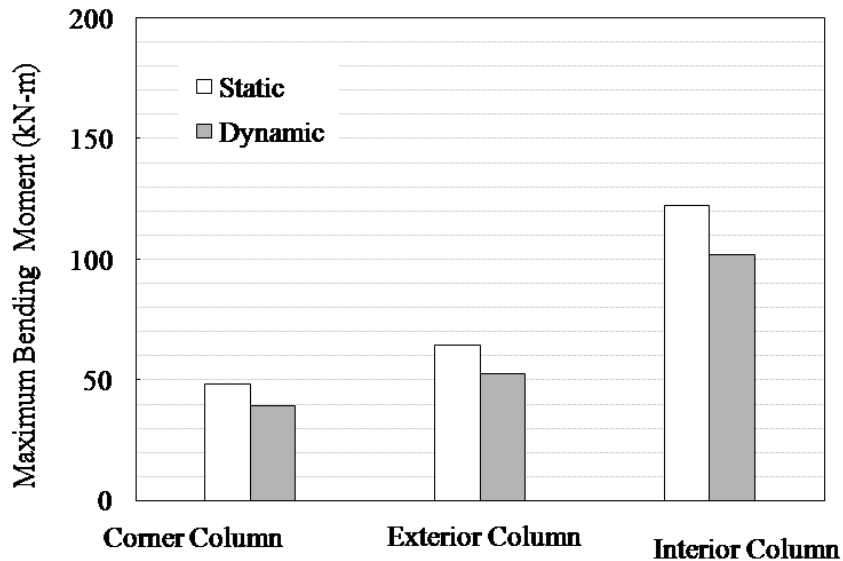


Figure 12: Bar Graph of Maximum Column Bending Moment

5.0 Conclusions

The important conclusions derived from the presented study are summarized as follows:

- The dynamic behavior are closely observed and compared with static behavior. It is clearly found that the responses of the structures in case of response spectrum analysis are significantly different from the static response. From dynamic response, it is observed from the present study that less internal resisting forces are developed in the structural elements in case of dynamic response spectrum analysis while compared with static ESF method.
- It is clear from the output results that the static analysis (ESFM) gives higher values for maximum story displacement in both directions rather than the dynamic RS analysis method. In case of maximum lateral displacement at top story level, dynamic value is about 78 % of the static value.

- Storey drifts obtained from dynamic analysis are little less than those of static analysis.
- In case of base shear, dynamic result is about 85% of static analysis. In this study, scaling factor of 1.06 is applied to the base shear obtained from RS analysis for obtaining the scaled base shear prescribed by BNBC code.
- In case of maximum shear forces in columns, dynamic results are about 87% of static results.
- In case of maximum column bending moment, the results obtained from dynamic RS analysis are about 81%, 82%, 83% of static analysis for corner column, exterior column and interior column respectively.

Even though the dynamic response spectrum method of seismic design is the preferred method due to the computational advantage in predicting response of structural systems where it involves the calculation of only the maximum values of the induced response in each mode, equivalent static force method (ESFM) is used as a benchmark to scale the design base shear obtained by the dynamic RS analysis before the distribution of the lateral seismic forces over the height of the structure under the dynamic RS base shear. Furthermore, engineers and researchers, however, should clearly understand that the response spectrum method is an approximate method used to estimate maximum peak values of displacements and forces and that it has significant limitations. It is restricted to linear elastic analysis. For inelastic analysis, other dynamic analysis techniques such as nonlinear time-history analysis method can be performed for getting analysis results more precisely.

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