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Scaling Of Ground Motions for Performing Incremental Dynamic Analysis of RC Framed Structures

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Abstract: In the modern world of structural engineering design of structures subjected to earthquake promotes a need of developing simple and practical methods for estimating seismic demands of structures. These methods are based on their behavior which is to be predicted prior to design. Researchers are implementing various static as well as dynamic, linear as well as nonlinear to predict the performance of the structure. This study aims towards performing incremental dynamic analysis of structures using SAP 2000 subjected to several scaled ground motions scaled using SEISMOMATCH 2016. This procedure is followed by the pushover curves plotted for each structural model. The 5, 12 and 18-storey moment resisting RC frames are used for study which is located in the highly active seismic region of north India. Due to improper knowledge of seismic hazards buildings designed using modern principles observe earlier failure. This leads to loss of property as well as lives.

Keywords: Seismic Hazard, IDA, Scaling, Pushover Curves, SAP 2000.

INTRODUCTION

Nowadays the Performance Based Earthquake Engineering (PBEE) approach has been successfully developed to do the same. It promotes the idea of designing structures with higher levels of performance standards across multiple limit states. Apart from PBEE, a new analysis approach, called Incremental Dynamic Analysis (IDA), has been developed to evaluate the performance of structures. It involves subjecting a structural model to one (or more) ground motion records, each scaled to multiple levels of intensity, thus producing IDA curves of response versus intensity level. Many studies have been conducted in this domain to improve the accuracy of prediction of response of the structure. However, the ground motions used in IDA play important role in increasing the efficiency of the method. These ground motions are scaled using various scaling methods such as frequency matching, spectral matching etc. to obtain suitable scale factors.

The selection and scaling of earthquake ground motions is an important step in defining the seismic loads that will be applied to a structure during structural analysis and serves as the interface between seismology and engineering.

Lampery and Abrahamson [3] investigated limits on scaling of ground motions by comparing traditional magnitude-distance based ground motion selection with the post scaling selection of ground motion. The study considered reference event of the magnitude of $M_w=7$ and compared it with 10 time series of similar magnitudes which were applied with scale factors ranging from 3.5- 12.6 and parameter considered was Newmark's displacement. The study observed that for post scaling time series selection having magnitude M_w ranging from 6.19 to 6.93 accuracy of response prediction with nearby values of Newmark's displacements as design event was increased.

Reyes and Kalkan [4] investigated the ASCE/SEI-7 ground motion scaling procedure to determine the number of records such that scaled records provide accurate, efficient and consistent estimates of true median structural responses. Records were selected based on magnitude, distance, soil type and period. The authors examined cases like fewer than seven and more than seven ground motions. It was concluded that the above procedure was neither efficient nor consistent for less than seven records. It was also found that increasing the number of records from 7 to 10 had a minor effect on the accuracy of procedure and use of 7 records was found efficient.

Tayyebi S. [9] performed and compared different types of nonlinear analysis methods for evaluating the seismic performances of structures. The study considered three models representing low-rise, medium-rise and high-rise structures consisting of a moment resisting reinforced concrete structures with no shear walls, located in a high-seismicity region of Turkey. The capacity curves of the structures, as derived by both DAP and FEMA440 pushover curves were compared with the IDA envelopes by using the SeismoStruct software. Both Adaptive Pushover Analysis as well as Incremental Dynamic Analysis were performed using 20 ground motions. The study concluded that IDA provides an optimal solution over ADP.

Pasticier et al. [11] investigated the application of SAP 2000 for incremental dynamic analysis of masonry building. Two walls modelled using equivalent frame modelling analyzed and compared with analysis of an existing two story building having stone masonry walls located in north-east Italy. The static and dynamic pushover analyses were performed to plot dynamic pushover curves followed by fragility curves. The study considered a two story existing building in North-east of Italy. Plastic hinges, nonlinear links were introduced in building and static pushover analysis, time history analysis was performed. The study observed that the minimum base shear strength was always obtained when the triangular distribution of seismic forces is applied.

Vamvatsikos and Cornell [14] compared Incremental Dynamic Analysis with the nonlinear static pushover and R-factor methods for prediction of response of the structure. The study illustrated single record IDA as well as multi-record IDA by analyzing 20 storey steel moment resisting frame and 5-storey steel chevron braced frame including P- delta effects. The study showed that for elastic range SPO and IDA had nearly equal displacements while IDA proved to be an effective tool as it addressed both capacities as well as demand.

Moniri [16] evaluated the seismic performance of RC framed buildings using IDA for near field earthquakes. The study considered three buildings of 6, 10 and 15 storey designed as per ACI code specifications using ETABS software. Also, the non-linear structural analysis was carried out using OpenSees software by applying 14 near -field and 14 far-field ground motions scaled using ASCE 07-05 standard. The results of study observed parameters like storey shear, storey drift, and inter-story displacement. The study showed that Near-fault conditions produce higher requirements' when compared to far-fault conditions and proved to be less efficient at higher periods.

Javanpour M. and Zarfani P. [20] investigated the application of IDA for studying the dynamic behavior of steel structures during the earthquakes. The two same-order steel structures with two types of structural systems (coaxial moment frames and moment frame) were modeled using OpenSees software. Seismic loading was based on the Fourth Edition of Iranian 2800 instruction. The study showed that depending on the type of IM and DM parameters, 20% to 90% of vulnerability values of steel moment frames were less than coaxial braced frame structures (cross).

II. OBJECTIVE

Following are the objectives of the proposed work:

1. To learn the extraction of time history data from PEER NGA-WEST ground motion database and COSMOS VDC.
2. To select and scale ground motions using the appropriate method to match the target spectrum.
3. To perform the incremental dynamic analysis for a building using scaled ground motions.
4. To understand the concept of EDP parameters using IDA curves for base shear, spectral displacement, storey displacement, storey drift.

III. METHODOLOGY

3.1 Probabilistic Seismic Hazard Analysis (PSHA)

PSHA provides a frame work in which these uncertainties can be identified, quantified and combined in a rational manner to provide a

A complete picture of the seismic hazard. The accuracy of PSHA depends on the accuracy with which uncertainty in earthquake size, location, recurrence, and effects can be characterized. Although models and procedures for characterization of the uncertainty of these parameters are available they may be based on data collected over periods of time that, geologically, are very short.

3.2 Incremental Dynamic Analysis (IDA)

IDA is able to estimate limit-state capacity and seismic demand by performing a series of nonlinear time history analyses under a suite of multiple scaled accelerogram records of earthquake ground motion acceleration. In IDA method, the intensity of selected ground motion is incrementally increased until the intended limit state seismic capacity of the global structural system is achieved. Besides, it contains plotting an intensity measure (i.e. first mode spectral acceleration.) Moreover, the accuracy of IDA results depends on the number of chosen accelerogram records. According to research performed by Shome and Cornell (1999), it is usually enough to select ten to twenty accelerograms records to estimate limit-state capacity and seismic demand of structures with sufficient accuracy. Appropriate post processing can present the results in terms of IDA curves, one for each ground motion record, of the seismic intensity, typically represented by a scalar Intensity Measure (IM), versus the structural response or Damage measure(DM), as measured by an Engineering Demand Parameter (EDP).

3.3 PEER Strong Motion Database

The web-based Pacific Earthquake Engineering Research Center (PEER) ground motion database provides tools for searching, selecting and downloading ground motion data. All downloaded records are unscaled and as-recorded. The scaling tool available on this site is to be used to determine the scale factors to be used in the simulation platform. These scale factors can be found with

the record metadata in the download. However strict limit has been imposed on the number of records that can be downloaded within a unique time window. The current limit is set at approximately 200 records every two weeks, 400 every month.

NGA-West2 -- Shallow Crustal Earthquakes in Active Tectonic Regimes

The NGA-West2 ground motion database includes a very large set of ground motions recorded in worldwide shallow crustal earthquakes in active tectonic regimes. The database has one of the most comprehensive sets of meta-data, including different distance measure, various site characterizations, earthquake source data, etc.

NGA-East -- Central & Eastern North-America

The objective of NGA-East is to develop a new ground motion characterization (GMC) model for the Central and Eastern North-American (CENA) region. The GMC model consists of a set of new ground motion models (GMMs) for median and standard deviation of ground motions (GMs).

3.4 Seismo Match 2016

SeismoMatch2016, V1.3.0 is an application capable of adjusting earthquake accelerograms to match a specific target response spectrum, using the wavelets algorithm proposed by Abrahamson (1992) and Hancock et al. (2006). Some of its features are:

- i. Simultaneous matching of a number of accelerograms, and then the creation of a mean matched spectrum whose maximum misfit respects a pre- defined tolerance.
- ii. The possibility of using this software in combination with records selection tools and record appropriateness verification algorithms to define adequate suites of records for nonlinear dynamic analysis of new or existing structures.
- iii. The capability of reading single accelerograms defined in both single- or multiple-values per line formats or of reading a number of accelerograms at the same time.
- iv. Creation of the target spectrum by following Eurocode 8 rules, by computing the spectrum of a specific accelerogram or by simply loading a user- defined spectrum.

3.5 COSMOS Virtual Data Centre

The VDC is a public, web-based search engine for accessing worldwide earthquake strong ground motion data. While the primary focus of the VDC is on data of engineering interest, it is also an interactive resource for scientific research and government and emergency response professionals. The VDC was developed at University of California Santa Barbara with funds from the National Science Foundation, with initial support provided by the Southern California Earthquake Center. Subsequent support has been provided by the US Geological Survey and the California Geological Survey. The VDC was incorporated as a part of the [Center for Engineering Strong Motion Data \(CESMD\)](#) in 2012. The Consortium of Organizations for Strong-Motion Observation Systems (COSMOS) serves as a liaison in facilitating data access from international strong-motion networks.

IV. PRESENT STUDY

The present study aims at performing IDA using scaled ground motion records for three models from low, medium and high rise category. The structural elements which are provided for analysis of RC framed building are presented in following tables.

Table 4.1 Details of building

No.of Story	5,12,18
Bottom story ht.	3m
Story ht.	3.2m
Soil type	Medium
Zone	IV
Thickness of floor	0.18m
Beam size	0.23 m x0.6 m
Column size	0.3m x0.9 m
Material properties	
Grade of concrete	M45
	M30

Grade of steel	Fe500
	Fe415
Dead load intensities	
F.F. on floor	1.75KN/m ²
F.F. on roof	2 KN/m ²
Live load intensities	
L.L. on floors	2 KN/m ²
L.L. on roof	1 KN/m ²

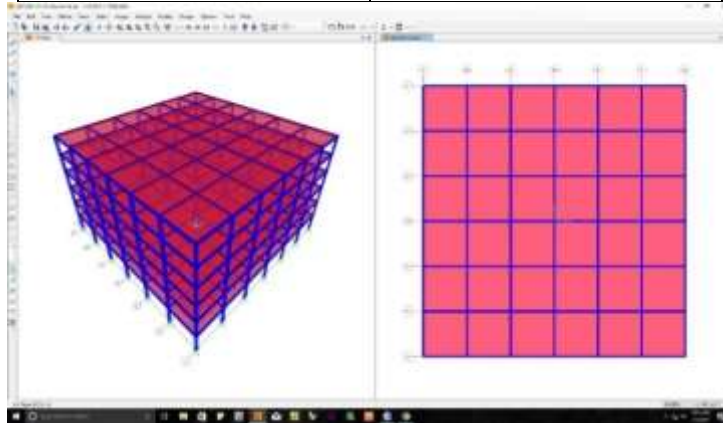


Fig. 4.1 Model of G+5 storey building

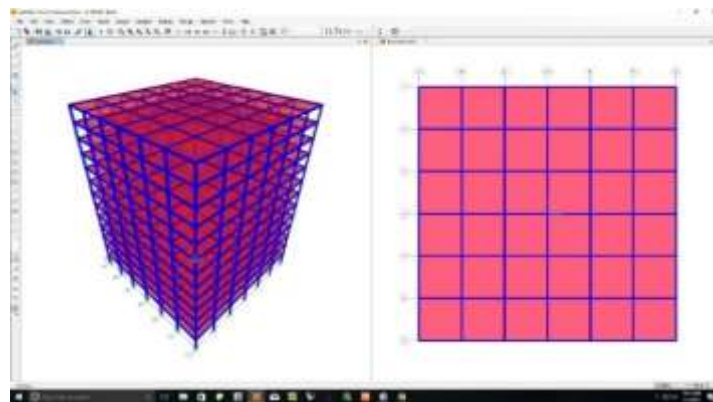


Fig. 4.2 Model of G+12 storey building

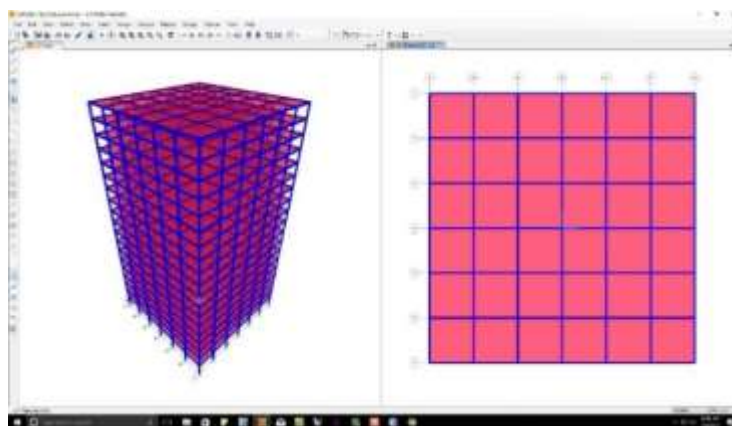


Fig. 4.3 Model of G+18 storey building

Table 4.2 Earthquake Records

Earthquake Records	Year	Record Station	ML	Component	PGA(g)	Hypocentral distance (Km)	Scale Factor
Uttarkashi	1991	IITR Bhatwari, India	7	N 85 E	0.34	21.7	3.5
Indo-Burma Border	1988	IITR Bokajan, India	6	S 56 E	0.22	41.9	4.48
Chamba	1995	IITR, Chamba, India	6.5	N 00 E	0.47	34.9	9.85
Chamoli	1999	IITR, Gopeshwar, India	6.6	N 20 E	0.42	17.3	1.14
Bhuj	2001	IITR, Ahmadabad, India	7	N 78 E	0.31	239	3.43
Imperial Valley, CA	1979	USGS 952, EL Centro Array 5 California	6.6	S 40 E	0.41	5.6	0.79
Northridge	1994	USC, 9009 LA, Saturn St California	6.4	N 20 E	0.24	26.9	3.65

All the earthquake records are obtained from COSMOS VDC within magnitude range of 6-7 as the aim of the study was to subject the structures to a higher magnitude. Also, most of the ground motion records are from Indian earthquakes to achieve a more accurate response of structures as they are located in the Indian region. After downloading these records are scaled to obtain scale factors using SEISMOMATCH 2016 as mentioned in Table 4.2. The scaling was carried out within the range of $0.2T_1-1.5T_1$ as specified by US codes. T_1 is the fundamental time period for the structure. Further Incremental Dynamic Analysis is carried out using commercially available SAP 2000 V15. The structures are designed according to Indian standard codes.

V. RESULTS AND DISCUSSION

Results of IDA are plotted in form of IDA curves. An IDA curve is a plot between intensity measure (IM) which can be 5% Damped spectral acceleration, pseudo acceleration, spectral velocity etc. and damage measure (DM) which can be base shear, storey drift, storey displacement etc.

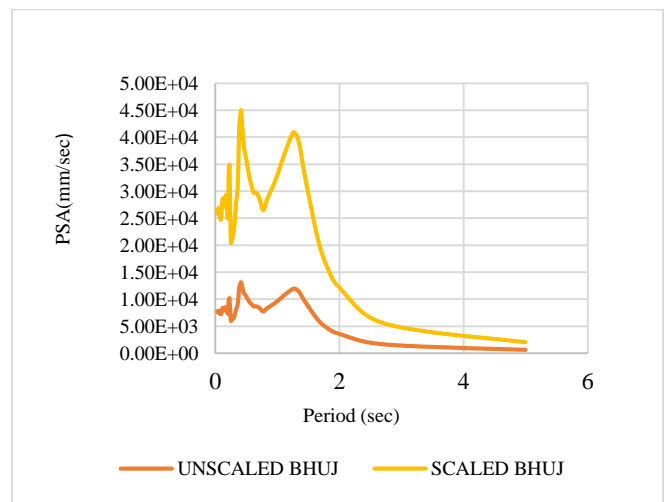


Fig.5.1 Response spectrum for Bhuj

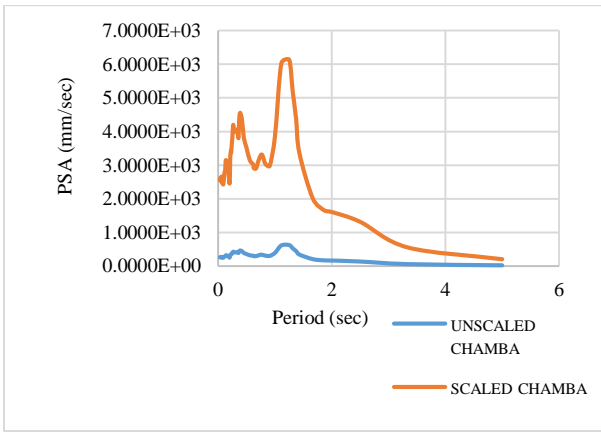


Fig.5.2 Response spectrum for Chamba

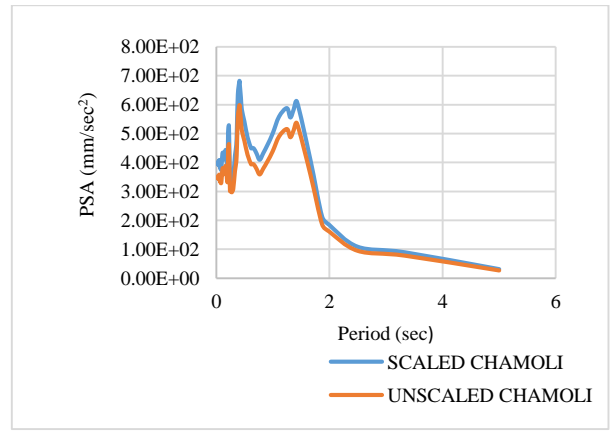


Figure 5.3 Response spectrum for Chamoli

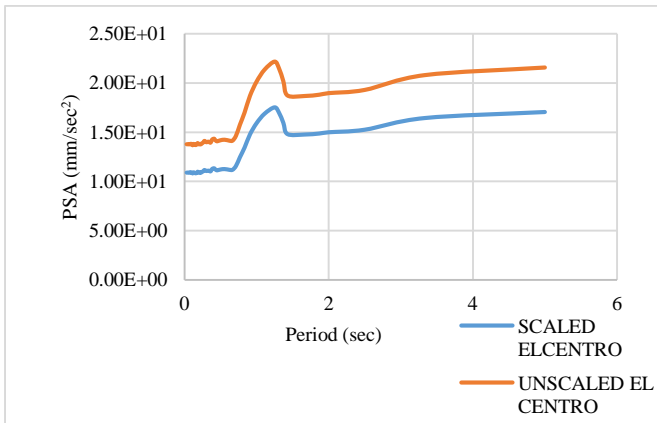


Fig.5.4 Response spectrum for El Centro

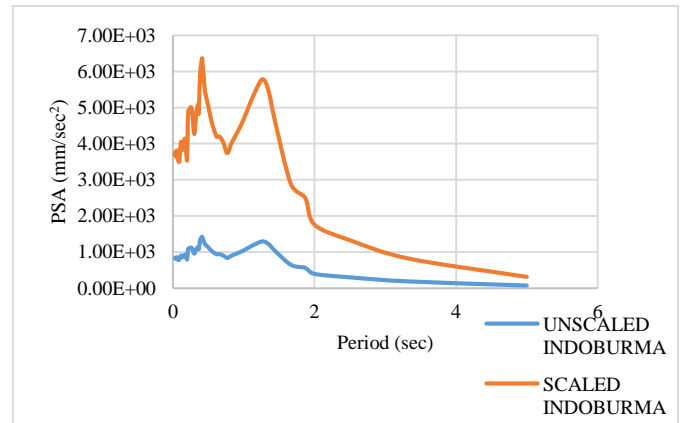


Fig.5.5 Response spectrum for Indo-Burma

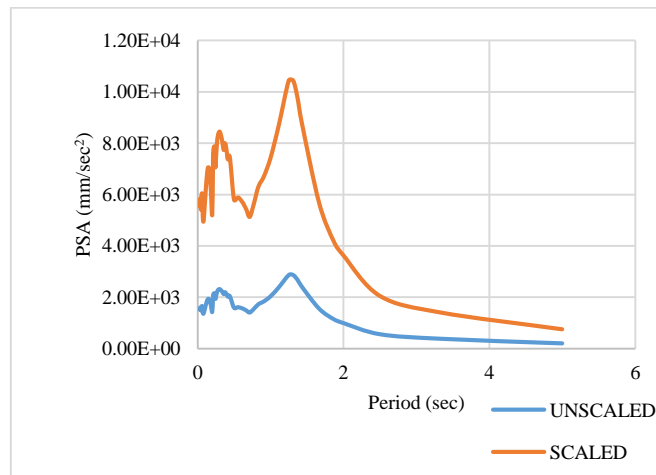


Figure 5.6 Response spectrum for Northridge

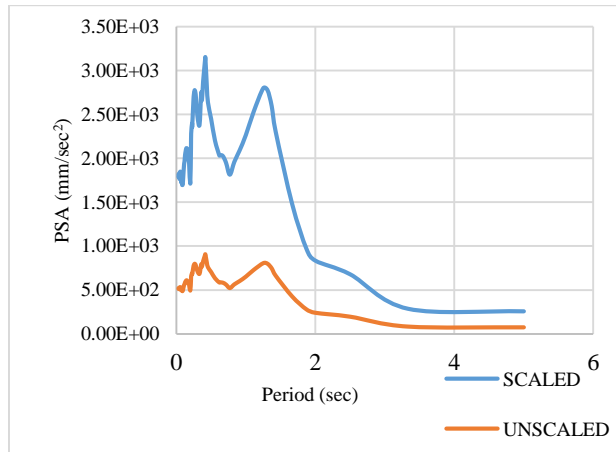


Figure 5.7 Response spectrum for Uttarkashi

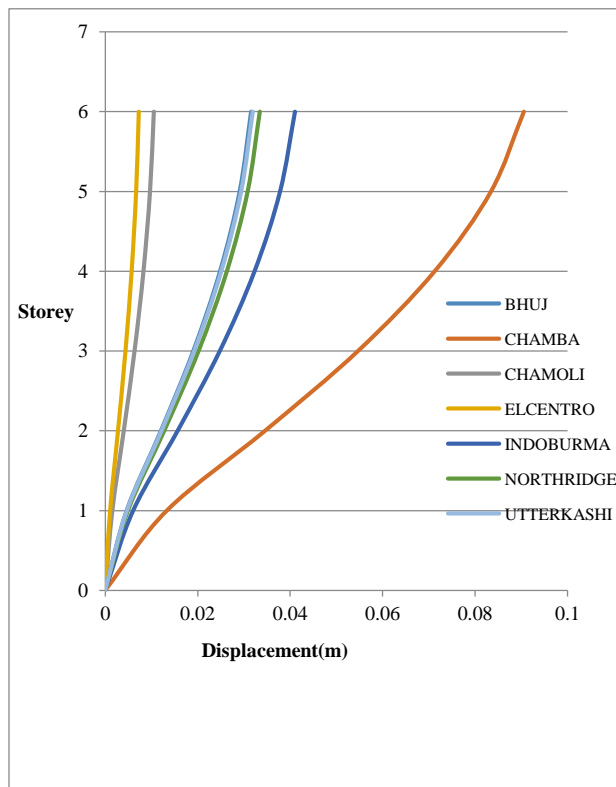
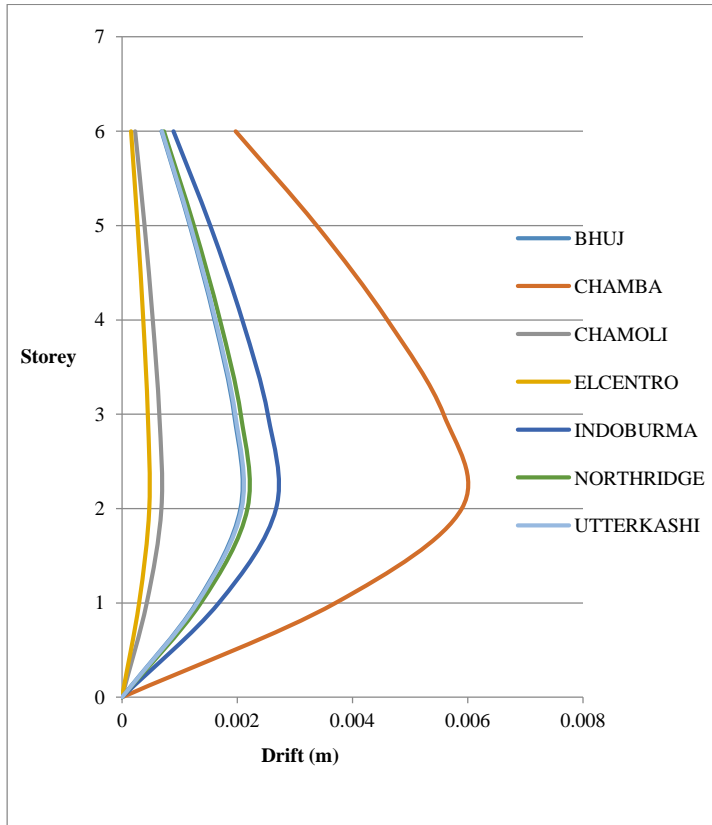


Figure 5.8 Storey displacement for G +5 storey

The above figures show response spectra as well as storey displacements for each of the ground motion records obtained for G+5 storey building. The comparison of storey displacements is also shown in tabular format in Table 5.1 below. The maximum displacement is obtained for Chamba earthquake.

TABLE 5.1 COMPARISON OF STOREY DISPLACEMENT



Sr. No	Earthquake Record	Max. Displacement (m)
1	Bhuj	0.031552
2	Chamba	0.090586
3	Chamoli	0.010485
4	El Centro	0.007257
5	Indo-Burma Border	0.041018
6	Northridge	0.033445
7	Uttarkashi	0.031899

Figure 5.9 Storey drift for G +5 storey

Table 5.2 Comparison of Storey Drift for G+5 storey

Sr. no	Earthquake Record	Max. Drift
1	Bhuj	0.002055
2	Chamba	0.005901
3	Chamoli	0.000683
4	El Centro	0.000473
5	Indo-Burma Border	0.002672
6	Northridge	0.002179
7	Uttarkashi	0.002078

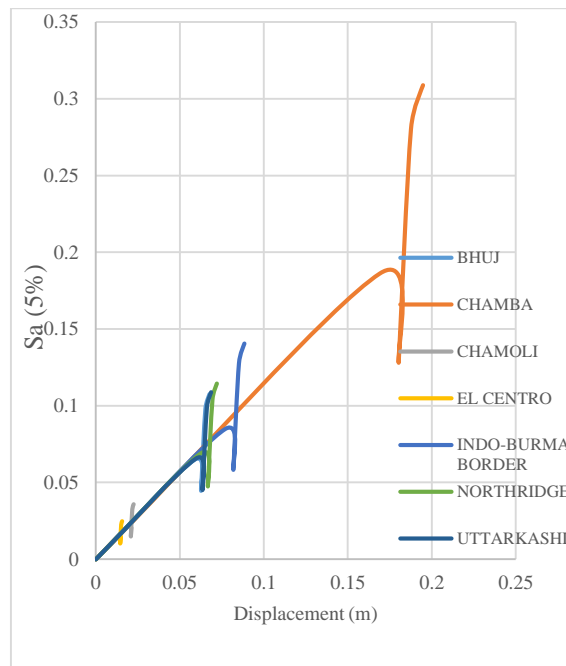


Figure 5.10 IDA curves for G +5 storey

The above figure shows IDA curves plotted for G+5 storey building where IM is 5% damped spectral acceleration and DM is Displacement.

5.2 Results for G+12 storey

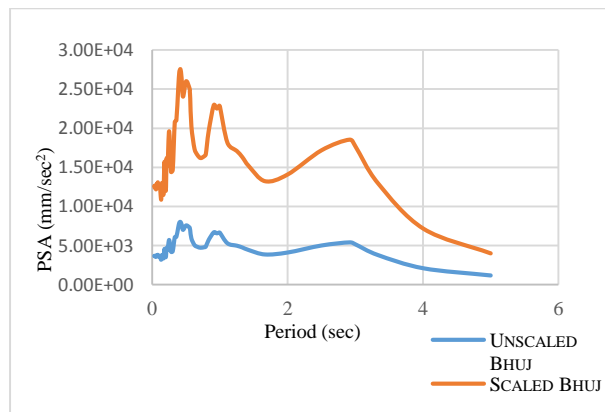


Figure 5.11 Response spectrum for Bhuj

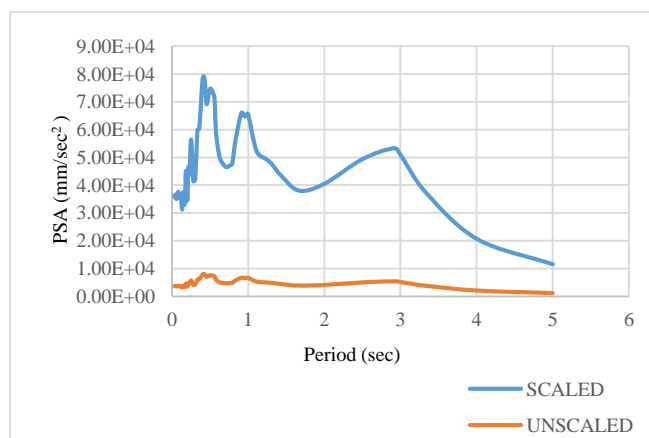


Figure 5.12 Response spectrum for chamba

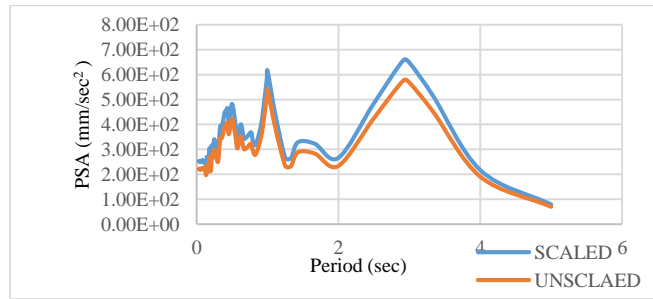


Figure 5.13 Response spectrum for chamoli

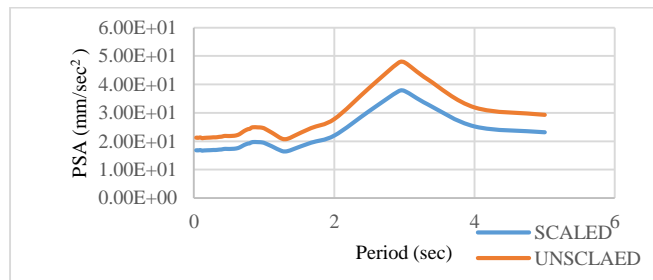


Figure 5.14 Response spectrum for El Centro

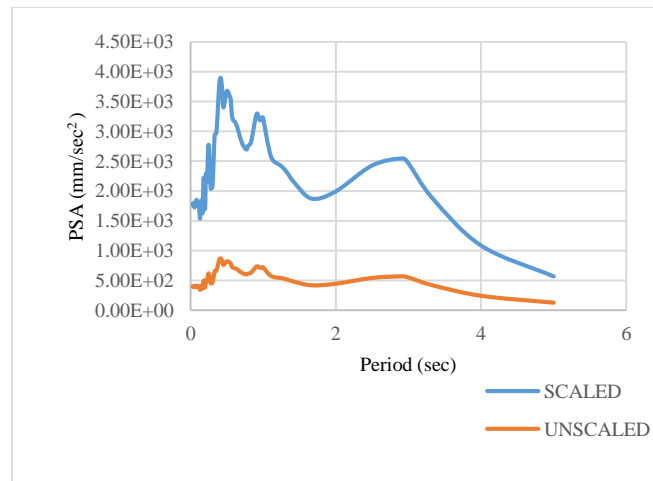


Figure 5.15 Response spectrum for Indo-Burma

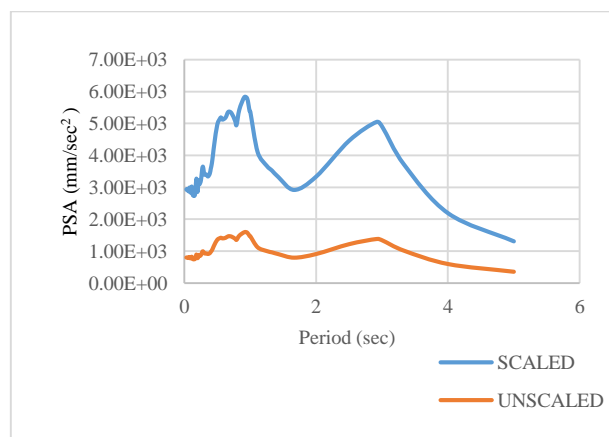


Figure 5.16 Response spectrum for Northridge

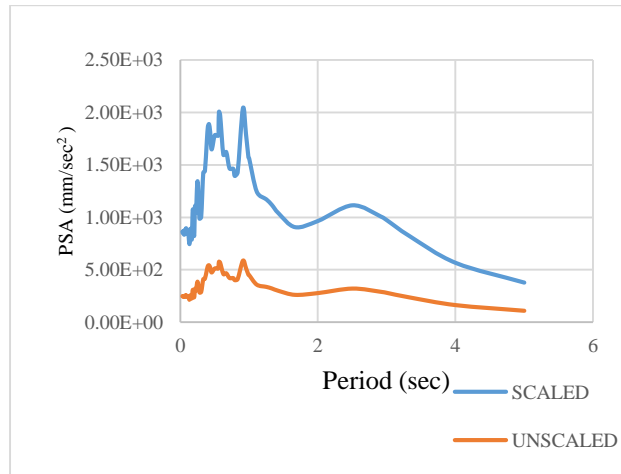


Figure 5.17 Response spectrum for Uttarkashi

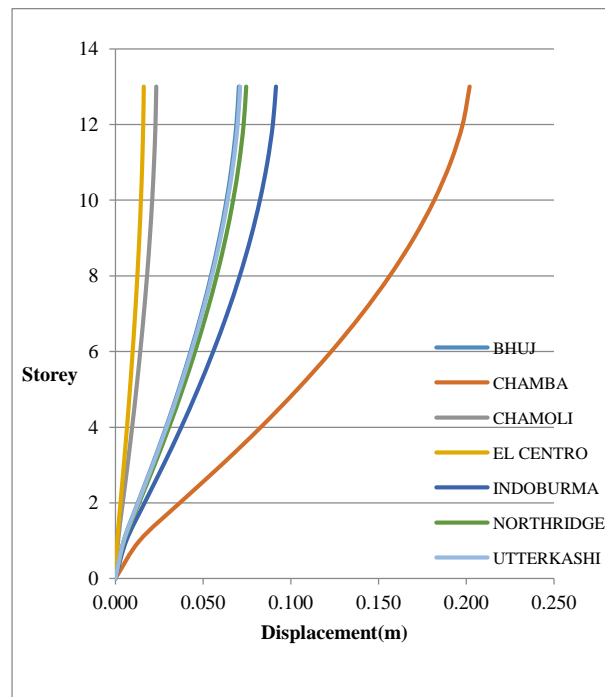


Figure 5.18 Storey Displacement for G+12 storey

Table 5.3 Comparison of Storey displacement

Sr. no	Earthquake Record	Max. Displacement (m)
1	Bhuj	0.070
2	Chamba	0.202
3	Chamoli	0.023
4	El Centro	0.016
5	Indo-Burma Border	0.091
6	Northridge	0.075
7	Uttarkashi	0.071

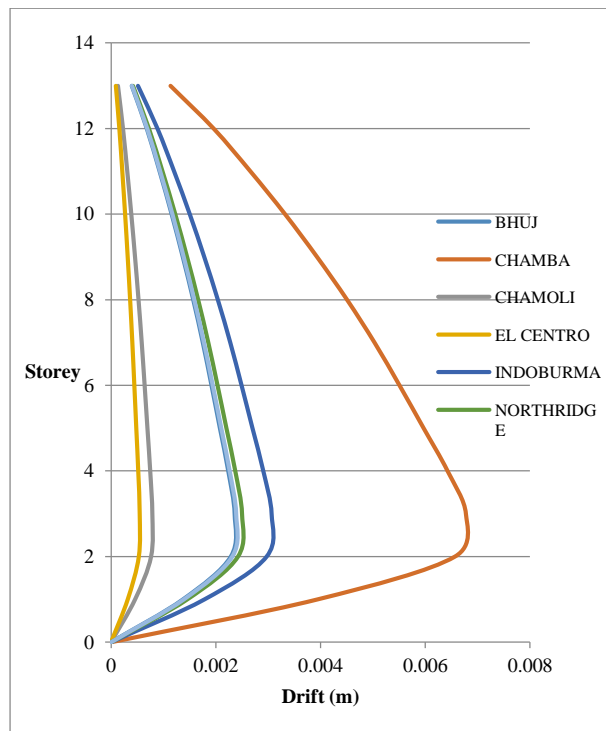


Figure 5.19 Storey Drift for G+12 storey

TABLE 5.4 COMPARISON OF STOREY DRIFT

Sr. no	Earthquake Record	Max. Drift
1	Bhuj	0.002359
2	Chamba	0.006773
3	Chamoli	0.000784
4	El Centro	0.000543
5	Indo-Burma Border	0.003067
6	Northridge	0.002501
7	Uttarkashi	0.002385

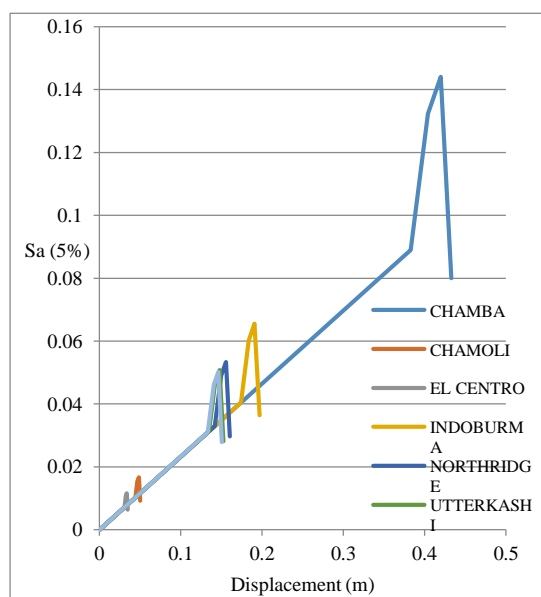


Figure 5.20 IDA curves for G+12 storey

5.4 RESULTS FOR 18 STORY BUILDING

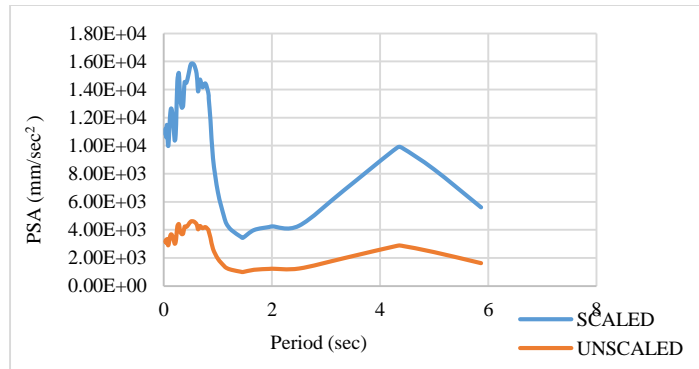


Fig.5.21 Response spectrum for Bhuj

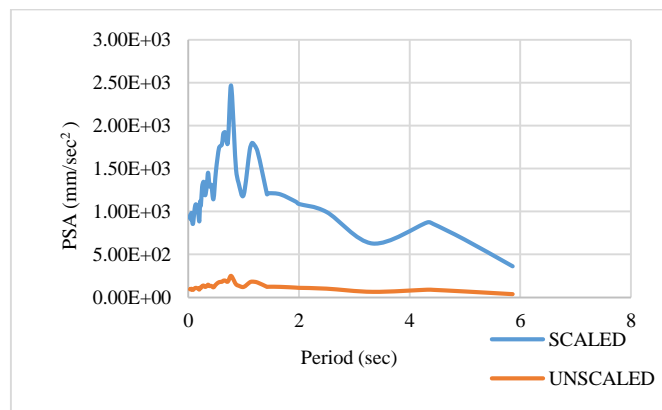


Fig.5.22 Response spectrum for Chamba

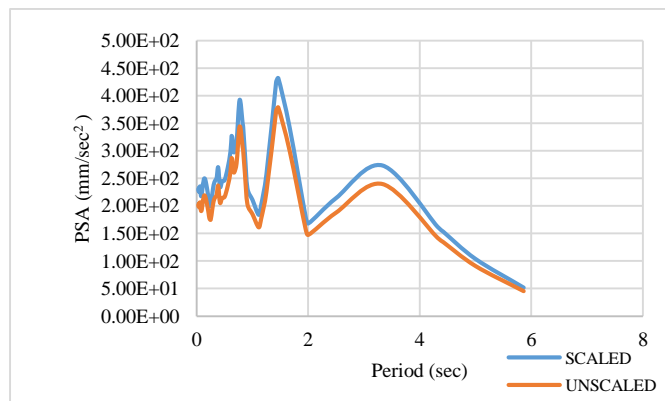


Figure 5.23 Response spectrum for Chamoli

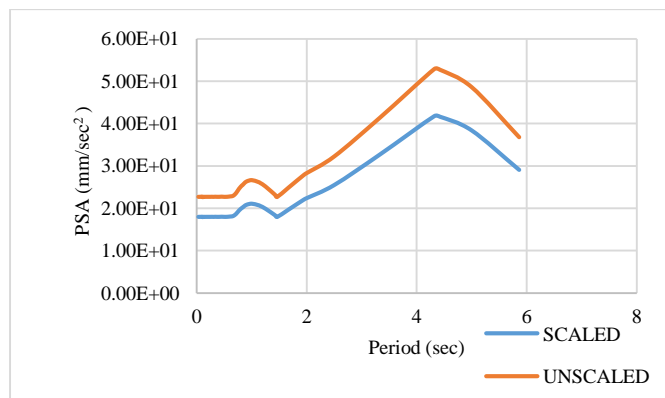


Fig.5.24 Response spectrum for El Centro

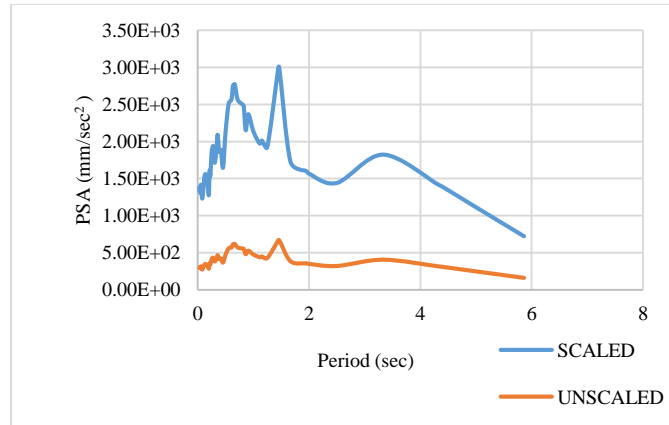


Figure 5.6 Response spectrum for Northridge

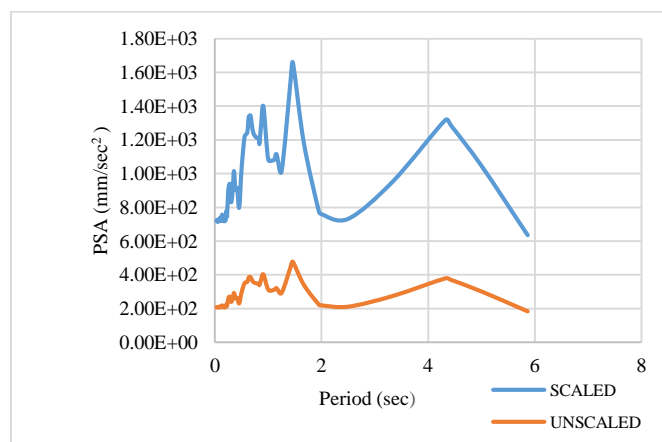


Figure 5.17 Response spectrum for Uttarkashi

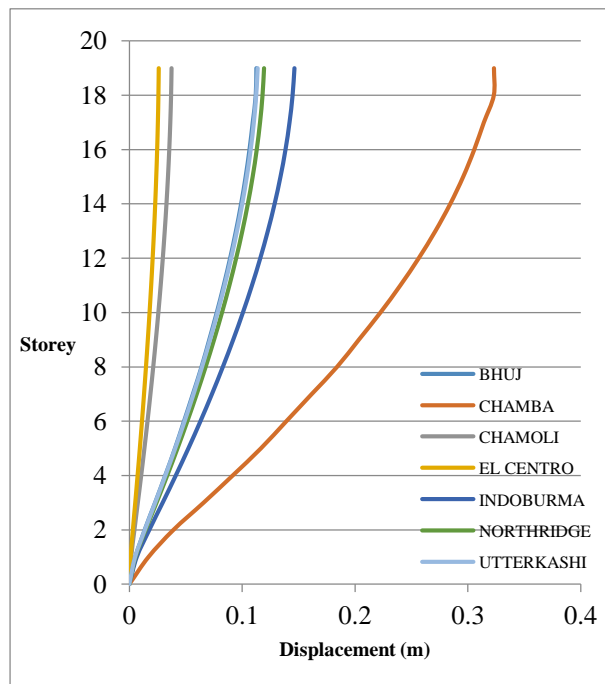


Figure 5.28 Storey Displacement for G+18 storey

Table 5.5 Comparison of Storey Displacement

Sr. No	Earthquake Record	Max. Displacement (m)
1	Bhuj	0.11259
2	Chamba	0.323246
3	Chamoli	0.037414
4	El Centro	0.025896
5	Indo-Burma Border	0.146367
6	Northridge	0.119345
7	Uttarkashi	0.113828

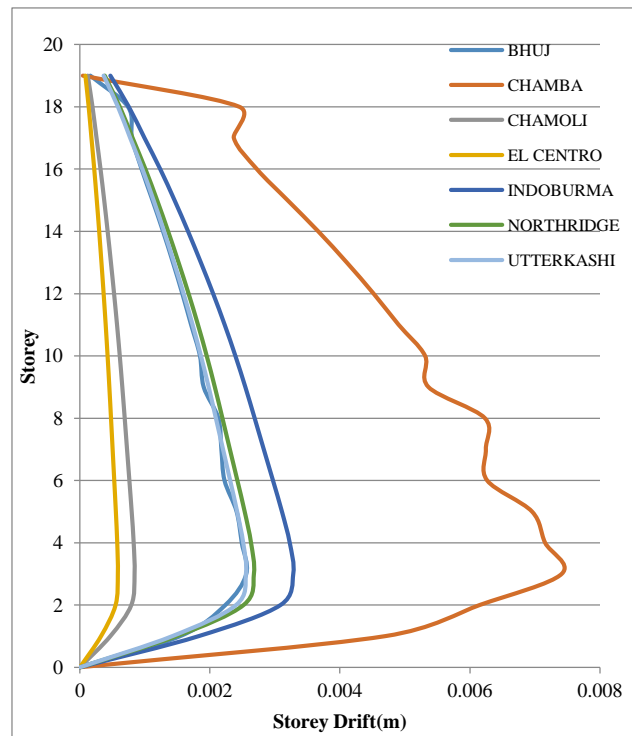


Figure 5.29 Storey Drift for G+18 storey

Table 5.6 Comparison of Maximum Storey Drift

Sr no.	Earthquake record	Max. Drift (m)
1	Bhuj	0.002559
2	Chamba	0.007416
3	Chamoli	0.000839
4	El Centro	0.000581
5	Indo-Burma Border	0.003283
6	Northridge	0.002677
7	Uttarkashi	0.002553

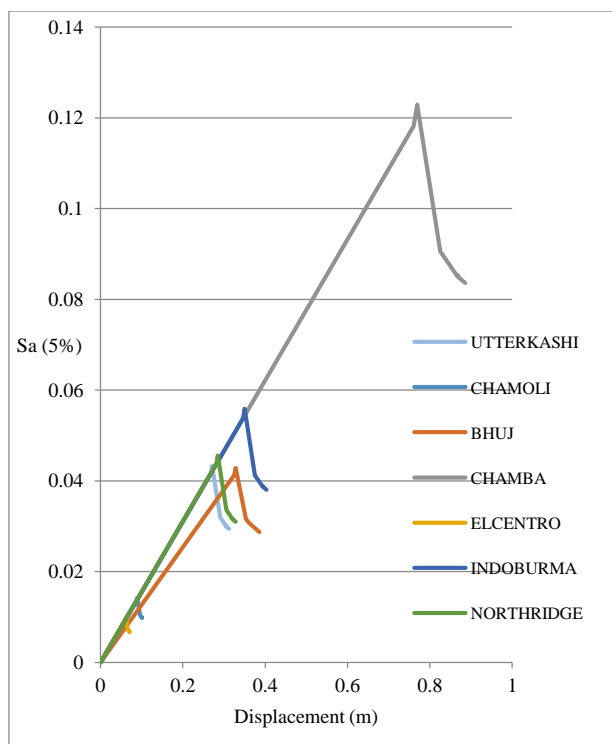


Figure 5.30 IDA curves for G+18 storey

CONCLUSION

Incremental Dynamic Analysis of three RC framed buildings of a different number of stories i.e 5, 12, 18 have been carried out using commercially available SAP 2000 V.15 software. The purpose of the analysis was to predict the behavior of the structures under a suite of seven ground motions scaled using SeismoMatch 2016 program. The results are presented in form of Storey displacement, story drift, and IDA curves.

Following conclusions were obtained from results:

- 1) All the ground motions were properly extracted from PEER Strong motion database as well as COSMOS VDC to input in SeismoMatch 2016 successfully.
- 2) Use of SeismoMatch 2016 for scaling of ground motions have yielded good results and accurate scale factors were obtained by using Spectral matching for all the ground motions as shown in table 4.2. Maximum Scale factor was found to be 9.85 for Chamba.
- 3) Storey displacement and Storey drift for the 12-storey building was found to be maximum for Chamba earthquake record having PGA of 0.47g and scale factor of 9.85.
- 4) The minimum value of Storey displacement and Storey drift was obtained for El Centro earthquake record having PGA of 0.41g and scale factor of 0.79
- 5) The earthquake records having more PGA and scale factors produced greater displacement as well as drift as Compared to those having least values, hence one can conclude that behavior of the structure is highly dependent on the magnitude of the earthquake.
- 6) The selection of earthquake records should be done carefully to increase the efficiency of the procedure. i.e. No aftershocks should be selected.

FUTURE SCOPE

In this work IDA analysis of regular RC framed structure was conducted by using SAP 2000, hence any other software can be used and compared. Also irregularities in shape, the height of the building can be considered using different methods of scaling the time history records. The number of ground motions can also be varied. The present study analyzed RC frame only, however composite structures, structures other than building such as, bridges can also be analyzed.

REFERENCES

- [1] Baker O., Akkar S. (2012) "Record Selection and Scaling for Nonlinear Structures", Earthquake Engineering and Structural Dynamics Vol. 3, Wiley Online Library.
- [2] Lin T., Haselton C., Baker J. (2013) "Conditional Spectrum Based Ground Motion Selection part-I: Hazard Consistency for Risk Based Assessments", Earthquake Engineering and Structural Dynamics Vol.42, No.12, pp. 1847-1865.
- [3] Lamperty J., Abrahamson N. (2006) "Selection of Ground Motion Time Series and Limits on Scaling", Soil Dynamics and Earthquake Engineering, Vol.26, pp. 477-482.
- [4] Reyes J., Kalkan E. (2012) "How Many Records Should be used in an ASCE/SEI-7 Ground Motion Scaling Procedure?" Earthquake Spectra, Vol.28, No.3, pp. 1223-1242.
- [5] Charney (2015), "Example 6 Ground Motion Scaling for Response History Analysis" Seismic Loads: Guide to the Seismic Load Provisions of ASCE 7-10, Ex-6, pp.29-36.
- [6] Odonell A., Kurama Y. (2013) "Experimental Evaluation of Ground Motion Scaling Methods for Nonlinear Analysis of Structural Systems", Structures Congress 2013, ASCE.
- [7] Bodin P., Manlanghini L. (2004) "Ground Motion Scaling in Kachchh basin, India Deduced from Aftershocks of the 2001 M_w 7.6 Bhuj Earthquake", Bulletin of Seismological Society of America, Vol. 94 No.5, pp. 1658-1669.
- [8] Kalkan E., Chopra A. (2011) "Modal Pushover Based Scaling Procedure", Journal of Structural Engineering, Vol. 137, No.3, pp. 298-310.
- [9] Tayyebi S. (2014), "Nonlinear Analysis Methods for Evaluating Seismic Performance of Multi-Story RC Buildings", Eastern Mediterranean University.
- [10] Chan G. (2005), "Nonlinear Analysis of Multistory Structures using NONLIN" Virginia Polytechnic Institute and State University.
- [11] Pasticier et al. (2008), "Non-linear seismic analysis and vulnerability evaluation of a masonry building by means of the SAP2000 V.10 code", Earthquake Engineering and Structural Dynamics, vol.37, pp.467-485.
- [12] Vejdani H., and Sooshturi A. (2008) "Comparison of Exact IDA and MPA based IDA for Reinforced Concrete frames", 14th World Conference on Earthquake Engineering.
- [13] Lew M. and Naem F. (1996), "Use of Design Spectrum Compatible Time Histories in Non-Linear Analysis", 11th World Conference on Earthquake Engineering.

- [14] Vamvatsikos D., and Cornell C. (2002) "Incremental Dynamic Analysis", Earthquake Engineering and Structural Dynamics Vol.31, No.12, pp. 491-514.
- [15] Huang Y., Whittakar A., Luco N., Hamburger R. (2011), "Scaling Earthquake Ground Motions for Performance-Based Assessment of Buildings", Journal of Structural Engineering Vol.137, pp. 311-321.
- [16] Moniri H. (2014), "Evaluation of Seismic Performance of Reinforced Concrete Buildings Using Incremental Dynamic Analysis (IDA) for Near Field Earthquakes", Eastern Mediterranean University, Gazimagusa, North Cyprus.
- [17] Dana M., Stojadinovic B. (2005), "Incremental Dynamic Analysis for Structures with Gap", ASCE Structures Congress.
- [18] Tirca L., Serban O., Wang M. and Modica D. (2013), "Incremental Dynamic Analysis of Existing Steel Braced Frame Buildings in Moderate Seismic Zones", ASCE Structures Congress.
- [19] Yun S., Hamburger R., Cornell C., and Fourth D. (2002), "Seismic Performance Evaluation for Steel Moment Frames", Journal of Structural Engineering Vol.128, pp-534-545.
- [20] Javanpour M. and Zarfani P. (2017), "Application of Incremental Dynamic Analysis (IDA) Method for Studying the Dynamic Behavior of Structures during Earthquakes", Journal of Engineering, Technology and Applied science research Vol.7, pp-1338-1344.
- [1] IS 1893-2002, "Indian Standard Code of Practice for Earthquake Resistant Design of Buildings"
- [2] SeismoMatch 2016 user guide.
- [3] SAP 2000 V.15 user guide.