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Scale Factor In Non-Linear Time History Analysis For RCC Multistorey Building

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Abstract: This research paper describes the result of the time history analysis on the fifteen-storey structure. Earthquake occurred in multistorey building shows that if the structures are not well designed and constructed with and adequate strength it leads to the complete collapse of the structures. To ensure safety against seismic forces of multi-storied building hence, there is need to study of seismic analysis to design earthquake resistance structures. Time history analysis provides for linear or nonlinear evaluation of dynamic structural response under loading which may vary according to the specified time function. This paper is explaining the evaluation of scale factor for various analysis in structure. The ETABS software is used to analyse G+15 storey building. The Bhuj, Alaska and Iran time history data are taken from peer database and further scaling is done as per IS 1892:2016 and ASCE code. This paper gives the idea about the scale factor calculation for earthquake analysis in RCC multistorey building. The response of building also checked for limiting value given in the IS code. The response results such as displacement, base shear and storey drifts are discussed further.

IndexTerms - Earthquake, time history, scale factor, response, displacement, base shear, storey shear, ETABS software

I. Introduction

All real physical structures, when subjected to loads or displacements, behave dynamically. The additional inertia forces, from Newton's second law, are equal to the mass times the acceleration. If the loads or displacements are applied very slowly then the inertia forces can be neglected and a static load analysis can be justified. Hence, dynamic analysis is a simple extension of static analysis In addition, all real structures potentially have an infinite number of displacements. Therefore, the most critical phase of a structural analysis is to create a computer model, with a finite number of mass less members and a finite number of node (joint) displacements, that will simulate the behavior of the real structure. The mass of a structural system, which can be accurately estimated, is lumped at the nodes. Also, for linear elastic structures the stiffness properties of the members, with the aid of experimental data, can be approximated with a high degree of confidence. Incremental dynamic analysis is an essential tool in earthquake engineering, as it can provide the seismic demand and capacity of a structure through nonlinear dynamic analyses for a set of ground motions. In incremental dynamic analysis, each ground motion is scaled to multiple intensity levels. A large scale factor (SF) is sometimes required for the selected intensity measure (IM) to produce the damage (e.g., collapse) in the structures; however, the bias on the structural response is inevitable. However, the dynamic loading, energy dissipation properties and boundary (foundation) conditions for many structures are difficult to estimate. This is always true for the cases of seismic input or wind loads. The IS 1893-2016 states that linear dynamic analysis shall be performed to obtain the design lateral force (design seismic base shear, and its distribution to the different levels along the height of the building, and to the various lateral load resisting element) for all building, other than regular building lower than 15m in seismic zone II. Practically all multistoried buildings be analyzed as three-dimensional systems. This is due to the fact that the buildings have generally irregularities in plan or elevation or in both.

II. Literature Review

Huang et al. (2010) studied four scaling methods are studied, namely, 1) geometric mean scaling of pairs of ground motions, 2) spectrum matching of ground motions, 3) first-mode-period scaling to a target spectral acceleration and 4) scaling of ground motions per the distribution of spectral demands to see the impact of alternate ground-motion scaling procedures on the distribution of displacement responses in single-degree-of-freedom (SDOF) structural systems. **Huang et al (2012)** The dispersions in structural responses are critical to the results of seismic performance assessment of buildings. From this investigation, it is also observed that the dispersions in response quantities are very much dependent on the dispersions in spectral ordinates for the scaled ground motions. The target seismic hazard for performance assessment of a high-rise building should be defined for both median magnitude and dispersion and the scaled ground motions should appropriately represent both the median magnitude of and dispersion in the spectral acceleration demand of ground motions. **Miguel et al ((2015)** obtained the series of time-history earthquake response analyses have been carried out using 3 different procedures to match an earthquake record to a target spectrum. Six different liquid storage tanks were considered. The main aim was to evaluate the different scaling procedures given by three internationally used design specifications and to develop an understanding of the different consequences of the scaling procedures for the tank response.

Sandy I. Yansiku (2017) states the spectral matching process of 28 strong ground motion records shows that ETABS yields better mean spectrum shape than seismomatch and has resulted in five best accelerograms for each site class which are then applied to a 10-story building structure to observe structural response and compare the difference due to the artificial accelerograms and the original El Centro record. Kazem Shakeri et al proposed the procedure through three regular 8-, 14- and 20-story buildings and an irregular 20-story building. The mean value of the story drift ratios obtained from the nonlinear time history analysis from 21 unscaled records is considered as the benchmark result. The mean values of the story drift ratios from three sets of records scaled based on the SSSP, P-SSSP, MPS and ASCE 7–10 methods are compared with benchmark result for each building. Weiping Wen et al. (2019) obtained the effects of ground motion scaling on the response of structures were evaluated in this study, in which the interdependency between the IM and SF was considered, based on the maximum displacement of inelastic SDOF systems with different periods and strengths. The bias introduced by ground motion scaling was computed based on the differences between the benchmark and scaled models. The former was derived from unscaled ground motions, while the latter was derived from scaled ground motions. Eight different IMs, including those related to ground acceleration (i.e., PGA, IA, and IC), ground velocity (i.e., PGV), ground velocity (i.e., drms and PGD) and spectra (i.e., Sa(T) and SI), were selected as alternative IMs. In total, 1593 ground motions were collected from the PEER NGA-West2 database by excluding the conditions of soft soil and pulse-like records.

III. METHODOLOGY

Seismic analysis is a subset of structural analysis and is the calculation of the response of a building (or non-building) structure to earthquakes. It is part of the process of structural design, earthquake engineering or structural assessment and retrofit (see structural engineering) in regions where earthquakes are prevalent. There are following methods by which we can analyse the seismic performance of the building :- 1. Linear Static Analysis: Equivalent Static Analysis 2. Nonlinear Static Analysis: Pushover Analysis 3. Linear Dynamic Analysis: Response Spectrum Analysis 4. Non-Linear Dynamic Analysis: Non-linear Time History Analysis.

Linear Static Analysis: The equivalent static lateral force method is a simplified technique to substitute the effect of dynamic loading of an expected earthquake by a static force distributed laterally on a structure for design purposes. The total applied seismic force V is generally evaluated in two horizontal directions parallel to the main axes of the building. It assumes that the building responds in its fundamental lateral mode. For this to be true, the building must be low rise and must be fairly symmetric to avoid torsional movement underground motions. The structure must be able to resist effects caused by seismic forces in either direction, but not in both directions simultaneously.

Response Spectrum analysis: As per IS 1893(Part 1): 2016, linear dynamic analysis shall be performed to obtain the design lateral force i.e., 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 the buildings other than regular buildings lower than 15 m in seismic zone II. Dynamic analysis may be performed by either Time History Analysis Method or the Response Spectrum Method.

Pushover Analysis: It is practical method in which analysis is carried out under permanent vertical loads and gradually increasing lateral loads to estimate deformation and damage pattern of structure. Non-linear static analysis is the method of seismic analysis in which behaviour of the structure is characterized by capacity curve that represents the relation between the base shear force and the displacement of the roof. It is also known as Pushover Analysis.

Non-linear dynamic analysis - time history analysis: Time history analysis is an important technique for structural seismic analysis especially when the evaluated structural response is nonlinear. To perform such an analysis, a representative earthquake, time history is required for a structure being evaluated. Time history analysis is a step-by step analysis of the dynamic response of a structure to a specified loading that may vary with time. Time history analysis is used to determine the seismic response of a structure under dynamic loading of representative earthquake.

Scaling of various methods:

The static analysis does not require any scaling factor to analyse the structures. IS 1893:2016 gives all the data and factors for which the structure is to be analyse. The time period formula and constant are given in the IS code directly.

Nonlinear analysis has to be done with application of some scaling factors. IS 1893 is given the procedure for scaling of response spectrum analysis. The ground motion should be taken as per code.

Selecting the seismic loading for design and/or assessment purposes is not an easy task due to the uncertainties involved in the very nature of seismic excitations. One possible approach for the treatment of the seismic loading is to assume that the structure is subjected to a set of records that are more likely to occur in the region where the structure is located.

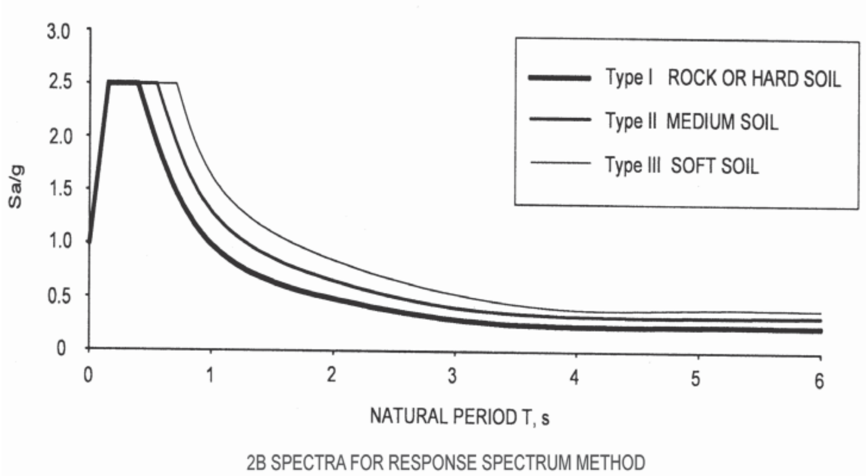


Figure 1. Response Spectrum curve IS 1983-2016

The first scale factor will be IG/2R (mentioned in ETABS manual) where the unit of G will be taken as the same unit of acceleration in the software. The scale factor should as per IS 1893-2016 Clause 7.7.3. To match Base shear.

Time History Scaling:

The procedure for time history scaling is not given in the IS code. So different country codes should be use for that purpose. FEMA and ASCE codes are giving the exact procedure to apply time history data to analyse the structure in any software tools.

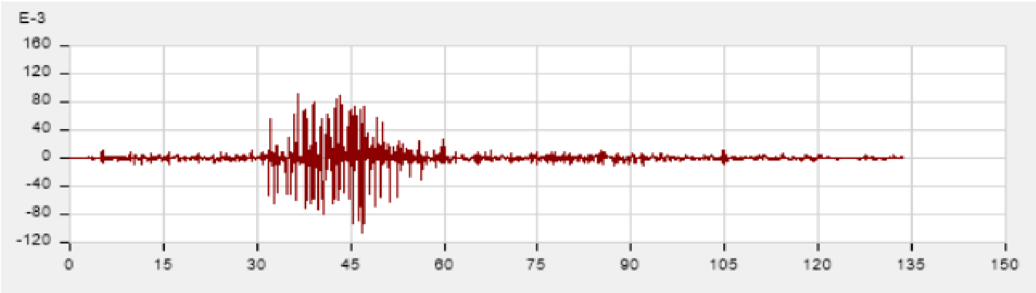


Figure 2 : BHUJ Time history data

Chapter 16 of ASCE 7 provides the requirements for performing a linear or a nonlinear response history analysis. Among the key components of such an analysis are the selection of an appropriate suite of ground motions and the scaling of these motions. Scaling for 2D and 3D analysis are separately explained. Here we will consider scaling only for 3D analysis.

The ground motion scaling requirements for 3D analysis are as follows: 1. For each earthquake in the suite, the square root of the sum of the squares (SRSS) of the spectra for each pair of horizontal components is computed. When computing the SRSS, the motion are recorded, without scale factors. 2. Individual scale factors are applied to the SRSS spectra such that the average of the scaled SRSS spectra does not fall below 1.3 times the design spectra by more than 10 percent for any period between 0.2T and 1.5T. 3. Table 5.12 shows the three-time history data taken for the analysis with their epicentral distance, magnitude and scale.

As per IS: 1893 – 2016 (part1) if the base shear obtained from the equivalent static analysis V is more than that obtained from dynamic analysis Vb then a scale factor of V/Vb has to be multiplied by the original scale factor. This IS code clause should be considered for the dynamic analysis.

IV. Modelling:

For time history analysis a building structure is modelled in ETABS software. The scaling of dynamic analysis applied to the building model to obtain the behaviour of time history ground motion.

Table 1: Configuration of building model

Height of Floor = 3 m
Height of Parapet = 1.2 m
Grade of Steel = Fe415
Grade of Concrete for Column = M30
Grade of Concrete for Beams and Slab = M25
External Wall = 230 mm
Internal Wall = 115 mm
Unit Weight of Brick Masonry = 18Kn/m3
Floor Finish = 1.875Kn/m3
Live Load = 2.5 Kn/m3
Size of Columns = 300X900 mm, 300X750 mm
Size of Beams = 300X450 mm
Frame type = Special moment Resistant Frame

Importance Factor = 1.2 (as IS 1893-2016)
Response Reduction Factor = 5 (as IS 1893-2016)
Zone Factor (Z) = 0.16
Soil Type: Medium
Gap Element
Grade of Shear wall = M30
Thickness of Shear wall = 180 mm

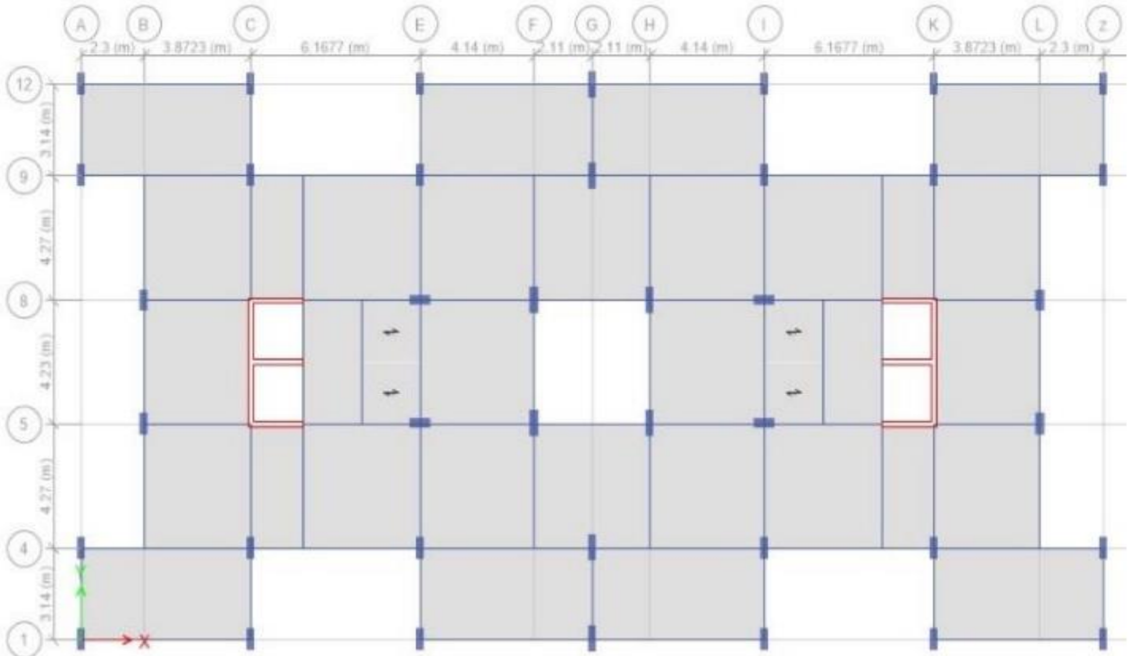


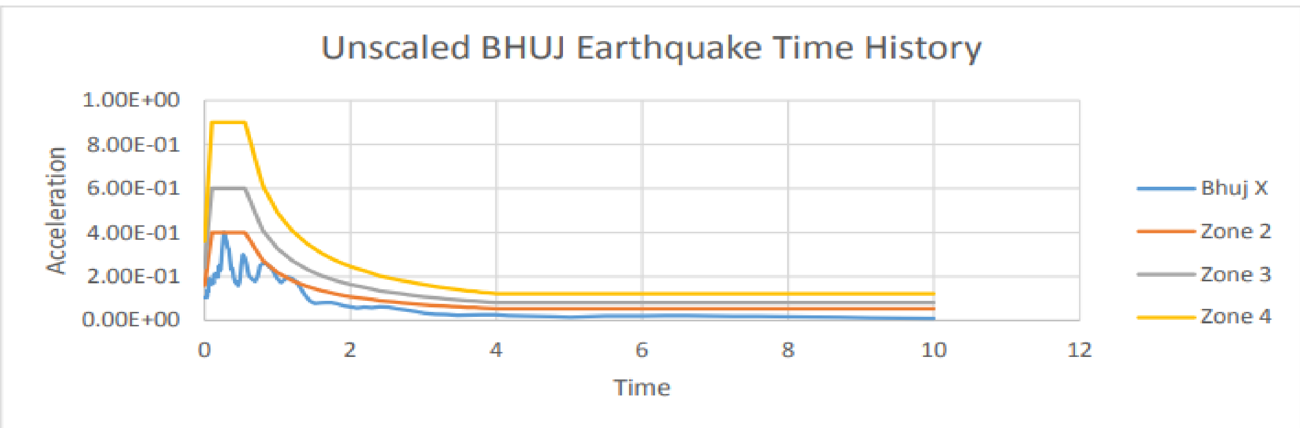
Figure 3: Model (G+15)

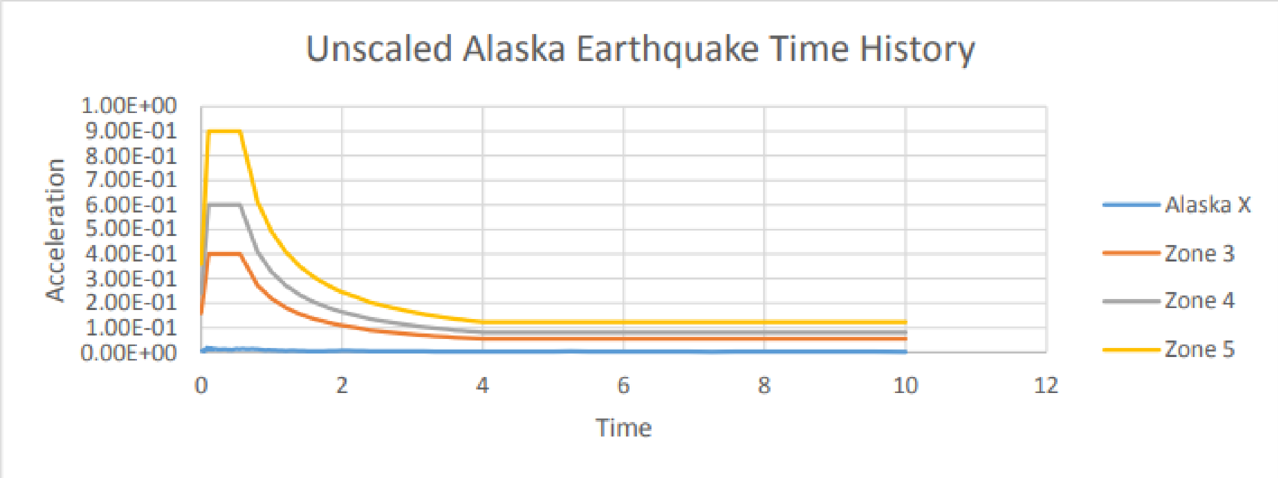
1) Scaling factor in ETABS:

The IS 1893:2016 has given the procedure for the scale factor which is already explained above. The procedure is followed and the factor is calculated for the model.

Table 2: Response Spectrum Scale Factor

Sr. No.	Scale Factor		Total
1	IG/2R	1177.2	
2	Scale to match Base Shear (X)	4.825	5679.99
3	Scale to match Base Shear (Y)	2.342	2757.002





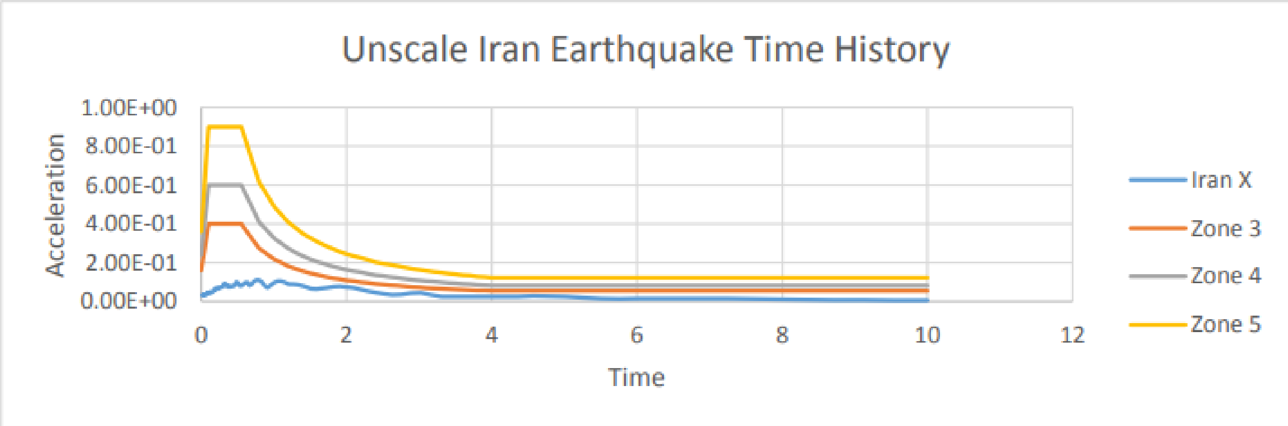
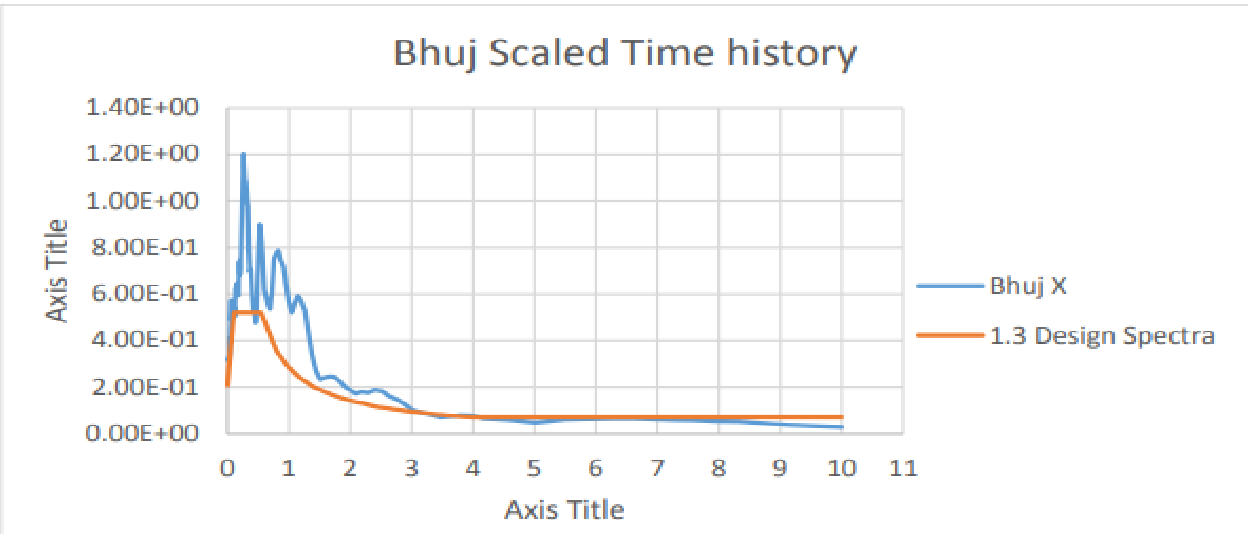
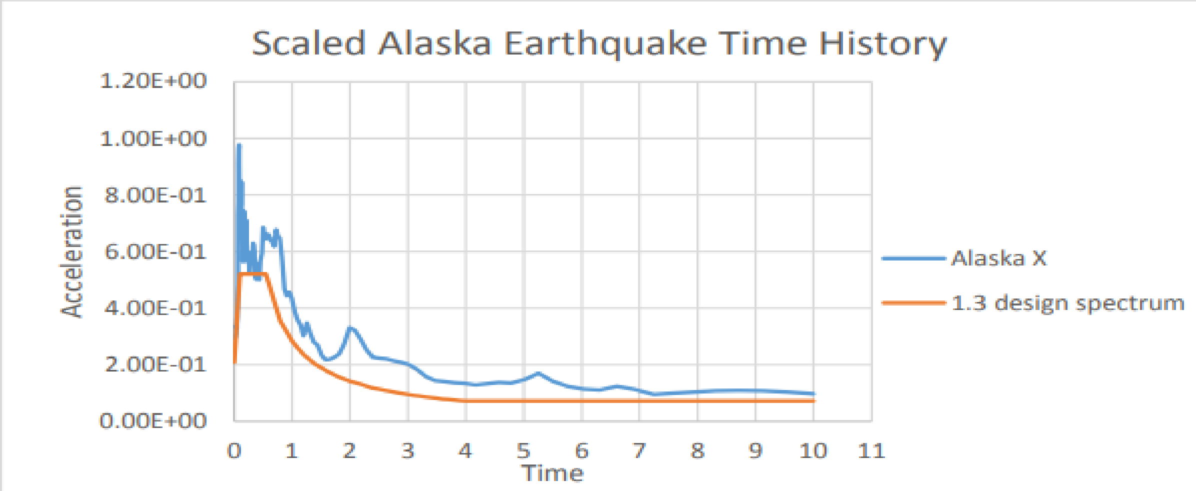


Figure 4: Unscale Time History Data

For the Time history function in ETABS the response of the unscaled three individual time history records in comparison with the design spectrum of zone 3,4 & 5. After the time history load case is define, the first scale factor will be IG/2R where the unit of G will be taken as the same unit of acceleration in the software. Hence first scale factor turns out to be (1.2*9810)/ (2*5) = 1177.2 75. The second scaling must be done if the response of the particular time history data is less than the design spectrum as shown in figure 5.11 which is then scaled up to 1.3 design spectrum as shown in figure 5.12. As per IS: 1893 – 2016 (part1) if the base shear obtained from the equivalent static analysis V is more than that obtained from dynamic analysis Vb then a scale factor of V/Vb has to be multiplied by the original scale factor.

The scaling of design spectra is done in Excel sheet for various try and error. The final scaled design spectra is taken for the analysis. The design spectra values are taken from the IS code. The calculation of various formulas also done in excel. The 70% scaled time history data should be above the design spectra of particular zone. The design spectra also different for all zones of IS code.





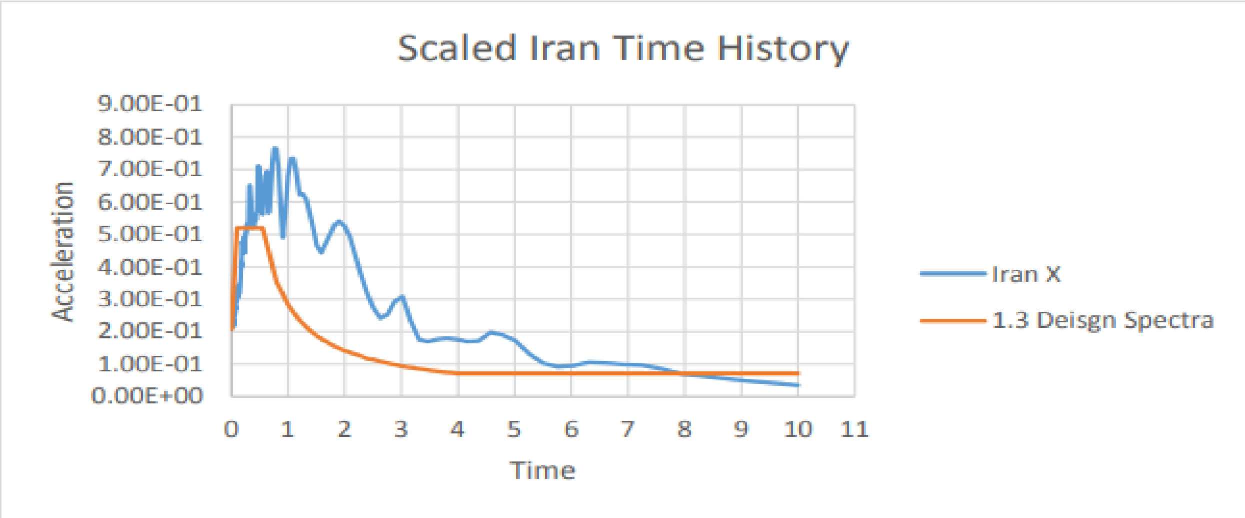


Figure 4: Scale Time History Data

The final scale factor for time history data are given in the table. This scale factor should be use for analysing the structure in ETABS software.

Table 2: Time History Scale Factor

Sr. No.	Scale Factor	Earthquake Event		
		Bhuj	Alaska	Iran
1	IG/2R	1177.2	1177.2	1177.2
2	Scaling For Design Spectra	3	50	7
3	Scaling to match Base Shear	2.804	2.2558	1.1195
Total		9902.606	132776.4	9225.128

V. Results and Discussion:

The dynamic and static analysis carried out in the ETABS software in different files. Base Shear, Displacement and storey drifts are obtained for the building model.

Table 3: Base Shear of structure for various analysis

MODEL	Base Shear (kN)				
	EQ X	RS	Time History		
			Bhuj	Alaska	Iran
Model 1	3610.306	3609.918	3610.151	3609.291	3609.107

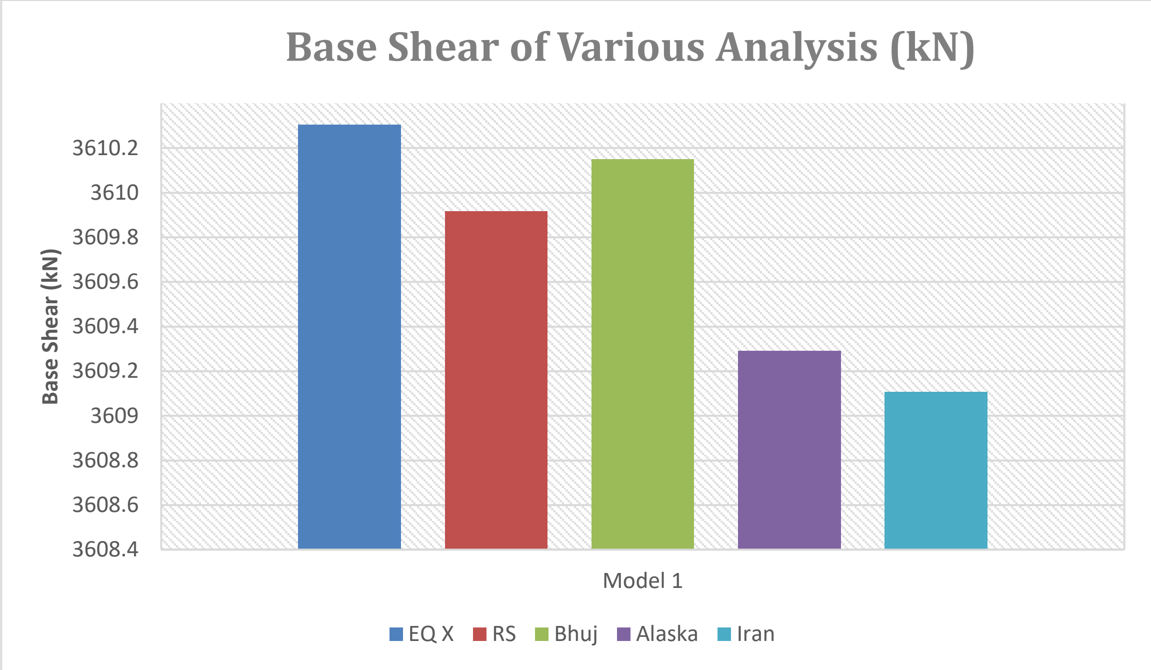


Figure 5: Base Shear of structure for various analysis

The base shear of the model is almost same for all analysis. It is because the scaling factor if the scaling is not done than the base shear may be fluctuate more than 40% which is not a exact solution for various analysis.
The displacement of the model is also obtained for various analysis. The displacement result is exact after taking scaling factor for dynamic analysis. The displacement of the building at top storey level is maximum which gives the idea about the deflection of the structure. The displacement should be under the limit given in the IS 1893 code.

Table 4: Displacement of structure for various analysis

MODEL	Displacement (mm)				
	EQ X	RS	Bhuj	Alaska	Iran
Model 1	326.01	233.36	220.97	349.43	246.72

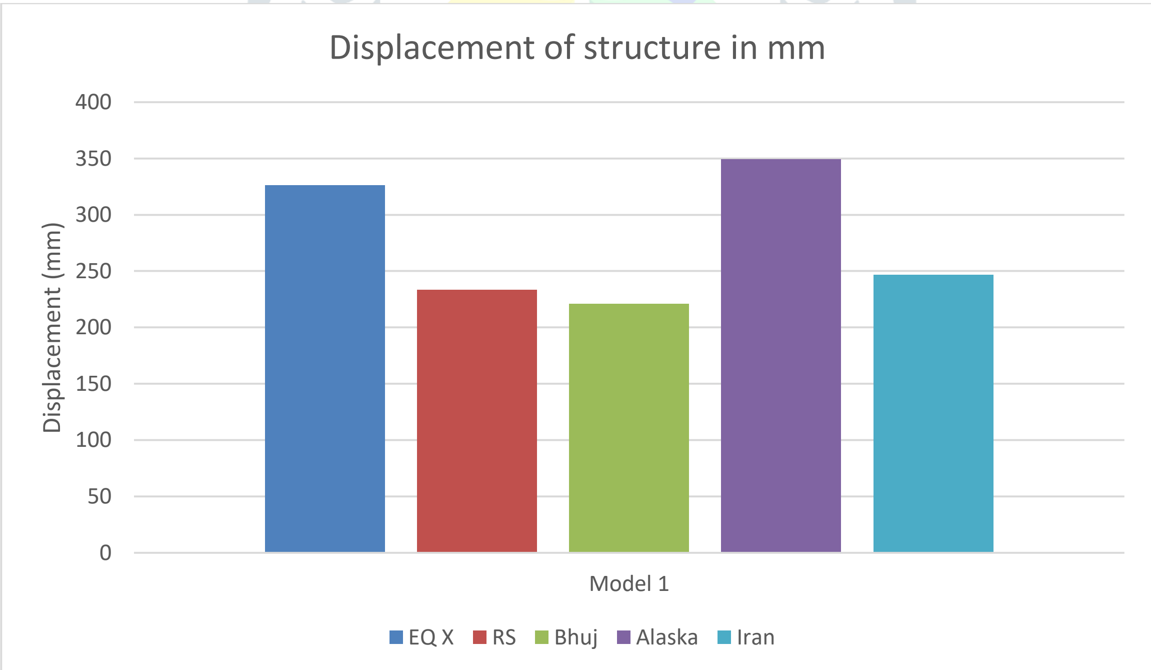


Figure 6: Displacement of structure for various analysis

The displacement in Alaska time history is greatest than all other analysis. The ground acceleration is maximum in Alaska data so the response is maximum.

Table 5: Storey Drift for various analysis

Storey	Height	EQ X	RS	Bhuj	Alaska	Iran

Storey 15	45	0.002177	0.001781	0.003025	0.002462	0.001536
storey 14	42	0.002506	0.002025	0.003392	0.002823	0.001779
Storey 13	39	0.002923	0.002298	0.003703	0.003253	0.002083
Storey 12	36	0.003363	0.002563	0.003851	0.003678	0.002384
Storey 11	33	0.003779	0.002809	0.003795	0.004063	0.002637
Storey 10	30	0.004142	0.003032	0.003869	0.00441	0.002814
Storey 9	27	0.004437	0.003233	0.003972	0.004728	0.002925
Storey 8	24	0.004648	0.003404	0.003959	0.004961	0.003025
Storey 7	21	0.004648	0.003537	0.00379	0.00507	0.003218
Storey 6	18	0.004766	0.003615	0.003586	0.005078	0.003427
Storey 5	15	0.004626	0.003609	0.00345	0.005032	0.003516
Storey 4	12	0.004298	0.003465	0.003255	0.004741	0.003415
Storey 3	9	0.003706	0.003095	0.003064	0.004102	0.003045
Storey 2	6	0.002728	0.002354	0.002509	0.003014	0.002294
Storey 1	3	0.001156	0.001024	0.001143	0.001275	0.000986
Base	0	0	0	0	0	0

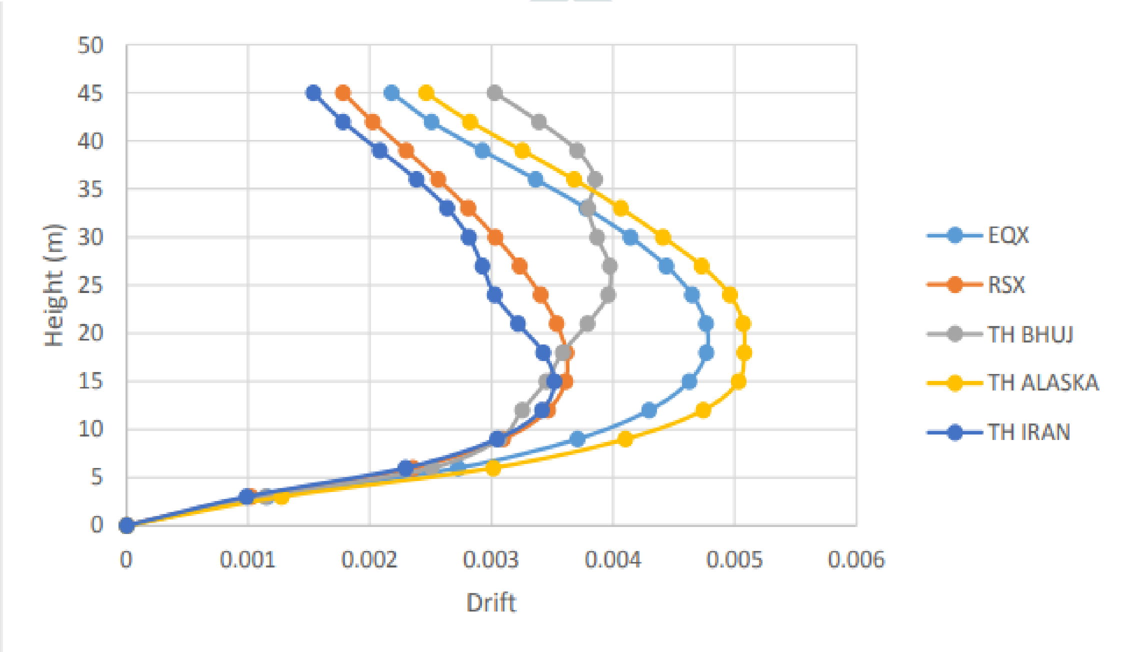


Figure 7: Storey Drift for structure in various analysis

The storey drift is maximum in mid storey. The storey drift for Alaska time history is maximum because the PGA is maximum. The Bhuj time history is giving the uncertain drift graph. All the values of the time history analysis obtained due to scaling of time history data. If the data is applied directly in the ETABS then the building response is very unrealistic. So, for design and analysis purpose the scaling should be done for real response of the building.

VI. Conclusion:

The static and dynamic analysis gives the different results for the same structure. When the time history data is scaled with proper procedure given in the IS code and different country codes. The following results are concluded in this study:

- Equivalent static analysis does not require any scale factor to analysis any structure in Etabs. The results obtained in this analysis are exact and real if the modelling and loading are applied accurately.
- For dynamic analysis the scaling factor is important to get real and exact results.
- Response spectrum analysis should be applied with the two types of scaling factor which is given in ETABS manual and IS code give the procedure. The scaling factor of IG/2R which is 1177.2 and scale factor for base shear is 4.825 in X direction and 2.342 in Y direction. Total will be multiplication of IG/2R and factor in respective direction.
- In time history analysis first scaling should be the same IG/2R which is given in manual. Another scaling factor is 70% of time history data should greater than 1.3-time design spectra of particular zone.
- The results obtain after applying this scale factor are exact and real. Base shear should not be more or less than 10% of static analysis which is criteria for dynamic analysis.
- Displacement is getting very different for all analysis techniques. This is due to PGA and response of building in particular time period. If the time period of the building matches the acceleration of time history data than the displacement will be under control.

- The maximum displacement getting from Alaska time history data because of PGA. Earthquake acceleration is higher in this data which results maximum response of the building.
- The storey drift also maximum in Alaska time history data. Drift is also depends on the acceleration of the earthquake excitation which is higher in Alaska data.
- The maximum drift is 0.003427 at 6th storey and the displacement 350 mm in top storey for Alaska data.

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